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<td>Electrical system coordination</td>
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<td>240.13(1)</td>
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<td>430.74, Exception Nos. 1 and 2</td>
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<td>430.102(A), Exception No. 2</td>
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<td>Energy from more than one source</td>
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<td>Uninterruptible power supplies</td>
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<td>Point of connection</td>
<td>705.12(A)</td>
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ARTICLE 690
Solar Photovoltaic Systems

Summary of Changes
- **690.4(D):** Specified that equipment be identified and listed for the application.
- **690.5:** Revised to require all grounded dc PV arrays be provided with ground-fault protection unless they meet either of the conditions in the two exceptions.
- **690.5(B):** Added requirement on permitted means to isolate faulted circuits.
- **690.5(C):** Provided specific wording for warning label required to be factory- or field-installed on the inverter.
- **690.10(A):** Clarified that the ac output of a stand-alone inverter may be less than the calculated load, provided the output is adequate to supply the largest single utilization equipment.
- **690.13:** Specified that a switch, circuit breaker, or other device, unless part of a ground-fault detection system, cannot be installed in the grounded conductor if it results in the grounded conductor’s becoming ungrounded and energized.
- **690.31(A):** Revised to require readily accessible conductors operating at over 30 volts to be installed in raceways.
- **690.31(B):** Revised to require use of either USE-2 or listed and labeled photovoltaic (PV) wire.

- **690.31(F):** Added section to provide termination requirements for flexible, fine-stranded cables.
- **690.33(C):** Added requirement for connectors that are readily accessible and used with systems operating at over 30 volts to require a tool for opening.
- **690.43:** Clarified that an equipment grounding conductor is required between the PV array and other equipment, and added requirements for devices used to ground metal frames of PV modules.
- **690.45:** Revised requirement on size of equipment grounding conductors to at least 14 AWG.
- **690.46:** Added requirement for physical protection of equipment grounding conductors smaller than 6 AWG.
- **690.47(C):** Specified the means of grounding and bonding PV systems with ac and dc grounding and bonding requirements.
- **690.47(D):** Added section to provide requirements for grounding electrodes at ground and pole-mounted arrays.
- **690.57:** Added requirement that load disconnects supplied by multiple sources disconnect all sources when in the off position.
- **690.64:** Specified that requirements apply to systems with utility-interactive inverters.
- **690.64(B)(1) through (7):** Revised to provide interconnecting requirements for distribution equipment capable of supplying multiple branch circuits or feeders while simultaneously connected to primary power and one or more interactive inverters.
- **690.74:** Added requirement for the use and termination of flexible fine-stranded cables for battery interconnections.

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I. General

690.1 Scope
The provisions of this article apply to solar photovoltaic electrical energy systems, including the array circuit(s), inverter(s), and controller(s) for such systems. [See Figure 690.1(A) and Figure 690.1(B).] Solar photovoltaic systems covered by this article may be interactive with other electrical power production sources or stand-alone, with or without electrical energy storage such as batteries. These systems may have ac or dc output for utilization.

The use of photovoltaic (PV) systems as utility-interactive or stand-alone power supply systems has steadily increased as the technology and availability of the PV equipment have evolved. The requirements of Article 690 cover the use of stand-alone and utility-interactive PV systems. Utility-interactive photovoltaic systems are subject to the requirements for interconnected electric power production sources contained in Article 705.

Exhibit 690.1 shows a custom-designed home with a PV electrical system.

690.2 Definitions

Alternating-Current (ac) Module (Alternating-Current Photovoltaic Module). A complete, environmentally protected unit consisting of solar cells, optics, inverter, and other components, exclusive of tracker, designed to generate ac power when exposed to sunlight.
An ac PV module consists of a single integrated mechanical unit. Because there is no accessible, field-installed dc wiring in this single unit, the dc PV source-circuit requirements in this Code are not applicable to the dc wiring in an ac PV module.

Array. A mechanically integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, as required, to form a direct-current power-producing unit.

The building blocks of an array are illustrated in Exhibit 690.2.

Bipolar Photovoltaic Array. A photovoltaic array that has two outputs, each having opposite polarity to a common reference point or center tap.

Blocking Diode. A diode used to block reverse flow of current into a photovoltaic source circuit.

Blocking diodes are not required by this Code, although the instructions or labels supplied with the PV module may require them. Blocking diodes are not overcurrent devices and may not be substituted for any overcurrent device required by this Code.

Building Integrated Photovoltaics. Photovoltaic cells, devices, modules, or modular materials that are integrated into the outer surface or structure of a building and serve as the outer protective surface of that building.

Charge Controller. Equipment that controls dc voltage or dc current, or both, used to charge a battery.

Diversion Charge Controller. Equipment that regulates the charging process of a battery by diverting power from energy storage to direct-current or alternating-current loads or to an interconnected utility service.

Electrical Production and Distribution Network. A power production, distribution, and utilization system, such as a utility system and connected loads, that is external to and not controlled by the photovoltaic power system.

Hybrid System. A system comprised of multiple power sources. These power sources may include photovoltaic, wind, micro-hydro generators, engine-driven generators, and others, but do not include electrical production and distribution network systems. Energy storage systems, such as batteries, do not constitute a power source for the purpose of this definition.

Interactive System. A solar photovoltaic system that operates in parallel with and may deliver power to an electrical production and distribution network. For the purpose of this definition, an energy storage subsystem of a solar photovoltaic system, such as a battery, is not another electrical production source.
Inverter. Equipment that is used to change voltage level or waveform, or both, of electrical energy. Commonly, an inverter [also known as a power conditioning unit (PCU) or power conversion system (PCS)] is a device that changes dc input to an ac output. Inverters may also function as battery chargers that use alternating current from another source and convert it into direct current for charging batteries.

Inverter Input Circuit. Conductors between the inverter and the battery in stand-alone systems or the conductors between the inverter and the photovoltaic output circuits for electrical production and distribution network.

Inverter Output Circuit. Conductors between the inverter and an ac panelboard for stand-alone systems or the conductors between the inverter and the service equipment or another electric power production source, such as a utility, for electrical production and distribution network.

Module. A complete, environmentally protected unit consisting of solar cells, optics, and other components, exclusive of tracker, designed to generate dc power when exposed to sunlight.

Panel. A collection of modules mechanically fastened together, wired, and designed to provide a field-installable unit.

Photovoltaic Output Circuit. Circuit conductors between the photovoltaic source circuit(s) and the inverter or dc utilization equipment.

Photovoltaic Power Source. An array or aggregate of arrays that generates dc power at system voltage and current.

Photovoltaic Source Circuit. Circuits between modules and from modules to the common connection point(s) of the dc system.

Photovoltaic System Voltage. The direct current (dc) voltage of any photovoltaic source or photovoltaic output circuit. For multiwire installations, the photovoltaic system voltage is the highest voltage between any two dc conductors.

Solar Cell. The basic photovoltaic device that generates electricity when exposed to light.

Solar Photovoltaic System. The total components and subsystems that, in combination, convert solar energy into electric energy suitable for connection to a utilization load.

Stand-Alone System. A solar photovoltaic system that supplies power independently of an electrical production and distribution network.

The simplified circuit diagrams in Exhibits 690.3 through 690.6 demonstrate the use of various components in a PV system. Specific requirements for overcurrent protection, disconnecting means, and grounding are covered in other sections of Article 690 and should not be assumed based on these diagrams. Instructions for or labels on the PV module might require additional overcurrent devices that may not be shown.
690.3 Other Articles

Wherever the requirements of other articles of this Code and Article 690 differ, the requirements of Article 690 shall apply and, if the system is operated in parallel with a primary source(s) of electricity, the requirements in 705.14, 705.16, 705.32, and 705.143 shall apply.

Exception: Solar photovoltaic systems, equipment, or wiring installed in a hazardous (classified) location shall also comply with the applicable portions of Articles 500 through 516.

690.4 Installation

(A) Solar Photovoltaic System. A solar photovoltaic system shall be permitted to supply a building or other structure in addition to any service(s) of another electricity supply system(s).

(B) Conductors of Different Systems. Photovoltaic source circuits and photovoltaic output circuits shall not be contained in the same raceway, cable tray, cable, outlet box, junction box, or similar fitting as feeders or branch circuits of other systems, unless the conductors of the different systems are separated by a partition or are connected together.

For example, 690.4(B) does not permit the conductors supplying an exterior luminaire located in close proximity to a roof-mounted PV array to be installed in the same raceway or cable with the conductors of PV source circuits or PV output circuits.

Conductors directly related to a specific PV system, such as those in dc and ac output power circuits, may be contained in the same raceway as PV source and output conductors, providing they meet the requirements of 300.3(C).

(C) Module Connection Arrangement. The connections to a module or panel shall be arranged so that removal of a module or panel from a photovoltaic source circuit does not interrupt a grounded conductor to another photovoltaic source circuit. Sets of modules interconnected as systems rated at 50 volts or less, with or without blocking diodes, and having a single overcurrent device shall be considered as...
Exhibit 690.5 Simplified circuit diagram of a remote-cabin dc-only system.

a single-source circuit. Supplementary overcurrent devices used for the exclusive protection of the photovoltaic modules are not considered as overcurrent devices for the purpose of this section.

In general, 690.4(C) requires that a jumper be installed between a module terminal or lead and the connection point to the grounded PV source circuit conductor. That way, a module can be removed without interrupting the grounded conductor to other PV source circuits. If interrupted, such conductors, although identified as grounded, would be operating at the system potential with respect to ground, and a shock hazard could result. The reverse-current protection requirement on nearly all PV modules (as indicated by the fuse requirement labeled on the back of each module) generally dictates that each module or string of modules have a series overcurrent device and become a source circuit.

(D) Equipment. Inverters, motor generators, photovoltaic modules, photovoltaic panels, ac photovoltaic modules, source-circuit combiners, and charge controllers intended for use in photovoltaic power systems shall be identified and listed for the application.

Equipment listed for marine, mobile, telecommunications, or other applications may not be suitable for installation in permanent PV power systems complying with this Code.

690.5 Ground-Fault Protection

Grounded dc photovoltaic arrays shall be provided with dc ground-fault protection meeting the requirements of 690.5(A) through (C) to reduce fire hazards. Ungrounded dc photovoltaic arrays shall comply with 690.35.

Exception No. 1: Ground-mounted or pole-mounted photovoltaic arrays with not more than two paralleled source circuits and with all dc source and dc output circuits isolated from buildings shall be permitted without ground-fault protection.

Exception No. 2: PV array units installed or other than dwelling units shall be permitted without ground-fault protection.
Article 690 • Solar Photovoltaic Systems

Exhibit 690.6 Simplified circuit diagram of a rooftop grid-connected system.

where the equipment grounding conductors are sized in accordance with 690.45.

Ground-fault detection and interruption for the direct-current portions of PV systems should not be confused with the requirements for alternating-current circuit GFCI protection, as defined in Article 100. A GFCI is intended for the protection of personnel in single-phase ac systems. The ac GFCI functions to open the ungrounded conductor when a 5-mA fault current is detected. In contrast, devices meeting 690.5 are intended to prevent fires in dc PV circuits due to ground faults.

(A) Ground-Fault Detection and Interruption. The ground-fault protection device or system shall be capable of detecting a ground-fault current, interrupting the flow of fault current, and providing an indication of the fault.

Automatically opening the grounded conductor of the faulted circuit to interrupt the ground-fault current path shall be permitted. If a grounded conductor is opened to interrupt the ground-fault current path, all conductors of the faulted circuit shall be automatically and simultaneously opened.

Manual operation of the main PV dc disconnect shall not activate the ground-fault protection device or result in grounded conductors becoming ungrounded.

Typical ground-fault protection devices meeting the requirements of 690.5(A) operate by opening the main dc bonding jumper. They sense dc ground faults anywhere on the dc system and may be mounted anywhere in that system. They are usually installed inside the utility-interactive inverters or in the dc power center in stand-alone PV systems. Ground-fault protection accomplished through the opening of the grounded conductor also has to incorporate disconnecting means to automatically open all conductors of the faulted circuit.

(B) Isolating Faulted Circuits. The faulted circuits shall be isolated by one of the two following methods:

(1) The ungrounded conductors of the faulted circuit shall be automatically disconnected.
(2) The inverter or charge controller fed by the faulted circuit shall automatically cease to supply power to output circuits.

Typical ground-fault protection devices operating in PV systems (48-volt nominal and below) automatically disconnect the ungrounded conductor with a circuit breaker mechanically linked to a ground-fault-sensing circuit breaker.

"No overcurrent protection required with certain inverters"
shuts off the connected equipment to meet this requirement when a ground fault is sensed. Both methods provide the intended second indication that something needs to be corrected.

(C) Labels and Markings. A warning label shall appear on the utility-interactive inverter or be applied by the installer near the ground-fault indicator at a visible location stating the following:

Many types of ground-fault detection and interruption equipment break the negative-to-ground bond to interrupt the fault currents, and the now ungrounded PV negative conductor generally is at open-circuit voltage below the ground reference (e.g., -400 volts).

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

When the photovoltaic system also has batteries, the same warning shall also be applied by the installer in a visible location at the batteries.

690.6 Alternating-Current (ac) Modules
(A) Photovoltaic Source Circuits. The requirements of Article 690 pertaining to photovoltaic source circuits shall not apply to ac modules. The photovoltaic source circuit, conductors, and inverters shall be considered as internal wiring of an ac module.

(B) Inverter Output Circuit. The output of an ac module shall be considered an inverter output circuit.

(C) Disconnecting Means. A single disconnecting means, in accordance with 690.15 and 690.17, shall be permitted for the combined ac output of one or more ac modules. Additionally, each ac module in a multiple ac module system shall be provided with a connector, bolted, or terminal-type disconnecting means.

Alternating-current PV modules, as utility-interactive devices, are designed to produce ac power only when they are connected to an external source of ac power at the correct voltage and frequency. A single disconnecting means removes the external source and turns off all ac PV modules connected to that disconnecting device.

(D) Ground-Fault Detection. Alternating-current module systems shall be permitted to use a single detection device to detect only ac ground faults and to disable the array by removing ac power to any ac module(s).

The permissive language of 690.6(D) for ac PV modules replaced the requirements of 690.5 that apply only to conventional dc PV modules. As in 690.5, this is a fire prevention device and is not intended to be a shock prevention device. Existing GFCI and equipment ground-fault protection devices are generally not listed for backfeeding and are not suitable for meeting this requirement.

(E) Overcurrent Protection. The output circuits of ac modules shall be permitted to have overcurrent protection and conductor sizing in accordance with 240.5(B)(2).

II. Circuit Requirements

690.7 Maximum Voltage

(A) Maximum Photovoltaic System Voltage. In a dc photovoltaic source circuit or output circuit, the maximum photovoltaic system voltage for that circuit shall be calculated as the sum of the rated open-circuit voltage of the series-connected photovoltaic modules corrected for the lowest expected ambient temperature. For crystalline and multicrystalline silicon modules, the rated open-circuit voltage shall be multiplied by the correction factor provided in Table 690.7. This voltage shall be used to determine the voltage rating of cables, disconnects, overcurrent devices, and other equipment. Where the lowest expected ambient temperature is below -40°C (-40°F), or where other than crystalline or multicrystalline silicon photovoltaic modules are used, the system voltage adjustment shall be made in accordance with the manufacturer's instructions.

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

A PV source is not a constant-voltage source, and the difference between the rated operating voltage determined under controlled laboratory conditions and the open-circuit voltage under field-installed conditions can be significant. Consequently, the higher-rated open-circuit voltage must be used to select circuit components with proper voltage ratings.

The voltage potential (both open circuit and operating) of a PV power source increases with decreasing temperature. The installer should note the temperature conditions under which the PV device was rated. If the anticipated lowest temperature at the installation site is lower than the rating condition (25°C), Table 690.7 should be used to adjust the maximum open-circuit voltage of the crystalline system be-
Table 690.7 Voltage Correction Factors for Crystalline and Multicrystalline Silicon Modules

<table>
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<th>Factor</th>
<th>Ambient Temperature (°F)</th>
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<td>24 to 20</td>
<td>1.02</td>
<td>76 to 68</td>
</tr>
<tr>
<td>19 to 15</td>
<td>1.04</td>
<td>67 to 59</td>
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<tr>
<td>14 to 10</td>
<td>1.06</td>
<td>58 to 50</td>
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<tr>
<td>9 to 5</td>
<td>1.08</td>
<td>49 to 41</td>
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<td>4 to 0</td>
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<td>1.23</td>
<td>-23 to -31</td>
</tr>
<tr>
<td>-36 to -40</td>
<td>1.25</td>
<td>-32 to -40</td>
</tr>
</tbody>
</table>

The requirements of 690.7(B) cover installations where the PV output is connected to dc utilization circuits.

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

PV dc circuits in buildings are permanently connected using wiring systems recognized by this Code. Requirements for protecting unqualified persons from contact with these circuits are included in 690.7(B) and (D). Unqualified persons are not likely to service equipment in these circuits due to its complexity. A significant difference exists between the rated open-circuit voltage and the operating voltage in PV dc circuits. For the PV system to perform its intended function, rated dc open-circuit voltages of up to 600 volts may be present.

(D) Circuits over 150 Volts to Ground. In one- and two-family dwellings, live parts in photovoltaic source circuits and photovoltaic output circuits over 150 volts to ground shall not be accessible to other than qualified persons while energized.

FPN: See 110.27 for guarding of live parts, and 210.6 for voltage to ground and between conductors.

Where dc circuitry over 150 volts to ground is present in one- and two-family dwellings, additional protection for unqualified persons may be needed. Protection may be in the form of conduit, a closed cabinet, or an enclosure that requires the use of tools to open it and that permits entry only by qualified persons.

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

1. One conductor of each circuit is solidly grounded.
2. Each circuit is connected to a separate subarray.
3. The equipment is clearly marked with a label as follows:

WARNING
BIPOLAR PHOTOVOLTAIC ARRAY. DISCONNECTION OF NEUTRAL OR GROUNDED CONDUCTORS MAY RESULT IN OVERVOLTAGE ON ARRAY OR INVERTER.
690.8 Circuit Sizing and Current

(A) Calculation of Maximum Circuit Current. The maximum current for the specific circuit shall be calculated in accordance with 690.8(A)(1) through (A)(4).

FPN: Where the requirements of 690.8(A)(1) and (B)(1) are both applied, the resulting multiplication factor is 156 percent.

(1) Photovoltaic Source Circuit Currents. The maximum current shall be the sum of parallel module rated short-circuit currents multiplied by 125 percent. The use of the array short-circuit current allows for proper sizing of conductors to handle the current generated during extended periods of operation under a short-circuit current operating point.

The 125 percent factor is required by 690.8(A)(1) because PV modules, PV source circuits, and PV output circuits can deliver output currents higher than the rated short-circuit currents for more than 3 hours near solar noon. This requirement is duplicated in the instructions provided with each listed module, and it should be noted that this factor only needs to be applied once. A second 125 percent factor is required by 690.8(B).

PV modules in hot climates operate at temperatures of 60°C to 80°C due to solar heating. Conductors with insulation types rated at least 90°C should be used, and these conductors should have the ampacity corrected in accordance with Table 310.16 or Table 310.17.

(2) Photovoltaic Output Circuit Currents. The maximum current shall be the sum of parallel source circuit maximum currents as calculated in 690.8(A)(1).

(3) Inverter Output Circuit Current. The maximum current shall be the inverter continuous output current rating. Both stand-alone and utility-interactive inverters are power-limited devices. Output circuits connected to these devices are sized on the continuous rated outputs of these devices and are not based on load calculations or reduced-size PV arrays or battery banks, if any. Some inverters may have specifications listing sustained maximum output currents, and the higher of this number or the rated output should be used.

(4) Stand-Alone Inverter Input Circuit Current. The maximum current shall be the stand-alone continuous inverter input current rating when the inverter is producing rated power at the lowest input voltage.

Stand-alone inverters are nearly constant-output-voltage devices. As the input battery voltage decreases, the input battery current increases to maintain a constant ac output power. The input current for such inverters is calculated by taking the rated full-power output of the inverter in watts and dividing it by the lowest operating battery voltage and then by the rated efficiency of the inverter under those operating conditions.

Calculation Example

The input current for a 4000-watt, 24-volt inverter that is 85 percent efficient at 22 volts can be calculated as follows:

\[
\text{Ampere input} = \frac{\text{watt output}}{\text{voltage} \times \text{efficiency}}
\]

\[
= \frac{4000 \text{ W}}{22 \text{ V} \times 0.85}
\]

\[
= 214 \text{ A}
\]

Ripple currents might be present in the dc-input circuits of single-phase, stand-alone inverters. These ripple currents might cause nuisance operation of overcurrent devices at continuous high inverter outputs. In such cases, the measured maximum true rms (root mean square) value of the total (ac + dc) input current, which will be greater than the average current calculated here, should be used to determine conductor sizes and overcurrent device ratings.

(B) Ampacity and Overcurrent Device Ratings. Photovoltaic system currents shall be considered to be continuous.

(1) Sizing of Conductors and Overcurrent Devices. The circuit conductors and overcurrent devices shall be sized to carry not less than 125 percent of the maximum currents as calculated in 690.8(A). The rating or setting of overcurrent devices shall be permitted in accordance with 240.4(8) and (C).

Exception: Circuits containing an assembly, together with its overcurrent device(s), that is listed for continuous operation at 100 percent of its rating shall be permitted to be utilized at 100 percent of its rating.

The exception to 690.8(B)(1) permits use at the full rating of assemblies, such as panelboards, incorporating overcurrent devices listed for continuous operation at 100 percent of the rating.

(2) Internal Current Limitation. Overcurrent protection for photovoltaic output circuits with devices that internally limit the current from the photovoltaic output circuit shall be permitted to be rated at less than the value calculated in 690.8(B)(1). This reduced rating shall be at least 125 percent of the limited current value. Photovoltaic output circuit conductors shall be sized in accordance with 690.8(B)(1).
In the circuits illustrated in Exhibits 690.2, 690.3, 690.4, 690.5, and 690.7, the PV source-circuit overcurrent devices are required to be rated so that the source-circuit conductors are protected in accordance with Article 240 and so that the overcurrent device ratings do not exceed the maximum overcurrent device rating marked on the modules. Possible backfeed currents from the other PV source circuits, other supply sources through the inverter, and storage-battery circuits, if any, have to be considered.

**Exception: An overcurrent device shall not be required for circuit conductors sized in accordance with 690.8(B) and located where one of the following apply:**

(a) There are no external sources such as parallel-connected source circuits, batteries, or backfeed from inverters.

(b) The short-circuit currents from all sources do not exceed the ampacity of the conductors.

FPN: Possible backfeed of current from any source of supply, including a supply through an inverter into the photovoltaic output circuit and photovoltaic source circuits, is a consideration in determining whether adequate overcurrent protection from all sources is provided for conductors and modules.
(C) Photovoltaic Source Circuits. Branch-circuit or supplementary-type overcurrent devices shall be permitted to provide overcurrent protection in photovoltaic source circuits. The overcurrent devices shall be accessible but shall not be required to be readily accessible.

Standard values of supplementary overcurrent devices allowed by this section shall be in one ampere size increments, starting at one ampere up to and including 15 amperes. Higher standard values above 15 amperes for supplementary overcurrent devices shall be based on the standard sizes provided in 240.6(A).

If the overcurrent protection of PV source circuits is considered supplementary overcurrent protection, use of overcurrent devices with ratings other than those suitable for branch-circuit protection is permitted. The use of such devices permits module protection closer to the specified ratings required on the labels attached to listed modules. It is anticipated that only qualified service personnel will replace or reset overcurrent devices in PV source circuits. Consequently, ready access to the user need not be provided. These supplementary overcurrent devices must be listed for dc operation and have appropriate voltage and current ratings.

Overcurrent devices used to protect modules or module interconnections may be installed in enclosures mounted outdoors in exposed locations subject to direct sunlight that may subject the overcurrent devices to operating temperatures higher than 40°C. Appropriate derating instructions are available from the overcurrent device manufacturer.

(D) Direct-Current Rating. Overcurrent devices, either fuses or circuit breakers, used in any dc portion of a photovoltaic power system shall be listed for use in dc circuits and shall have the appropriate voltage, current, and interrupt ratings.

Direct-current fault currents are considerably harder to interrupt than ac faults. Overcurrent devices marked or listed only for ac use should not be used in dc circuits. Automotive- and marine-type fuses, although used in these dc systems, are not suitable for use in permanently wired residential or commercial electrical power systems meeting the requirements of the Code.

(E) Series Overcurrent Protection. In series-connected strings of two or more modules, a single overcurrent protection device shall be permitted.

The single overcurrent device (when required) may provide both the reverse-current protection required for the series-connected PV modules and the overcurrent protection required for the interconnecting conductors.

690.10 Stand-Alone Systems

The premises wiring system shall be adequate to meet the requirements of this Code for a similar installation connected to a service. The wiring on the supply side of the building or structure disconnecting means shall comply with this Code except as modified by 690.10(A) through (D).

(A) Inverter Output. The ac output from a stand-alone inverter(s) shall be permitted to supply ac power to the building or structure disconnecting means at current levels less than the calculated load connected to that disconnect. The inverter output rating or the rating of an alternate energy source shall be equal to or greater than the load posed by the largest single utilization equipment connected to the system. Calculated general lighting loads shall not be considered as a single load.

A stand-alone residential or commercial PV installation may have an ac output and be connected to a building wired in full compliance with all articles of this Code. Even though such an installation may have service-entrance equipment rated at 100 or 200 amperes at 120/240 volts, there is no requirement that the PV source provide either the rated full current or the dual voltages of the service equipment. While safety requirements dictate full compliance with the ac wiring sections of the Code, a PV installation is usually designed so that the actual ac demands on the system are sized to the output rating of the PV system. The inverter output is required to have sufficient capacity to power the largest single piece of utilization equipment to be supplied by the PV system, but the inverter output does not have to be sized for the potential multiple loads to be simultaneously connected to it. Lighting loads are managed by the user based on the available energy from the PV system.

(B) Sizing and Protection. The circuit conductors between the inverter output and the building or structure disconnecting means shall be sized based on the output rating of the inverter. These conductors shall be protected from overcurrents in accordance with Article 240. The overcurrent protection shall be located at the output of the inverter.

(C) Single 120-Volt Supply. The inverter output of a stand-alone solar photovoltaic system shall be permitted to supply 120 volts to single-phase, 3-wire, 120/240-volt service equipment or distribution panels where there are no 240-volt outlets and where there are no multwire branch circuits. In all installations, the rating of the overcurrent device connected to the output of the inverter shall be less than the rating of the neutral bus in the service equipment. This equipment shall be marked with the following words or equivalent:

WARNING

SINGLE 120-VOLT SUPPLY. DO NOT CONNECT MULTIWIRE BRANCH CIRCUITS!
Multiwire branch circuits are common in one- and two-family dwelling units. When connected to a normal 120/20-volt ac service, the currents in the neutral conductors of these multiwire branch circuits (typically 14-3 AWG) are, at most, no larger than the rating of the branch-circuit overcurrent device. When these electrical systems are connected to a single 120-volt PV power system inverter by paralleling the two ungrounded conductors in the service entrance load center, the currents in the neutral conductor for each multiwire branch circuit add rather than subtract. The currents in the neutral conductor may be as much as twice the rating of the branch-circuit overcurrent device. With this configuration, neutral conductor overloading is possible.

(D) Equipment. Equipment such as photovoltaic source circuit isolating switches, overcurrent devices, and blocking diodes shall be permitted on the photovoltaic side of the photovoltaic disconnecting means.

In general, equipment that needs servicing must be disconnected from sources of supply. In a PV system, however, some equipment, as indicated, is permitted to be located on the PV power source side of the disconnecting means. See Exhibit 690.8. Servicing the exempted equipment might require disabling all or portions of the array, as explained in the commentary following 690.18.

There is no intent or requirement to have a disconnecting means located in each PV source circuit or located physically at each PV module location. Unlike load circuits (e.g., rooftop air conditioners), PV source-circuit conductors may be energized at any time from the PV modules. A centrally located disconnect meeting the requirements of 690.14(C)(1) near the inverter or batteries serves to disconnect the PV source circuits from the other portions of the electric power system.

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

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

The photovoltaic system disconnecting means shall not be installed in bathrooms.

These requirements generally prohibit long runs of PV source and output circuits inside a building before reaching the required PV disconnect. A short conductor run through a wall at the point of first penetration to reach a disconnect mounted inside the building is allowed. Section 690.31(E) permits these circuits to be run inside a building when installed in metal conduit from the point of entrance to the system disconnecting means.

(2) **Marking.** Each photovoltaic system disconnecting means shall be permanently marked to identify it as a photovoltaic system disconnect.

(3) **Suitable for Use.** Each photovoltaic system disconnecting means shall be suitable for the prevailing conditions. Equipment installed in hazardous (classified) locations shall comply with the requirements of Articles 500 through 517.

(4) **Maximum Number of Disconnects.** The photovoltaic system disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure, in a group of separate enclosures, or in or on a switchboard.

(5) **Grouping.** The photovoltaic system disconnecting means shall be grouped with other disconnecting means for the system to comply with 690.14(C)(4). A photovoltaic disconnecting means shall not be required at the photovoltaic module or array location.

PV systems may be one of multiple sources of power for a building or structure, including the utility, the PV array, a backup generator, and a wind system. No more than six disconnects for each source of power to the building are allowed, and the disconnects for each source should be grouped together. A PV system may be considered a source of supply separate from a utility source, and each source may have up to six grouped disconnects. See 230.2 and 230.72.

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

1. A direct-current photovoltaic disconnecting means shall be mounted within sight of or in the inverter.
2. An alternating-current disconnecting means shall be mounted within sight of or in the inverter.

The requirements in 690.14(D)(1) and (D)(2) provide for servicing disconnects at the inverter.

3. The alternating-current output conductors from the inverter and an additional alternating-current disconnecting means for the inverter shall comply with 690.14(C)(1).

The disconnect required by 690.14(C)(1) allows the inverter(s) and the circuit to it (them) to be de-energized from a readily accessible location.

4. A plaque shall be installed in accordance with 705.10.

**690.15 Disconnection of Photovoltaic Equipment**

Means shall be provided to disconnect equipment, such as inverters, batteries, charge controllers, and the like, from all ungrounded conductors of all sources. If the equipment is energized from more than one source, the disconnecting means shall be grouped and identified.

A single disconnecting means in accordance with 690.17 shall be permitted for the combined ac output of one or more inverters or ac modules in an interactive system.

**690.16 Fuses**

Disconnecting means shall be provided to disconnect a fuse from all sources of supply if the fuse is energized from both directions and is accessible to other than qualified persons. Such a fuse in a photovoltaic source circuit shall be capable of being disconnected independently of fuses in other photovoltaic source circuits.

Switches, pullouts, or similar devices that have suitable ratings may serve as means to disconnect fuses from all sources of supply.

**690.17 Switch or Circuit Breaker**

The disconnecting means for ungrounded conductors shall consist of a manually operable switch(es) or circuit break-
(1) Located where readily accessible.
(2) Externally operable without exposing the operator to contact with live parts.
(3) Plainly indicating whether in the open or closed position.
(4) Having an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment.

Where all terminals of the disconnecting means may be energized in the open position, a warning sign shall be mounted on or adjacent to the disconnecting means. The sign shall be clearly legible and have the following words or equivalent:

**WARNING**

**ELECTRIC SHOCK HAZARD.**

**DO NOT TOUCH TERMINALS.**

**TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.**

**Exception:** A connector shall be permitted to be used as an ac or a dc disconnecting means, provided that it complies with the requirements of 690.33 and is listed and identified for the use.

### 690.18 Installation and Service of an Array

Open circuiting, short circuiting, or opaque covering shall be used to disable an array or portions of an array for installation and service.

**FPN:** Photovoltaic modules are energized while exposed to light. Installation, replacement, or servicing of array components while a module(s) is irradiated may expose persons to electric shock.

To prevent contact by personnel with energized parts during installation, servicing, or other procedures, a number of methods can be used to disable an array or portions of an array. One method, used infrequently because of the expense in time and materials, is to cover all of the array or portions of it with an opaque material. Care must be taken that all of the area to be covered is shielded from light.

Another method divides the array into nonhazardous segments, which can be accomplished by switches or connectors. Also see 690.33.

Short-circuiting all or portions of an array by means of switches or plug-in connectors, in conjunction with the bypass diodes internal to each module, can also provide the necessary disablement. (Bypass diodes are incorporated in PV modules for performance purposes.)

### IV. Wiring Methods

#### 690.31 Methods Permitted

(A) **Wiring Systems.** All raceway and cable wiring methods included in this Code and other wiring systems and fittings specifically intended and identified for use on photovoltaic arrays shall be permitted. Where wiring devices with integral enclosures are used, sufficient length of cable shall be provided to facilitate replacement.

Where photovoltaic source and output circuits operating at maximum system voltages greater than 30 volts are installed in readily accessible locations, circuit conductors shall be installed in a raceway.

Most PV modules do not have provisions for attaching raceways. These circuits may have to be made “not readily accessible” by use of physical barriers such as wire screening.

**FPN:** Photovoltaic modules operate at elevated temperatures when exposed to high ambient temperatures and to bright sunlight. These temperatures may routinely exceed 71°C (158°F) in many locations. Module interconnection conductors are available with insulation rated for wet locations and a temperature rating of 90°C (194°F) or greater.

(B) **Single-Conductor Cable.** Single-conductor cable type USE-2, and single-conductor cable listed and labeled as photovoltaic (PV) wire shall be permitted in exposed outdoor locations in photovoltaic source circuits for photovoltaic module interconnections within the photovoltaic array.

Most PV modules are designed for a direct series connection by using factory-installed leads and connectors. To accommodate such a direct series connection without the waste of one or more conductors in a multicore cable, use of a single-conductor Type USE-2 cable and single conductor cable listed and labeled for PV applications is permitted in PV source circuits. Long runs of separated conductors (with loop inductance and distributed capacitance) and the resulting long-time constants in dc circuits may result in improper operation of overcurrent devices. It is suggested that, wherever possible, both positive and negative conductors of each circuit and the equipment grounding conductor be routed as close together as possible to minimize the circuit time constant. The smaller loop resulting from the close routing also decreases induced currents from nearby lightning strikes. Because PV modules may operate at high temperatures and are installed in outdoor, exposed locations, the use of high-temperature, wet-rated conductors such as USE-2, THWN-2, or RHW-2 is advisable. See 310.15(B)(2) for requirements on the ampacities of conductors in conduit exposed to sunlight. Single-conductor cables listed and labeled for use in PV applications will be identified as **PV Wire, PV Cable, Photovoltaic Wire, or Photovoltaic Cable.**

**Exception:** Raceways shall be used when required by 690.31(A).
(C) **Flexible Cords and Cables.** Flexible cords and cables, where used to connect the moving parts of tracking PV modules, shall comply with Article 400 and shall be of a type identified as a hard service cord or portable power cable; they shall be suitable for extra-hard usage, listed for outdoor use, water resistant, and sunlight resistant. Allowable ampacities shall be in accordance with 400.5. For ambient temperatures exceeding 30°C (86°F), the ampacities shall be derated by the appropriate factors given in Table 690.31(C).

(D) **Small-Conductor Cables.** Single-conductor cables listed for outdoor use that are sunlight resistant and moisture resistant in sizes 16 AWG and 18 AWG shall be permitted for module interconnections where such cables meet the ampacity requirements of 690.8. Section 310.15 shall be used to determine the cable ampacity and temperature derating factors.

Because these smaller cables are not normally marked with standard Code-recognized markings (e.g., USE-2), the PV module manufacturer or installer should verify that these cables are listed and labeled for PV use, thereby indicating that they have the necessary sunlight and moisture resistance and are suitable for exposed, outdoor use.

In accordance with 200.6(A), grounded conductors that are smaller than 6 AWG and used in PV source circuits are permitted to be marked at the time of installation with a white marking at all terminations.

(E) **Direct-Current Photovoltaic Source and Output Circuits Inside a Building.** Where direct-current photovoltaic source or output circuits of a utility-interactive inverter from a building-integrated or other photovoltaic system are run inside a building or structure, they shall be contained in metal raceways, or metal enclosures, from the point of penetration of the surface of the building or structure to the first readily accessible disconnecting means. The disconnecting means shall comply with 690.14(A) through (D).

The use of metallic raceways or metal enclosures inside a building provides additional physical protection for these circuits. Metallic raceways also provide additional fire resistance should faults develop in the cable, and they provide an additional ground-fault detection path for the ground-fault protection device required by 690.5.

(F) **Flexible, Fine-Stranded Cables.** Flexible, fine-stranded cables shall be terminated only with terminals, lugs, devices, or connectors that are identified and listed for such use.

Flexible, fine-stranded cables (also known as welding cables or battery cables) have numerous, very fine strands and can be used only with specially tested, listed and identified terminations. The terminals, connectors, and crimp-on lugs found on most electrical equipment used in PV systems are not suitable for use with these types of cables.

### 690.32 Component Interconnections

Fittings and connectors that are intended to be concealed at the time of on-site assembly, where listed for such use, shall be permitted for on-site interconnection of modules or other array components. Such fittings and connectors shall be equal to the wiring method employed in insulation, temperature rise, and fault-current withstand, and shall be capable of resisting the effects of the environment in which they are used.

### 690.33 Connectors

The connectors permitted by Article 690 shall comply with 690.33(A) through (E).

(A) **Configuration.** The connectors shall be polarized and shall have a configuration that is noninterchangeable with receptacles in other electrical systems on the premises.

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<th>Ambient Temperature (°F)</th>
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<td>105°C (221°F)</td>
<td>1.00</td>
<td>105–113</td>
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</tbody>
</table>

Table 690.31(C) Correction Factors
(B) Guarding. The connectors shall be constructed and installed so as to guard against inadvertent contact with live parts by persons.

(C) Type. The connectors shall be of the latching or locking type. Connectors that are readily accessible and that are used in circuits operating at over 30 volts, nominal, maximum system voltage for dc circuits, or 30 volts for ac circuits, shall require a tool for opening.

(D) Grounding Member. The grounding member shall be the first to make and the last to break contact with the mating connector.

(E) Interruption of Circuit. Connectors shall be either (1) or (2):

1. Be rated for interrupting current without hazard to the operator.
2. Be a type that requires the use of a tool to open and marked "Do Not Disconnect Under Load" or "Not for Current Interrupting."

Connectors that can be opened or disconnected using only the hands are not acceptable.

690.34 Access to Boxes

Junction, pull, and outlet boxes located behind modules or panels shall be so installed that the wiring contained in them can be rendered accessible directly or by displacement of a module(s) or panel(s) secured by removable fasteners and connected by a flexible wiring system.

690.35 Ungrounded Photovoltaic Power Systems

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

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

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

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

1. Detects a ground fault.
2. Indicates that a ground fault has occurred
3. Automatically disconnects all conductors or causes the inverter or charge controller connected to the faulted circuit to automatically cease supplying power to output circuits.

(D) The photovoltaic source conductors shall consist of the following:

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

Three options for PV source output circuits are provided by this section. All cables and conductors installed outdoors and exposed to direct sunlight and wet conditions have to be suitable for these conditions and such suitability is verified by the cables and conductors being listed. Conductors inside raceways installed in wet locations are required to be identified or listed as suitable for this environmental condition. See 310.8(C) for the requirements on conductors installed in wet locations. Open, single conductors are permitted where listed and identified as Photovoltaic Wire, Photovoltaic Cable, PV Wire, or PV Cable. These conductors are evaluated for use where exposed to direct sunlight and wet conditions. Although not required as a general rule, these conductors can be installed in a raceway at the discretion of the installer.

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

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

WARNING

ELECTRIC SHOCK HAZARD. THE DC CONDUCTORS OF THIS PHOTOVOLTAIC SYSTEM ARE UNGROUNDED AND MAY BE ENERGIZED.

PV dc circuits operate in outdoor environments and are expected to be energized for 40 years or more. Aging of the conductors, dust and dirt infiltration, and moisture and water intrusion create leakage paths from the conductors to ground.
These high-resistance leakage paths can result in leakage current values less than those detected by the required ground-fault detection device, but they can cause any ungrounded conductor to become a potential shock hazard with respect to ground.

(G) The inverters or charge controllers used in systems with ungrounded photovoltaic source and output circuits shall be listed for the purpose.

Many types of PV equipment are designed to operate only on grounded systems. Equipment to be used on ungrounded systems must be tested and evaluated for such use.

V. Grounding

690.41 System Grounding

For a photovoltaic power source, one conductor of a 2-wire system with a photovoltaic system voltage over 50 volts and the reference (center tap) conductor of a bipolar system shall be solidly grounded or shall use other methods that accomplish equivalent system protection in accordance with 250.4(A) and that utilize equipment listed and identified for the use.

Exception: Systems complying with 690.35.

Low-voltage systems that are not grounded must have overcurrent protection in each of the ungrounded conductors, as required by 240.21.

Other methods that employ available equipment may be used to achieve objectives contained in 250.4(A), thereby providing protection for the PV power source circuits equivalent to solid grounding.

690.42 Point of System Grounding Connection

The dc circuit grounding connection shall be made at any single point on the photovoltaic output circuit.

FPN: Locating the grounding connection point as close as practicable to the photovoltaic source better protects the system from voltage surges due to lightning.

Exception: Systems with a 690.5 ground-fault protection device shall be permitted to have the required grounded conductor-to-ground bond made by the ground-fault protection device. This bond, where internal to the ground-fault equipment, shall not be duplicated with an external connection.

If other than solid grounding is utilized, as permitted by 690.41, the connections should be made in accordance with the markings found on the equipment or in the installation instructions.

Stand-alone PV systems might require the grounding connection point to be located close to the high-current conductors associated with the battery and the inverter.

PV systems requiring ground-fault protection devices (see 690.5) are permitted to have the single-point grounding connection made inside the ground-fault protection equipment or inside the utility-interactive inverter and additional external bonding connections are not permitted. Connections are to be made in accordance with markings on the equipment or in the installation instructions.

690.43 Equipment Grounding

Exposed non-current-carrying metal parts of module frames, equipment, and conductor enclosures shall be grounded in accordance with 250.134 or 250.136(A) regardless of voltage. An equipment grounding conductor between a PV array and other equipment shall be required in accordance with 250.110.

Devices listed and identified for grounding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to grounded mounting structures. Devices identified and listed for bonding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to the metallic frames of adjacent PV modules.

Equipment grounding conductors for the PV array and structure (where installed) shall be contained within the same raceway or cable, or otherwise run with the PV array circuit conductors when those circuit conductors leave the vicinity of the PV array.

Equipment grounding is required even in low-voltage (12- and 24-volt) systems not otherwise required to have a system ground. A grounding electrode must be added to an ungrounded system to accommodate the equipment grounds.

To maintain the shortest electrical time constant in each dc circuit, the equipment grounding conductor should be routed as close as possible to the circuit conductors. This routing facilitates the operation of overcurrent devices.

690.45 Size of Equipment Grounding Conductors

Equipment grounding conductors for photovoltaic source and photovoltaic output circuits shall be sized in accordance with 690.45(A) or (B).

(A) General. Equipment grounding conductors in photovoltaic source and photovoltaic output circuits shall be sized in accordance with Table 250.122. Where no overcurrent protective device is used in the circuit, an insulated device rated at the photovoltaic rated short-circuit cur-
ent shall be used in Table 250.122. Increases in equipment grounding conductor size to address voltage drop considerations shall not be required. The equipment grounding conductors shall be no smaller than 14 AWG.

(3) Ground-Fault Protection Not Provided. For other than dwelling units where ground-fault protection is not provided in accordance with 690.5(A) through (C), each equipment grounding conductor shall have an ampacity of at least two (2) times the temperature and conduit fill corrected circuit conductor ampacity.

Equipment grounding conductors on PV systems without ground-fault protection may have ground-fault currents that circulate continuously until the ground fault is corrected. These conductors must have their ampacity corrected for dc conditions of use just like the circuit conductors. Fault currents from parallel source circuits may allow currents in equipment grounding conductors up to twice the normal circuit current under ground-fault conditions.

FPN: The short-circuit current of photovoltaic modules and photovoltaic sources is just slightly above the full-load normal output rating. In ground-fault conditions, these sources are not able to supply the high levels of short-circuit or ground-fault currents necessary to quickly activate overcurrent devices as in typical ac systems. Protection for equipment grounding conductors in photovoltaic systems that are not provided with ground-fault protection is related to size and withstand capability of the equipment grounding conductor, rather than overcurrent device operation.

690.46 Array Equipment Grounding Conductors

Equipment grounding conductors for photovoltaic modules smaller than 6 AWG shall comply with 250.120(C).

690.47 Grounding Electrode System

(A) Alternating-Current Systems. If installing an ac system, a grounding electrode system shall be provided in accordance with 250.50 through 250.60. The grounding electrode conductor shall be installed in accordance with 250.64.

(B) Direct-Current Systems. If installing a dc system, a grounding electrode system shall be provided in accordance with 250.166 for grounded systems or 250.169 for ungrounded systems. The grounding electrode conductor shall be installed in accordance with 250.64.

(C) Systems with Alternating-Current and Direct-Current Grounding Requirements. Systems with alternating-current and direct-current grounding requirements shall comply with items (C)(1) through (C)(8):

(1) Where photovoltaic power systems have both alternating-current (ac) and direct-current (dc) grounding requirements, the dc grounding system shall be bonded to the ac grounding system.

(2) A bonding conductor between these systems shall be sized as the larger of the dc requirement in accordance with 690.45, the ac requirements based on the inverter alternating current overcurrent device rating and 250.122, and the system bonding requirements of 250.28.

(3) A conductor that serves as both an equipment grounding conductor and as part of the bond between ac and dc systems for an inverter incorporating dc ground-fault protection shall meet the requirements for equipment bonding jumpers in accordance with 250.102 but shall not be subject to the requirements for bonding jumpers in accordance with 250.28. A single conductor shall be permitted to be used to perform the multiple functions of dc grounding, ac grounding, and bonding between ac and dc systems.

(4) A bonding conductor or equipment grounding conductor that serves multiple inverters shall be sized based on the sum of applicable maximum currents used in item (2).

(5) A common ground bus shall be permitted to be used for both systems.

(6) A common grounding electrode shall be permitted to be used for both systems, in which case the grounding electrode conductor shall be connected to the ac ground system bonding point.

(7) Grounding electrode conductor(s) shall be sized to meet the requirements of both 250.66 (ac system) and 250.166 (dc system).

(8) For systems with utility-interactive inverters, the premises grounding system serves as the ac grounding system.

Inverters used in PV power systems usually contain a transformer that isolates the dc grounded circuit conductor from the ac grounded circuit conductor. Isolation necessitates that both a dc and an ac grounding system be installed. The two grounding systems are to be bonded together or have a common grounding electrode so that all ac and dc grounded circuit conductors and equipment grounding conductors have the same near-zero potential to earth.

The combined dc equipment grounding, dc system grounding, and ac equipment grounding required by this section establishes only one grounding circuit and connection for the entire PV system from the PV array to the ac point of connection. Under PV dc ground-fault conditions, an interruption of this single circuit may allow exposed metal surfaces to become energized up to the maximum PV system voltage.
(D) Additional Electrodes for Array Grounding.
Grounding electrodes shall be installed in accordance with 250.52 at the location of all ground- and pole-mounted photovoltaic arrays and as close as practicable to the location of roof-mounted photovoltaic arrays. The electrodes shall be connected directly to the array frame(s) or structure. The dc grounding electrode conductor shall be sized according to 250.166. Additional electrodes are not permitted to be used as a substitute for equipment bonding or equipment grounding conductor requirements.

The structure of a ground- or pole-mounted photovoltaic array shall be permitted to be considered a grounding electrode if it meets the requirements of 250.52. Roof-mounted photovoltaic arrays shall be permitted to use the metal frame of a building or structure if the requirements of 250.52(A)(2) are met.

Exception No. 1: Array grounding electrode(s) shall not be required where the load served by the array is integral with the array.

Enhanced protection from lightning-induced surges may be afforded by connecting an array grounding electrode even on buildings with colocated loads (including inverters).

Exception No. 2: Additional array grounding electrode(s) shall not be required if located within 6 ft of the premises wiring electrode.

690.48 Continuity of Equipment Grounding Systems
Where the removal of equipment disconnects the bonding connection between the grounding electrode conductor and exposed conducting surfaces in the photovoltaic source or output circuit equipment, a bonding jumper shall be installed while the equipment is removed.

PV source and output circuits are energized anytime the PV modules are exposed to light. The equipment grounding system is a primary line of defense against electric shocks and fires. In many PV systems, the main bonding jumper is located in the inverter or a dc power center that may require removal for service. The continuity of the equipment grounding conductors should be maintained even when the equipment is removed.

690.50 Equipment Bonding Jumpers
Equipment bonding jumpers, if used, shall comply with 250.120(C).

VI. Marking

690.51 Modules
Modules shall be marked with identification of terminals or leads as to polarity, maximum overcurrent device rating for module protection, and with the following ratings:

(1) Open-circuit voltage
(2) Operating voltage
(3) Maximum permissible system voltage
(4) Operating current
(5) Short-circuit current
(6) Maximum power

690.52 Alternating-Current Photovoltaic Modules
Alternating-current modules shall be marked with identification of terminals or leads and with identification of the following ratings:

(1) Nominal operating ac voltage
(2) Nominal operating ac frequency
(3) Maximum ac power
(4) Maximum ac current
(5) Maximum overcurrent device rating for ac module protection

690.53 Direct-Current Photovoltaic Power Source
A permanent label for the direct-current photovoltaic power source indicating items (1) through (5) shall be provided by the installer at the photovoltaic disconnecting means:

(1) Rated maximum power-point current
(2) Rated maximum power-point voltage
(3) Maximum system voltage
FPN to (3): See 690.7(A) for maximum photovoltaic system voltage.

4) Short-circuit current

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

5) Maximum rated output current of the charge controller (if installed)

FPN: Reflecting systems used for irradiance enhancement may result in increased levels of output current and power.

After installation of PV arrays, it may be difficult to determine the system’s rated voltage and current. These ratings, along with the open-circuit voltage and short-circuit current, are necessary to size the remainder of the system components, as specified elsewhere in Article 690.

Generally, the marking described in 690.53 is required to be provided by the installer. The rated values for the PV power source can be calculated by adding voltage ratings of series-connected modules and adding current ratings of parallel-connected modules or PV source circuits.

Some charge controllers have higher rated output currents than the input currents from the PV array. They reduce the input voltage from the PV array while increasing the output to the battery.

With respect to the fine print note, a deliberate increase in the level of irradiance by reflectors or the like can cause the power source to operate at levels above those recommended by the manufacturer. See 110.3.

690.54 Interactive System Point of Interconnection

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

690.55 Photovoltaic Power Systems Employing Energy Storage

Photovoltaic power systems employing energy storage shall also be marked with the maximum operating voltage, including any equalization voltage and the polarity of the grounded circuit conductor.

690.56 Identification of Power Sources

(A) Facilities with Stand-Alone Systems. Any structure or building with a photovoltaic power system that is not connected to a utility service source and is a stand-alone system shall have a permanent plaque or directory installed on the exterior of the building or structure at a readily visible location acceptable to the authority having jurisdiction. The plaque or directory shall indicate the location of system disconnecting means and that the structure contains a stand-alone electrical power system.

(B) Facilities with Utility Services and PV Systems. Buildings or structures with both utility service and a photovoltaic system shall have a permanent plaque or directory providing the location of the service disconnecting means and the photovoltaic system disconnecting means if not located at the same location.

VII. Connection to Other Sources

690.57 Load Disconnect

A load disconnect that has multiple sources of power shall disconnect all sources when in the off position.

690.60 Identified Interactive Equipment

Only inverters and ac modules listed and identified as interactive shall be permitted in interactive systems.

690.61 Loss of Interactive System Power

An inverter or an ac module in an interactive solar photovoltaic system shall automatically de-energize its output to the connected electrical production and distribution network upon loss of voltage in that system and shall remain in that state until the electrical production and distribution network voltage has been restored.

A normally interactive solar photovoltaic system shall be permitted to operate as a stand-alone system to supply loads that have been disconnected from electrical production and distribution network sources.

The requirement of 690.61 prevents energizing of otherwise de-energized system conductors or output conductors of other off-site sources (e.g., an electrical utility) and is intended to prevent electric shock. This feature normally is provided as part of the utility-interactive inverter.

690.62 Ampacity of Neutral Conductor

If a single-phase, 2-wire inverter output is connected to the neutral conductor and one ungrounded conductor (only) of a 3-wire system or of a 3-phase, 4-wire, wye-connected system, the maximum load connected between the neutral conductor and any one ungrounded conductor plus the inverter output rating shall not exceed the ampacity of the neutral conductor.

A conductor used solely for instrumentation, voltage detection, or phase detection, and connected to a single-phase or 3-phase utility-interactive inverter, shall be permitted to be sized at less than the ampacity of the other.
current-carrying conductors and shall be sized equal to or larger than the equipment grounding conductor.

690.63 Unbalanced Interconnections

(A) Single Phase. Single-phase inverters for photovoltaic systems and ac modules in interactive solar photovoltaic systems shall not be connected to 3-phase power systems unless the interconnected system is designed so that significant unbalanced voltages cannot result.

(B) Three Phase. Three-phase inverters and 3-phase ac modules in interactive systems shall have all phases automatically de-energized upon loss of, or unbalanced, voltage in one or more phases unless the interconnected system is designed so that significant unbalanced voltages will not result.

690.64 Point of Connection

The output of a utility-interactive inverter shall be connected as specified in 690.64(A) or (B).

(A) Supply Side. The output of a utility-interactive inverter shall be permitted to be connected to the supply side of the service disconnecting means as permitted in 230.82(6).

The supply-side connection is similar to installing a second service entrance, and the numerous requirements of Article 230 apply.

(B) Load Side. The output of a utility-interactive inverter shall be permitted to be connected to the load side of the service disconnecting means of the other source(s) at any distribution equipment on the premises. Where distribution equipment, including switchboards and panelboards, is fed simultaneously by a primary source(s) of electricity and one or more utility-interactive inverters, and where this distribution equipment is capable of supplying multiple branch circuits or feeders, or both, the interconnecting provisions for the utility-interactive inverter(s) shall comply with (B)(1) through (B)(7).

(1) Dedicated Overcurrent and Disconnect. Each source interconnection shall be made at a dedicated circuit breaker or fusible disconnecting means.

The outputs of utility-interactive inverters may not be connected directly in parallel without first being connected to the required dedicated circuit breaker or fusible disconnecting means.

(2) Bus or Conductor Rating. The sum of the ampere ratings of overcurrent devices in circuits supplying power to a busbar or conductor shall not exceed 120 percent of the rating of the busbar or conductor. In systems with panelboards connected in series, the rating of the first overcurrent device directly connected to the output of a utility-interactive inverter(s) shall be used in the calculations for all busbars and conductors.

In order to use this 120 percent factor, see 690.64(B)(7) for the required backfed overcurrent device location in relation to the utility-connected overcurrent device.

While this requirement will minimize the possibility of overloading the busbar or conductor from higher-than-rated currents, the possibility of inadvertent thermal overloading of the panelboard may still exist where plug loads are increased to the point where the load on the busbar exceeds its rating.

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

Exception: Connection shall be permitted to be made to the load side of ground-fault protection, provided that there is ground-fault protection for equipment from all ground-fault current sources. Ground-fault protection devices used with supplies connected to the load-side terminals shall be identified and listed as suitable for backfeeding.

Load-side connection of energy sources to commonly available ac GFCI and ac equipment ground-fault protection circuit breakers may result in backfeed currents from the PV system output. Tests have shown that backfeed currents through these devices may damage them and prevent proper operation.

Sections 215.10 and 230.95 are requirements calling for ground-fault protection of equipment based on the voltage level, type of electrical supply system, and rating of the equipment or trip element of a circuit breaker. Where PV systems are interfaced with large capacity service or feeder circuit breakers equipped with ground-fault protection of equipment, load-side connections to these devices should not be made unless the devices are listed and identified for backfed installations.

(4) Marking. Equipment containing overcurrent devices in circuits supplying power to a busbar or conductor supplied from multiple sources shall be marked to indicate the presence of all sources.

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

FPN: Circuit breakers that are marked “Line” and “Load” have been evaluated only in the direction 
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marked. Circuit breakers without “Line” and “Load” have been evaluated in both directions.

Circuit breakers not marked Line and Load are considered to be identified as suitable for backfeeding.

690.71 Installation

(A) General. Storage batteries in a solar photovoltaic system shall be installed in accordance with the provisions of Article 480. The interconnected battery cells shall be considered grounded where the photovoltaic power source is installed in accordance with 690.41.

(B) Current Limiting. A listed, current-limiting, overcurrent device shall be installed in each circuit adjacent to the batteries where the available short-circuit current from a battery or battery bank exceeds the interrupting or withstand ratings of other equipment in that circuit. The installation of current-limiting fuses shall comply with 690.16.

At any voltage, a primary safety concern in battery systems is that a fault (e.g., a metal tool dropped onto a terminal) might cause a fire or an explosion. Guarded, as defined in Article 100, describes the best method to reduce this hazard.

(C) Battery Nonconductive Cases and Conductive Racks. Flooded, vented, lead-acid batteries with more than twenty-four 2-volt cells connected in series (48 volts, nominal) shall not use conductive cases or shall not be installed in conductive cases. Conductive racks used to support the nonconductive cases shall be permitted where no rack material is located within 150 mm (6 in.) of the tops of the nonconductive cases.

This requirement shall not apply to any type of valve-regulated lead-acid (VRLA) battery or any other types of sealed batteries that may require steel cases for proper operation.

Grounded metal trays and cases or containers (as normally required by 250.110) in flooded, lead-acid battery systems operating over 48 volts, nominal, have been shown to be a contributing factor in ground faults. Nonconductive racks, trays, and cases minimize this problem.

(D) Battery Maintenance Disconnecting Means. Battery installations, where there are more than twenty-four 2-volt cells connected in series (48 volts, nominal), shall have provisions to disconnect the series-connected strings into segments of 24 cells or less for maintenance by qualified persons. Non-load-break bolted or plug-in disconnects shall be permitted.

(F) Battery Maintenance Disconnecting Means. Battery installations, where there are more than twenty-four 2-volt cells connected in series (48 volts, nominal), shall have a disconnecting means, accessible only to qualified persons, that disconnects the grounded circuit conductor(s) in the battery electrical system for maintenance. This disconnect...
nnecting means shall not disconnect the grounded circuit conductor(s) for the remainder of the photovoltaic electrical system. A non-load-break-rated switch shall be permitted to be used as the disconnecting means.

(G) Battery Systems of More Than 48 Volts. On photovoltaic systems where the battery system consists of more than twenty-four 2-volt cells connected in series (more than 48 volts, nominal), the battery system shall be permitted to operate with ungrounded conductors, provided the following conditions are met:

1. The photovoltaic array source and output circuits shall comply with 690.41.
2. The dc and ac load circuits shall be solidly grounded.
3. All main ungrounded battery input/output circuit conductors shall be provided with switched disconnects and overcurrent protection.
4. A ground-fault detector and indicator shall be installed to monitor for ground faults in the battery bank.

690.72 Charge Control
(A) General. Equipment shall be provided to control the charging process of the battery. Charge control shall not be required where the design of the photovoltaic source circuit is matched to the voltage rating and charge current requirements of the interconnected battery cells and the maximum charging current multiplied by 1 hour is less than 3 percent of the rated battery capacity expressed in ampere-hours or as recommended by the battery manufacturer.

All adjusting means for control of the charging process shall be accessible only to qualified persons.

FPN: Certain battery types such as valve-regulated lead acid or nickel cadmium can experience thermal failure when overcharged.

(B) Diversion Charge Controller.
(1) Sole Means of Regulating Charging. A photovoltaic power system employing a diversion charge controller as the sole means of regulating the charging of a battery shall be equipped with a second independent means to prevent overcharging of the battery.

(2) Circuits with Direct-Current Diversion Charge Controller and Diversion Load. Circuits containing a dc diversion charge controller and a dc diversion load shall comply with the following:

1. The current rating of the diversion load shall be less than or equal to the current rating of the diversion load charge controller. The voltage rating of the diversion load shall be greater than the maximum battery voltage. The power rating of the diversion load shall be at least 150 percent of the power rating of the photovoltaic array.

Diversion loads are typically rated by the current that they will draw at some rated voltage. If the rated current of the diversion load exceeds the current rating of the diversion load controller, the controller may not function properly.

(2) The conductor ampacity and the rating of the overcurrent device for this circuit shall be at least 150 percent of the maximum current rating of the diversion charge controller.

If any portion of a diversion charge control system fails, the batteries may be overcharged and can create a potentially hazardous condition. Requiring a second, independent charge control method (usually a series regulator) and robust diversion controller circuits will minimize the potential problems.

(3) PV Systems Using Utility-Interactive Inverters. Photovoltaic power systems using utility-interactive inverters to control battery state-of-charge by diverting excess power into the utility system shall comply with (1) and (2):

1. These systems shall not be required to comply with 690.72(B)(2). The charge regulation circuits used shall comply with the requirements of 690.8.
2. These systems shall have a second, independent means of controlling the battery charging process for use when the utility is not present or when the primary charge controller fails or is disabled.

690.74 Battery Interconnections
Flexible cables, as identified in Article 400, in sizes 20 AWG and larger shall be permitted within the battery enclosure from battery terminals to a nearby junction box where they shall be connected to an approved wiring method. Flexible battery cables shall also be permitted between batteries and cells within the battery enclosure. Such cables shall be listed for hard-service use and identified as moisture resistant.

Flexible, fine-stranded cables shall only be used with terminals, lugs, devices, and connectors that are listed and marked for such use.

Battery plates and terminals are sometimes constructed of relatively soft lead and lead alloys encased in plastics that are sealed with asphalt. Large-size, low-stranding stiff copper conductors attached to these components may cause them to be distorted. The use of flexible cables (see Article 400) may reduce the possibility of such distortions. Listed cables with the appropriate physical and chemical-resistant properties should be used. Welding and "battery" cables are not allowed or described in the NEC for this use. Flexible "build-
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**Summary of Changes**

- **692.41(A) & (B):** Revised to reference applicable sections of Article 250 for ac and dc grounding.
- **692.41(C):** Added section to specify means of grounding and bonding of fuel cell systems with ac and dc grounding and bonding requirements.
- **692.65:** Specified that requirements apply to systems with utility-interactive inverters.
- **692.65(B)(1) through (7):** Provided interconnecting requirements for distribution equipment capable of supplying multiple branch circuits or feeders while simultaneously connected to primary power and one or more interactive inverters.

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Flexible wire-type cables (Chapter 3) are also available and suitable for this use. Terminals intended for connection of stranded conductors using other than Class B stranding are required to be listed and marked for this use. Flexible, fine-stranded battery connection cables cannot be connected to terminals identified for use with conductors using the larger strands of conductors using Class B stranding. See the commentary on 690.31(F).

**IX. Systems over 600 Volts**

00.80 General

Solar photovoltaic systems with a maximum system voltage over 600 volts dc shall comply with Article 490 and other requirements applicable to installations rated over 600 volts.

00.85 Definitions

For the purposes of Part IX of this article, the voltages used to determine cable and equipment ratings are as follows.

Battery Circuits. In battery circuits, the highest voltage experienced under charging or equalizing conditions.

Photovoltaic Circuits. In dc photovoltaic source circuits and photovoltaic output circuits, the maximum system voltage.

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