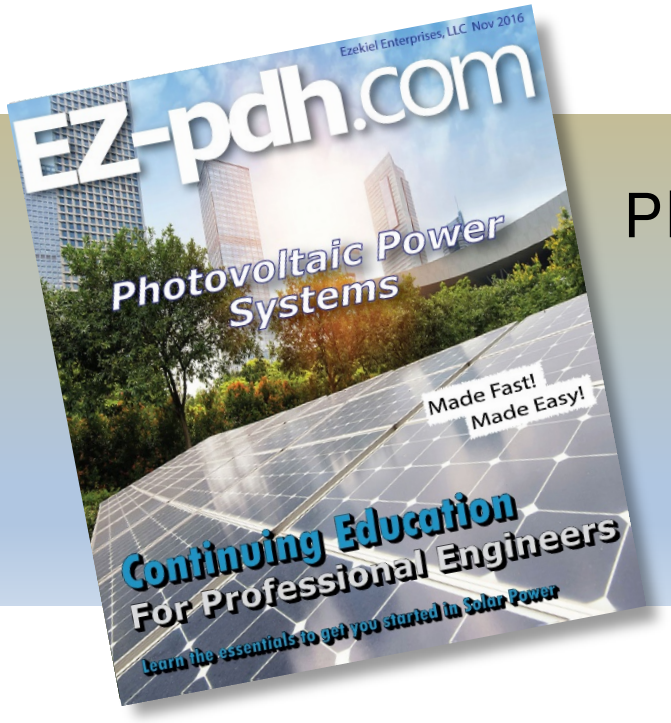

Photovoltaic Power Systems

Edition 1.0
Course # EE1605

Continuing Education for Professional Engineers

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LEARNING OBJECTIVES

Upon completion of this course, the student will be able to:

1. Understand the various components and terminologies associated with photovoltaic systems
2. Learn photovoltaic system's circuit requirements and installation guidelines including wiring methods
3. Discuss grounding methods as well as standard markings of photovoltaic system components
4. Identify standard methods to connect to other power systems and loads

Introduction

In this course the student will review guidelines for designing and installing a photovoltaic power system. The material covered comes directly from the National Electrical Code (NEC) section 690. In effort to easily cross reference between this course and the NEC; all headings and figures are similar to the NEC.

690.1 SCOPE.

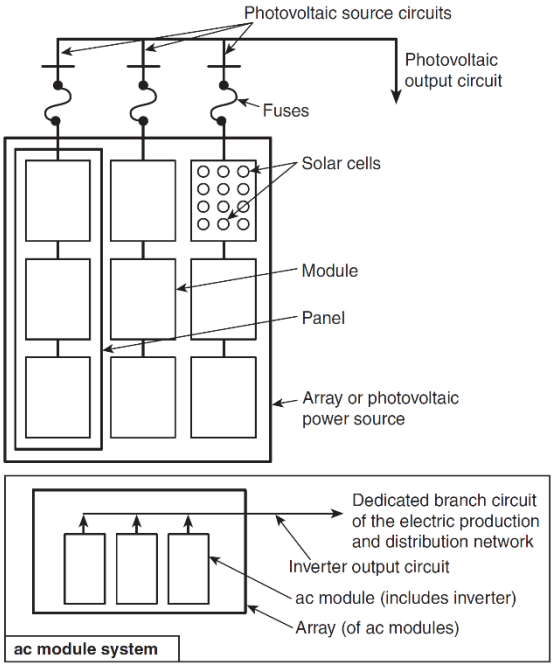
The provisions of this article apply to solar photovoltaic (PV) electrical energy systems, including the array circuit(s), inverter(s), and controller(s) for such systems. [See Figure 690.1(A) and Figure 690.1(B).] Solar photovoltaic systems covered by this article may be interactive with other electrical 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.

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.

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.

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



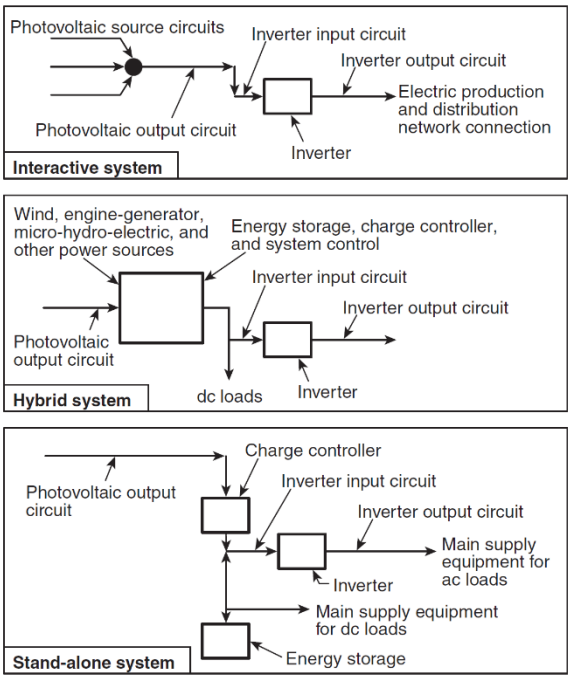
Notes:
1. These diagrams are intended to be a means of identification for photovoltaic system components, circuits, and connections.
2. Disconnecting means required by Article 690, Part III, are not shown.
3. System grounding and equipment grounding are not shown. See Article 690, Part V.

Figure 690.1(A) Identification of Solar Photovoltaic System Components.

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

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.



Notes:
1. These diagrams are intended to be a means of identification for photovoltaic system components, circuits, and connections.
2. Disconnecting means required by Article 690 are not shown.
3. System grounding and equipment grounding are not shown. See Article 690, Part V.
4. Custom designs occur in each configuration, and some components are optional

Figure 690.1(B) Identification of Solar Photovoltaic System Components. In Common System Configurations

Direct Current (dc) Combiner. A device used in the PV Source and PV Output circuits to combine two or more dc circuit inputs and provide one dc circuit output.

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.

Monopole Subarray. A PV subarray that has two conductors in the output circuit, one positive (+) and one negative(-). Two monopole PV subarrays are used to form a bipolar PV array.

Multimode Inverter. Equipment having capabilities of both the utility-interactive inverter and the stand-alone inverter.

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

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.

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

Subarray. An electrical subset of a PV array.

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 GENERAL REQUIREMENTS.

(A) Photovoltaic Systems. Photovoltaic systems shall be permitted to supply a building or other structure in addition to any other electrical supply system(s).

(B) Equipment. Inverters, motor generators, PV modules, PV panels, ac PV modules, dc combiners, dc-to-dc converters and charge controllers intended for use in PV power systems shall be listed for the PV application.

(C) Qualified Personnel. The installation of equipment and all associated wiring and interconnections shall be performed only by qualified persons. [ROP 4–188a] Informational Note: See Article 100 for the definition of qualified person. [ROP 4–188a, ROP 4–195]

(D) Multiple Inverters. A PV system shall be permitted to have multiple inverters installed in or on a single building or structure. Where the inverters are remotely located from each other, a directory in accordance with 705.10 shall be installed 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.

Exception: A directory shall not be required where all inverters and PV dc disconnecting means are grouped at the main service disconnecting means.

(E) Circuit Routing. Where circuits are embedded in built-up, laminate, or membrane roofing materials in roof areas not covered by PV modules and associated equipment, the location of circuits shall be clearly marked using a marking protocol that is approved as being suitable for continuous exposure to sunlight and weather.

(F) Bipolar Photovoltaic Systems. Where the sum, without consideration of polarity, of the PV system voltages of the two monopole subarrays exceeds the rating of the conductors and connected equipment, monopole subarrays in a bipolar PV system shall be physically separated, and the electrical output circuits from each monopole subarray shall be installed in separate raceways until connected to the inverter. The disconnecting means and overcurrent protective devices for each monopole subarray output shall be in separate enclosures. All conductors from each separate monopole subarray shall be routed in the same raceway. Bipolar photovoltaic systems shall be clearly marked with a permanent, legible warning notice indicating that the disconnection of the grounded conductor(s) may result in overvoltage on the equipment.

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: 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.

(A) Ground-Fault Detection and Interruption. The ground-fault protection device or system shall:

(1) Determine the pv input circuit has isolation prior to export of current,

(2) Be capable of detecting a ground-fault

(3) Interrupt the flow of fault current, and

(4) Provide an indication of the fault.

Automatically opening the grounded conductor for measurement purposes or 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.

(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.

(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:

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. The warning sign(s) or label(s) shall comply with 110.21(B).

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 terminaltype disconnecting means.

(D) 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 seriesconnected 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.

Informational Note: One source for statistically valid, lowest-expected, ambient temperature design data for

various locations is the Extreme Annual Mean Minimum Design Dry Bulb Temperature found in the ASHRAE Handbook — Fundamentals. These temperature data can be used to calculate maximum voltage using the manufacturer's temperature coefficients relative to the rating temperature of 25°C.

(B) Direct-Current Utilization Circuits. The voltage of dc utilization circuits shall conform to 210.6.

Correction Factors for Ambient Temperatures Below 25°C (77°F). (Multiply the rated open circuit voltage by the appropriate correction factor shown below.)

Ambient Temperature (°C)	Factor	Ambient Temperature (°F)
24 to 20	1.02	76 to 68
19 to 15	1.04	67 to 59
14 to 10	1.06	58 to 50
9 to 5	1.08	49 to 41
4 to	1.10	40 to 32
−1 to −5	1.12	31 to 23
−6 to −10	1.14	22 to 14
−11 to −15	1.16	13 to 5
−16 to −20	1.18	4 to −4
−21 to −25	1.20	−5 to −13
−26 to −30	1.21	−14 to −22
−31 to −35	1.23	−23 to −31
−36 to −40	1.25	−32 to −40

Table 690.7 Voltage Correction Factors for Crystalline and Multicrystalline Silicon Modules

(C) Photovoltaic Source and Output Circuits. In oneand 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 1000 volts. Other installations with a maximum photovoltaic system voltage over 1000 volts shall comply with Article 690, Part IX.

(D) Circuits over 150 Volts to Ground. In one- and twofamily 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.

Informational Note: See 110.28 for guarding of live parts, and 210.6 for voltage to ground and between conductors.

(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 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.

(3) The equipment is clearly marked with a label as follows:

WARNING BIPOLAR PHOTOVOLTAIC ARRAY. DISCONNECTION OF NEUTRAL OR GROUNDED CONTDUCTORS MAY RESULT IN OVERVOLTAGE ON ARRAY OR INVERTER.

The warning sign(s) or label(s) shall comply with 110.21(B).

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)(5).

Informational Note: 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 shortcircuit currents multiplied by 125 percent.

(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.

(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.

(5) DC-to-DC Converter Output Current. The maximum current shall be the dc- to-dc converter continuous output current rating.

(B) Conductor Ampacity. PV system currents shall be considered to be continuous. Circuit

conductors shall be sized to carry not less than the larger of 690.8(B)(1) or (2).

(1). One hundred and twenty-five percent of the maximum currents calculated in 690.8(A) before the application of adjustment and correction factors.

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 used at 100 percent of its rating.

(2). The maximum currents calculated in 690.8(A) after the application of adjustment and correction factors.

(C) Systems with Multiple Direct-Current Voltages. For a PV power source that has multiple output circuit voltages and employs a common-return conductor, the ampacity of the common-return conductor shall not be less than the sum of the ampere ratings of the overcurrent devices of the individual output circuits.

(D) Sizing of Module Interconnection Conductors. Where a single overcurrent device is used to protect a set of two or more parallel-connected module circuits, the ampacity of each of the module interconnection conductors shall not be less than the sum of the rating of the single overcurrent device plus 125 percent of the short-circuit current from the other parallel-connected modules.

690.9 OVERCURRENT PROTECTION.

(A) Circuits and Equipment. PV source circuit, PV output circuit, inverter output circuit, and storage battery circuit conductors and equipment shall be protected in accordance with the requirements of Article 240. Protection devices for PV source circuits and PV output circuits shall be listed for use in PV systems. Circuits, either ac or dc, connected to current limited supplies (e.g. PV modules, ac output of utility-interactive inverters) and also connected to sources having significantly higher current availability (e.g. parallel strings of modules, utility power) shall be protected at the source from overcurrent.

Exception: An overcurrent device shall not be required for PV modules or PV source circuit conductors sized in accordance with 690.8(B) where one of the following applies:

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

(b) The short-circuit currents from all sources do not exceed the ampacity of the conductors and the maximum overcurrent protective device size specified on the PV module nameplate.

(B) Overcurrent Devices. Overcurrent devices, where required, shall be rated as required by 690.9(B)(1) through (4).

(1) To carry not less than 125 percent of the maximum currents calculated in 690.8(A).

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 used at 100 percent of its rating.

(2) Terminal temperature limits shall be in accordance with 110.3(B) and 110.14(C).

(3) Where operated at temperatures greater than 40°C (104°F), the manufacturer's temperature correction factors shall apply.

(4) The rating or setting of overcurrent devices shall be permitted in accordance with 240.4(B), (C), and (D).

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

(D) Photovoltaic Source and Output Circuits. Listed PV overcurrent devices shall be required to provide overcurrent protection in photovoltaic source and output circuits. The overcurrent devices shall be accessible but shall not be required to be readily accessible.

(E) Series Overcurrent Protection. In grounded PV source circuits, a single overcurrent protection device, where required, shall be permitted to protect the PV modules and the interconnecting conductors. In ungrounded PV source circuits complying with 690.35, an overcurrent protection device, where required, shall be installed in each ungrounded circuit conductor and shall be permitted to protect the PV modules and the interconnecting cables.

(F) Power Transformers. Overcurrent protection for a transformer with a source(s) on each side shall be provided in accordance with 450.3 by

considering first one side of the transformer, then the other side of the transformer, as the primary.

Exception: A power transformer with a current rating on the side connected toward the utility-interactive inverter output, not less than the rated continuous output current of the inverter, shall be permitted without overcurrent protection from the inverter.

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 the requirements of Article 707.

(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.

(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 multiwire 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!

The warning sign(s) or label(s) shall comply with 110.21(B).

(D) Energy Storage or Backup Power System Requirements. Energy storage or backup power supplies are not required.

(E) Back-fed Circuit Breakers. Plug-in type back-fed circuit breakers connected to a stand-alone inverter output in stand-alone or multimode inverter systems shall be secured in accordance with 408.36(D). Circuit breakers marked "line" and "load" shall not be backfed.

690.11 ARC-FAULT CIRCUIT PROTECTION (DIRECT CURRENT).

Photovoltaic systems with dc source circuits, dc output circuits, or both, operating at a PV system maximum system voltage of 80 volts or greater, shall be protected by a listed (dc) arc-fault circuit interrupter, PV type, or other system components listed to provide equivalent protection. The PV arc-fault protection means shall comply with the following requirements: [ROP 4–251]

(1) The system shall detect and interrupt arcing faults in dc PV source and output circuits.

(2) The system shall require that the disabled or disconnected equipment be manually restarted.

(3) The system shall have an annunciator that provides a visual indication that the circuit interrupter has operated. This indication shall not reset automatically.

690.12 PV ARRAYS ON BUILDINGS RESPONSE TO EMERGENCY SHUTDOWN.

For PV Systems installed on roofs of buildings, photovoltaic source circuits shall be deenergized from all sources within 10 seconds of when emergency shutdown is initiated or when the PV power source disconnecting means is opened. When the source circuits are deenergized, the maximum voltage at the module and module conductors shall be 80 volts.

III. DISCONNECTING MEANS

690.13 BUILDING OR OTHER STRUCTURE SUPPLIED BY A PHOTOVOLTAIC SYSTEM.

Means shall be provided to disconnect all ungrounded dc conductors of a photovoltaic system from all other conductors in a building or other structure.

(A) 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(F) 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.

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

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

(D) 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, or in a group of separate enclosures.

(E) Grouping. The photovoltaic system disconnecting means shall be grouped with other disconnecting means for the system in accordance with 690.13(D). A photovoltaic disconnecting means shall not be required at the photovoltaic module or array location.

690.15 DISCONNECTION OF PHOTOVOLTAIC EQUIPMENT.

Means shall be provided to disconnect equipment, such as inverters, batteries, and charge controllers, 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.

(A) 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 and shall comply with (1) through (4):

(1) A direct-current PV disconnecting means shall be mounted within sight of or in each inverter.

(2) An alternating-current disconnecting means shall be mounted within sight of or in each inverter.

(3) The alternating-current output conductors from the inverter and an additional alternating-current disconnecting means for the inverter shall comply with 690.13(A).

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

(B) Equipment. Equipment such as PV source circuit isolating switches, overcurrent devices, dc–to–dc converters, and blocking diodes shall be permitted on the PV side of the PV disconnecting means.

(C) DC Combiner Disconnects. The direct current (dc) output of dc combiners mounted on roofs of dwellings or other buildings shall have a load break disconnecting means located in the combiner or within 1.8 m (6 ft) of the combiner. The disconnecting means shall be permitted to be remotely controlled, but shall be manually operable locally when control power is not available.

(D) 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, or in a group of a separate enclosures.

690.16 FUSES.

(A) Disconnecting Means. Disconnecting means shall be provided to disconnect a fuse from all sources of supply if the fuse is energized from both directions. Such a fuse in a photovoltaic source circuit shall be capable of being disconnected independently of fuses in other photovoltaic source circuits.

(B) Fuse Servicing. Disconnecting means shall be installed on PV output circuits where overcurrent devices (fuses) must be serviced that cannot be isolated from energized circuits. The disconnecting means shall be within sight of, and accessible to, the location of the fuse or integral with fuse holder and shall comply with 690.17. Where the disconnecting means are located more than 1.8 m (6 ft) from the overcurrent device, a directory showing the location of each disconnect shall be installed at the overcurrent device location.

Non-load-break-rated disconnecting means shall be marked "Do not open under load."

690.17 DISCONNECT TYPE.

(A) Manually Operable. The disconnecting means for ungrounded PV conductors shall consist of a manually operable switch(es) or circuit breaker(s). The disconnecting means shall be permitted to be power operable with provisions for manual operation in the event of a power supply failure. The disconnecting means shall be one of the following devices:

(1) A listed PV industrial control switch marked for use in PV systems.

(2) A listed PV molded case circuit breaker marked for use in PV systems

(3) A listed PV molded case switch marked for use in PV systems.

(4) A listed PV enclosed switch marked for use in PV systems.

(5) A listed PV open-type switch marked for use in PV systems.

(6) A listed, dc-rated molded case circuit breaker suitable for backfeed operation.

(7) A listed, dc-rated, molded case switch suitable for backfeed operation.

(8) A listed, dc-rated enclosed switch.

(9) A listed, dc-rated open-type switch.
Informational Note: Devices marked with "line" and "load" are not suitable for backfeed or reverse current.

(B) Simultaneous Opening of Poles. The PV disconnecting means shall simultaneously disconnect all ungrounded supply conductors that it controls from the building or structure wiring system.

(C) Externally Operable and Indicating. The PV disconnecting means shall be externally operable without exposing the operator to contact with live parts and indicate whether in the open or closed position.

(D) Disconnection of Grounded Conductor. A switch, circuit breaker, or other device shall not be installed in a grounded conductor if operation of that switch, circuit breaker, or other device leaves the marked, grounded conductor in an ungrounded and energized state.

Exception No. 1: A switch or circuit breaker that is part of a ground-fault detection system required by 690.5, or that is part of an arc-fault detection/interruption system required by 690.11, shall be permitted to open the grounded conductor when that switch or circuit breaker is automatically opened as a normal function of the device in responding to ground faults.

Exception No. 2: A disconnecting switch shall be permitted in a grounded conductor if all of the following conditions are met:

(1) The switch is used only for PV array maintenance.

(2) The switch is accessible only by qualified persons.

(3) The switch is rated for the maximum dc voltage and current that could be present during any operation, including ground-fault conditions.

> *Informational Note: The grounded conductor may have a bolted or terminal disconnecting means to allow maintenance or troubleshooting by qualified personnel.*

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

WARNING

ELECTRIC SHOCK HAZARD DO NOT TOUCH TERMINALS. TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

The warning sign(s) or label(s) shall comply with 110.21(B).

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 use with specific equipment.

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.

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

IV. WIRING METHODS

690.31 METHODS PERMITTED.

(A) Wiring Systems. All raceway and cable wiring methods included in this Code, other wiring systems and fittings specifically listed for use on PV arrays, and wiring as part of a listed system 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 guarded or installed in a raceway.

Informational Note: Photovoltaic modules operate at elevated temperatures when exposed to high ambient temperatures and to bright sunlight. These temperatures may routinely exceed 70°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) Identification and Grouping. PV source circuits and PV output circuits shall not be contained in the same raceway, cable tray, cable, outlet box, junction box, or similar fitting as conductors, feeders, branch circuits of other non-PV systems, or inverter output circuits unless the conductors of the different systems are separated by a partition. PV system conductors shall be identified and grouped as required by 690.31(B)(1) through (4). The means of identification shall be permitted by separate color coding, marking tape, tagging, or other approved means.

(1) PV Source Circuits. PV source circuits shall be identified at all points of termination, connection, and splices.

(2) PV Output and Inverter Circuits. The conductors of PV output circuits and inverter input and output circuits shall be identified at all points of termination, connection, and splices.

(3) Conductors of Multiple Systems. Where the conductors of more than one PV system occupy the same junction box, raceway, or equipment, the conductors of each system shall be identified at all termination, connection, and splice points.

Exception: Where the identification of the conductors is evident by spacing or arrangement, further identification is not required.

(4) Grouping. Where the conductors of more than one PV system occupy the same junction box or raceway with a removable cover(s), the ac and dc conductors of each system shall be grouped separately by cable ties or similar means at least once, and then shall be grouped at intervals not to exceed 1.8 m (6 ft).

Exception: The requirement for grouping shall not apply if the circuit enters from a cable or raceway unique to the circuit that makes the grouping obvious.

(C) 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 PV source circuits for PV module interconnections within the PV array. Exception: Raceways shall be used when required by 690.31(A). Informational Note: Photovoltaic (PV) wire [also photovoltaic (PV) cable] has a nonstandard outer diameter. Conduit fill may be calculated using Table 1 of Chapter 9.

(D) Multi-Conductor Cable. Multi-conductor cable type TC-ER or USE-2 shall be permitted in outdoor locations in PV inverter output circuits when used with utilityinteractive inverters mounted in not-readily-accessible locations. The cable shall be secured at intervals not exceeding 1.8 m (6 ft). Equipment grounding for the utilization equipment shall be provided by an equipment grounding conductor within the cable.

(E) 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

Ambient Temperature (°C)	Temperature Rating of Conductor				Ambient Temperature (°F)
	60°C (140°F)	75°C (167°F)	90°C (194°F)	105°C (221°F)	
30	1.00	1.00	1.00	1.00	86
31–35	0.91	0.94	0.96	0.97	87–95
36–40	0.82	0.88	0.91	0.93	96–104
41–45	0.71	0.82	0.87	0.89	105–113
46–50	0.58	0.75	0.82	0.86	114–122
51–55	0.41	0.67	0.76	0.82	123–131
56–60	—	0.58	0.71	0.77	132–140
61–70	—	0.33	0.58	0.68	141–158
71–80	—	—	0.41	0.58	159–176

Table 690.31(E) Correction Factors

derated by the appropriate factors given in Table 690.31(E).

(F) 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 adjustment and correction factors.

(G) Direct-Current Photovoltaic Source and DC Output Circuits On or Inside a Building. Where dc PV source or dc PV output circuits from a building-integrated or other PV systems are run inside a building or structure, they shall be contained in metal raceways, Type MC metalclad cable that complies with 250.118(10), or metal enclosures from the point of penetration of the surface of the building or structure to the first readily accessible disconnecting means. The disconnecting means shall comply with 690.13(B), (C), and 690.15(A), (B). The wiring methods shall comply with the additional installation requirements in (1) through (4)

(1) Embedded in Building Surfaces. Where circuits are embedded in built-up, laminate, or membrane roofing materials in roof areas not covered by PV modules and associated equipment, the location of circuits shall be clearly marked using a marking protocol that is approved as being suitable for continuous exposure to sunlight and weather.

(2) Flexible Wiring Methods. Where flexible metal conduit (FMC) smaller than metric designator 21 (trade size 3⁄4) or Type MC cable smaller than 25 mm (1 in.) in diameter containing PV power circuit conductors is installed across ceilings or floor joists, the raceway or cable shall be protected by substantial guard strips that are at least as high as the raceway or cable. Where run exposed, other than within 1.8 m (6 ft) of their connection to equipment, these wiring methods shall closely follow the building surface or be protected from physical damage by an approved means.

(3) Marking or Labeling Required. The following wiring methods and enclosures that contain PV power source conductors shall be marked with the wording "WARNING: PHOTOVOLTAIC POWER SOURCE" by means of permanently affixed labels or other approved permanent marking:

(1) Exposed raceways, cable trays, and other wiring methods

(2) Covers or enclosures of pull boxes and junction boxes

(3) Conduit bodies in which any of the available conduit openings are unused

(4) Marking and Labeling Methods and Locations. The labels or markings shall be visible after installation. The labels shall be reflective and shall have all letters capitalized with a minimum height of 9.5 mm (3⁄8 in.) white on red background. PV power circuit labels shall appear on every section of the wiring system that is separated by enclosures, walls, partitions, ceilings, or floors. Spacing between labels or markings, or between a label and a marking, shall not be more than 3 m (10 ft). Labels required by this section shall be suitable for the environment where they are installed.

(H) Flexible, Fine-Stranded Cables. Flexible, finestranded cables shall be terminated only with

terminals, lugs, devices, or connectors in accordance with 110.14.

(I) Bipolar Photovoltaic Systems. Where the sum, without consideration of polarity, of the PV system voltages of the two monopole subarrays exceeds the rating of the conductors and connected equipment, monopole subarrays in a bipolar PV system shall be physically separated, and the electrical output circuits from each monopole subarray shall be installed in separate raceways until connected to the inverter. The disconnecting means and overcurrent protective devices for each monopole subarray output shall be in separate enclosures. All conductors from each separate monopole subarray shall be routed in the same raceway. Bipolar PV systems shall be clearly marked with a permanent, legible warning notice indicating that the disconnection of the grounded conductor(s) may result in overvoltage on the equipment.

Exception: Listed switchgear rated for the maximum voltage between circuits and containing a physical barrier separating the disconnecting means for each monopole subarray shall be permitted to be used instead of disconnecting means in separate enclosures.

(J) Module Connection Arrangement. The connection 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 other PV source circuits.

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.

(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."

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.

V. GROUNDING

690.41 SYSTEM GROUNDING.

For a photovoltaic power source, systems shall comply with 690.35, or one conductor of a 2-wire system with a photovoltaic system voltage over 50 volts, but not greater than 300 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.

690.42 POINT OF SYSTEM GROUNDING CONNECTION.

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

Informational Note: 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 groundfault equipment, shall not be duplicated with an external connection.

690.43 EQUIPMENT GROUNDING.

Equipment grounding conductors and devices shall comply with 690.43(A) through (F).

(A) Equipment Grounding Required. Exposed non– current-carrying metal parts of PV module frames, electrical equipment, and conductor enclosures shall be grounded in accordance with 250.134 or 250.136(A), regardless of voltage.

(B) Equipment Grounding Conductor Required. An equipment grounding conductor between a PV array and other equipment shall be required in accordance with 250.110.

(C) Structure as Equipment Grounding Conductor. Devices listed and identified for grounding the metallic frames of PV modules or other equipment shall be permitted to bond the exposed metal surfaces or other equipment to mounting structures. Metallic mounting structures, other than building steel, used for grounding purposes shall be identified as equipment-grounding conductors or shall have identified bonding jumpers or devices connected between the separate metallic sections and shall be bonded to the grounding system.

(D) Photovoltaic Mounting Systems and Devices. Devices and systems used for mounting PV modules that are also used to provide grounding of the module frames shall be identified for the purpose of grounding PV modules.

(E) Adjacent Modules. 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.

(F) All Conductors Together. 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.

690.45 SIZE OF EQUIPMENT GROUNDING CONDUCTORS.

Equipment Grounding conductors for PV source and PV output circuits shall be sized in accordance with Table 250.122. Where no overcurrent protective device is used in the circuit, an assumed overcurrent device rated at the PV maximum circuit current shall be used in Table 250.122. Increases in equipment grounding conductor size to address voltage drop considerations shall not be required. An equipment grounding conductor shall not be smaller than 14 AWG.

690.46 ARRAY EQUIPMENT GROUNDING CONDUCTORS.

Equipment grounding conductors for photovoltaic modules smaller than 6 AWG shall comply with 250.120(C). Solid (non-stranded) equipment-grounding conductors and grounding-electrode conductors of 6 AWG and smaller shall be permitted in raceways for PV array grounding.

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. A common dc grounding-electrode conductor shall be permitted to serve multiple inverters. The size of the common grounding electrode and the tap conductors shall be in accordance with 250.166. The tap conductors shall be connected to the common grounding-electrode conductor by exothermic welding or with connectors listed as grounding and bonding equipment in such a manner that the common grounding electrode conductor remains without a splice or joint. An ac equipment grounding system shall be permitted to be used for equipment grounding of inverters and other equipment, and the ground-fault detection reference for ungrounded PV systems.

(C) Systems with Alternating-Current and Direct-Current Grounding Requirements. Photovoltaic

systems having dc circuits and ac circuits with no direct connection between the dc grounded conductor and ac grounded conductor shall have a dc grounding system. The dc grounding system shall be bonded to the ac grounding system by one of the methods in (1), (2), or (3).

This section shall not apply to ac PV modules. When using the methods of (C)(2) or (C)(3), the existing ac grounding electrode system shall meet the applicable requirements of Article 250, Part III.

Informational Note No. 1: ANSI/UL 1741, Standard for Inverters, Converters, and Controllers for Use in Independent Power Systems, requires that any inverter or charge controller that has a bonding jumper between the grounded dc conductor and the grounding system connection point have that point marked as a grounding electrode conductor (GEC) connection point. In PV inverters, the terminals for the dc equipment grounding conductors and the terminals for ac equipment grounding conductors are generally connected to, or electrically in common with, a grounding busbar that has a marked dc GEC terminal.

Informational Note No. 2: For utility-interactive systems, the existing premises grounding system serves as the ac grounding system.

(1) Separate Direct-Current Grounding Electrode System Bonded to the Alternating-Current Grounding Electrode System. A separate dc grounding electrode or system shall be installed, and it shall be bonded directly to the ac grounding electrode system. The size of any bonding jumper(s) between the ac and dc systems shall be based on the larger size of the existing ac grounding electrode conductor or the size of the dc grounding electrode conductor specified by 250.166. The dc grounding electrode system conductor(s) or the bonding jumpers to the ac grounding electrode system shall not be used as a substitute for any required ac equipment grounding conductors.

(2) Common Direct-Current and Alternating-Current Grounding Electrode. A dc grounding electrode conductor of the size specified by 250.166 shall be run from the marked dc grounding electrode connection point to the ac grounding electrode. Where an ac grounding electrode is not accessible, the dc grounding electrode conductor shall be connected to the ac grounding electrode conductor in accordance with 250.64(C)(1), 250.64(C)(2), or connector listed for grounding and bonding.

(3) Combined Direct-Current Grounding Electrode Conductor, PV Bonding Jumper, and Alternating- Current Equipment Grounding Conductor. An unspliced, or irreversibly spliced, combined grounding bonding conductor shall be run from the marked dc grounding electrode conductor or PV bonding jumper connection point along with the ac circuit conductors to the grounding busbar located in the main service disconnect or the first disconnect of a separately derived system in the associated ac equipment. This combined grounding bonding conductor shall be the larger of the sizes specified by 250.122 based on the rating of the inverter output circuit overcurrent device or 250.168. or 250.166, and shall be installed in accordance with 250.64(E).

(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. 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.

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.

690.49 CONTINUITY OF PHOTOVOLTAIC SOURCE AND OUTPUT CIRCUIT GROUNDED CONDUCTORS.

Where the removal of the utility-interactive inverter or other equipment disconnects the bonding connection between the grounding electrode conductor and the photovoltaic source and/or photovoltaic output circuit grounded conductor, a bonding jumper shall be installed to maintain the system grounding while the inverter or other 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

Informational Note to (3): See 690.7(A) for maximum photovoltaic system voltage.

(4) Maximum-circuit current

> Where the PV power source has multiple outputs, items (1) and (4) shall be specified for each output.

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

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

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

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. The marking shall be in accordance with 690.31(E). [ROP 4–320]

(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. The marking shall be in accordance with 690.31(E). For PV systems complying with 690.12, the plaque or directory shall include the wording:

MAXIMUM VOLTAGE AT ARRAY 80VDC AFTER SHUTDOWN

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.

690.63 UNBALANCED INTERCONNECTIONS.

Unbalanced connections shall be in accordance with 705.100.

690.64 POINT OF CONNECTION.

Point of connection shall be in accordance with 705.12.

VIII. SYSTEMS OVER 1000 VOLTS

690.80 GENERAL.

Solar photovoltaic systems with a maximum system voltage over 1000 volts dc shall comply with Article 490 and other requirements applicable to installations rated over 1000 volts.

690.85 DEFINITIONS.

For the purposes of Part VIII 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. X. Electric Vehicle Charging.

690.90 GENERAL.

PV systems used directly to charge electric vehicles shall comply with Article 625 in addition to the requirements of this article.

690.91 CHARGING EQUIPMENT.

Electric vehicle couplers shall comply with 625.9. Personnel protection systems according to 625.22 and automatic de-energization of cables according to 625.19 are not required for PV systems with maximum system voltages of less than 80V dc.

Quiz Questions

The following ten (10) question quiz will test the student's comprehension of the course. The student must past this quiz with a score greater than 70%.

Question 1: What is the purpose of a photovoltaic (PV) system?

a) Converting pictures into electric energy
b) Converting solar energy into electric energy
c) Converting electric energy into solar energy
d) None of the above

Question 2: In a PV system, which device generates electricity when exposed to light?

a) Solar cell
b) Fuel cell
c) PV cell
d) Battery

Question 3: A PV system is not permitted to have multiple inverters when installed on a single building:

a) True
b) False

Question 4: How many volts is a stand-alone PV system permitted to supply to single-phase?

a) 120
b) 240
c) Both a or c
d) None of the above

Question 5: The PV system disconnecting means cannot be installed in:

a) Bedrooms
b) Kitchens
c) Basements
d) Bathrooms

Question 6: When PV modules operate in high temperatures and bright sunlight, conductors rated for ___°C should be used.

a) 70
b) 80
c) 90
d) 100

Question 7: Which of the following is a rating that a module is marked with?

a) Open-circuit voltage
b) Maximum power
c) Operating voltage
d) All of the above

Question 8: The PV source conductors shall consist of:

a) Metallic jacketed multiconductor cables
b) Conductors installed in raceways
c) Conductors identified as PV Wire
d) All of the above

Question 9: What makes first contact with the mating connector?

a) Grounding member
b) Conductor
c) Disconnect
d) None of the above

Question 10: A PV system may be installed underground:

a) True
b) False