

NECA 412



Standard for Installing and Maintaining Photovoltaic (PV) Power Systems

**ANSI Review Draft
June 2020**

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Table of Contents

Foreword

1.	Scope
1.1	Products and Applications Included
1.2	Products and Applications Excluded
1.3	Regulatory and Other Requirements.....
1.4	Mandatory Requirements, Permissive Requirements, Quality and Performance Recommendations, Explanatory Material, and Informative Annexes
2.	Definitions
3.	Overview
3.1	General.....
3.2	Photovoltaic (PV) Power System Operation.....
3.3	Equipment Ratings.....
4.	Receiving, Handling and Storage
4.1	Receiving
4.2	Handling.....
4.3	Storage
5.	PV Power System Safety
5.1	General.....
5.2	Safe Work Practices.....
5.3	Electrical Hazards
5.4	Battery Systems
6.	Pre-Installation Considerations
6.1	General.....
6.2	Local Solar Resource
6.3	Environmental Conditions
6.4	Building Codes, Permits and Inspections
6.5	Utility Interconnection Requirements.....
6.6	Locating Solar Arrays
6.7	Access and Required Clearances
6.8	Structural Systems
6.9	Electrical Systems and Equipment.....
6.10	Power Requirements
6.11	Performance Estimate
6.12	PV Power System Components
6.13	Energy Storage Batteries.....
6.14	Utility Interactive Systems.....
6.15	Stand-Alone Systems
6.16	Utility Interactive Inverters.....
6.17	Sizing Conductors.....

1 6.18 Disconnecting Means.....

2 6.19 Overcurrent Protection.....

3 6.20 Grounding and Bonding.....

4 6.21 Rapid Shut Down.....

5

6 **7. Installing PV Power Systems**

7 7.1 General.....

8 7.2 Installing PV Arrays

9 7.3 Installing Inverters and Charge Controllers.....

10 7.4 Disconnecting Means.....

11 7.5 Energy Storage Batteries.....

12 7.6 Wiring Methods

13 7.7 Labels and Warning Signs

14 7.8 Large-Scale PV Electric Power Production Facilities

15

16 **8. Start-up and Commissioning**

17 8.1 General.....

18 8.2 Connecting the Inverter or Charge Controller

19 8.3 Starting the Inverter or Charge Controller

20 8.4 Batteries

21 8.5 Troubleshooting.....

22

23 **9. Site Cleanup.....**

24 9.1 General.....

25 9.2 Test Data and Operating Manuals.....

26 9.3 Training.....

27 9.4 Spare Parts and Special Tools.....

28

29 **10. Maintenance**

30 10.1 General.....

31 10.2 Periodic Maintenance.....

32 10.3 Biennial Maintenance

33 10.4 Post-Repair Testing.....

34

35 **Annex A: Sizing PV Power Systems.....**

36

37 **Annex B: List of Figures.....**

38

39 **Annex C: Referenced Standards**

40

41

1 (This foreword is not a part of the standard)
2

3 **Foreword**

4

5 *National Electrical Installation Standards*[™] (NEIS[™]) are designed to improve communication among
6 specifiers, purchasers, and suppliers of electrical construction services. They define a minimum baseline
7 of quality and workmanship for installing electrical products and systems. NEIS[™] are intended to be
8 referenced in contract documents for electrical construction projects. The following language is
9 recommended:

10
11 Photovoltaic (PV) power systems should be installed and maintained in accordance with NECA 412-
12 2xxx, *Standard for Installing and Maintaining Photovoltaic (PV) Power Systems* (ANSI).

13
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16 or non-member of NECA from specifying or using alternate construction methods permitted by
17 applicable regulations.
18

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20 Standards, NEIS may in some instances go beyond the minimum safety requirements of the NEC. It is
21 the responsibility of users of this publication to comply with state and local electrical codes and Federal
22 and state OSHA safety regulations as well as follow manufacturer installation instructions when installing
23 electrical products and systems.
24

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1. Scope

This Standard describes the application procedures for installing and maintaining photovoltaic (PV) power systems and components.

1.1 Products and Applications Included

This Standard covers the installation and maintenance of low-voltage AC and DC PV power systems, rated 1000V and less, for grid-connected and stand-alone operation for residential, commercial, and industrial applications. See Figure 1.1 for an example of photovoltaic modules forming an array that is part of a photovoltaic power system.



Figure 1.1 Typical roof-mounted array of a photovoltaic power system (I-Stock Photo Courtesy of NECA)

1.2 Products and Applications Excluded

This Standard does not apply to solar heating systems or PV power systems rated more than 1000V.

1.3 Regulatory and Other Requirements

1 All information in this publication is intended to conform to the *National Electrical Code* (ANSI/NFPA
2 70) and National Electrical Safety Code® (ANSI/IEEE C2). Installers shall follow the NEC, NESC,
3 applicable federal, state and local codes, manufacturer instructions, and contract documents when
4 installing PV power systems and components.
5

6 Only qualified persons as defined in the *National Electrical Code* familiar with the installation, operation,
7 and maintenance of PV power systems and components shall perform the technical work described in this
8 publication. Administrative functions such as receiving, handling, and storing equipment and
9 components and other tasks may be performed under the supervision of a qualified person. All work shall
10 be performed in accordance with NFPA 70E, *Standard for Electrical Safety in the Workplace*.
11

12 General requirements for installing electrical products and systems are described in NECA 1, *Standard*
13 *Practices for Good Workmanship in Electrical Construction (ANSI)*. Other NEIS provide additional
14 guidance for installing particular types of electrical products and systems. A complete list of NEIS is
15 provided in Annex C.
16
17

18 **1.4 Mandatory Requirements, Permissive Requirements, Quality and Performance** 19 **Recommendations, Explanatory Material, and Informative Annexes** 20

21 Mandatory requirements in manufacturer instructions, Codes, or other mandatory Standards that may or
22 may not be adopted into law are those that identify actions that are specifically required or prohibited and
23 are characterized in this Standard by the use of the terms “must” or “must not,” “shall” or “shall not,” or
24 “may not,” or “are not permitted,” or “are required,” or by the use of positive phrasing of mandatory
25 requirements. Examples of mandatory requirements may equally take the form of, “equipment must be
26 protected . . .,” “equipment shall be protected . . .,” or “protect equipment . . .,” with the latter interpreted
27 (understood) as “(it is necessary to) protect equipment . . .”
28

29 Permissive requirements of manufacturer instructions, Codes, or other mandatory Standards that may or
30 may not be adopted into law are those that identify actions that are allowed but not required or are
31 normally used to describe options or alternative means and methods and are characterized in this Standard
32 by the use of the terms “may,” or “are permitted,” or “are not required.”
33

34 Quality and performance recommendations identify actions that are recommended or not recommended to
35 improve the overall quality or performance of the installation and are characterized in this Standard by the
36 use of the terms “should” or “should not.”
37

38 Explanatory material, such as references to other Codes, Standards, documents, references to related
39 sections of this Standard, information related to another Code, Standard, or document, and supplemental
40 application and design information and data, is included throughout this Standard to expand the
41 understanding of mandatory requirements, permissive requirements, and quality and performance
42 recommendations. Such explanatory material is included for information only and is identified by the use
43 of the term “NOTE,” or by the use of italicized text.
44

45 Non-mandatory information and other reference Standards or documents relative to the application and
46 use of materials, equipment, and systems covered by this Standard are provided in informative annexes.
47 Informative annexes are not part of the enforceable requirements of this Standard but are included for
48 information purposes only.
49

2. Definitions

Alternating-Current (AC) module (Alternating-Current PV 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 module(s) or panel(s) with a support structure and foundation, tracker, and other components, as required, to form a DC or AC power producing unit. See Figure 2.1 for an example of a photovoltaic array.



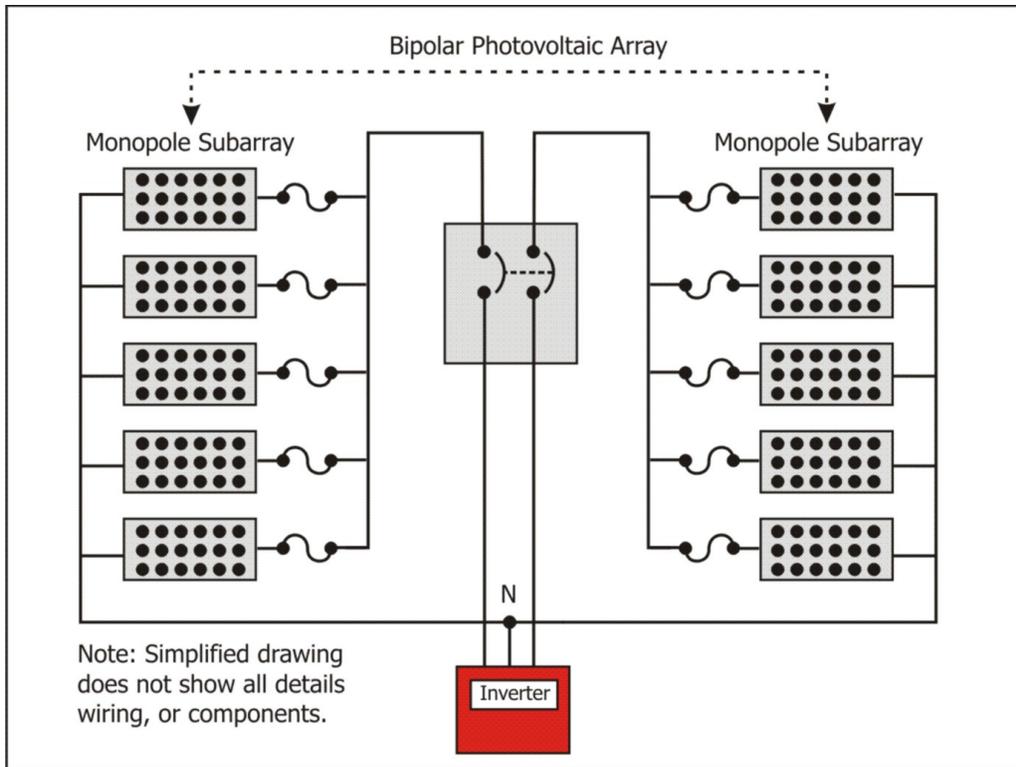
Figure 2.1 Typical roof-mounted photovoltaic array (I-Stock Photo Courtesy of NECA)

Azimuth: The orientation angle of the solar array with respect to solar south (0°) expressed in degrees. Sun position to the east of solar south is typically represented by a positive azimuth angle, where sun position to the west of solar south is typically represented by a negative azimuth angle.

Battery. An electrochemical device that transforms stored chemical energy into electric energy during discharge.

Battery charger. A device that can maintain a unidirectional current in a battery in the opposite direction to that during discharge thereby converting electric energy into stored chemical energy within the battery.

Bipolar PV array: A DC PV array that has two outputs, each having opposite polarity to a common reference point or center tap. See Figure 2.2 for an example simplified diagram showing the concept of a bipolar photovoltaic array.



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Figure 2.2 Basic diagram of bipolar photovoltaic array [Note: Simplified drawing shows concepts of a bipolar array only; it does not include all details or components and is intended to help visualize a bipolar array]

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. See Figure 2.3 for an example of building integrated photovoltaic modules.



13
14

1 Figure 2.3 Photo of typical building integrated photovoltaic modules as part of clay roofing materials.
2 (Photo Courtesy of Rick Maddox, Clark County, NV)

3
4 **Continuous load:** A load where the maximum current is expected to continue for 3 hours or more.

5
6 **Current-limited:** A source that is not capable of supplying a significant amount of current.

7
8 **DC (direct current) bus:** Where DC (direct current) sources of power connect to an inverter.

9
10 **DC (direct current) voltage:** Electric potential difference that is constant, and whose magnitude does
11 not vary with time.

12
13 **DC-to-DC converter:** A device installed in the PV source circuit or PV output circuit that can provide
14 an output DC voltage and current at a higher or lower value than the input DC voltage and current.

15
16 **DC-to-DC converter output circuit:** Circuit conductors between the DC-to-DC converter source
17 circuit(s) and the inverter or DC utilization equipment.

18
19 **DC-to-DC converter source circuit:** Circuits between DC-to-DC converters and from DC-to-DC
20 converters to the common connection point(s) of the DC system.

21
22 **Direct-Current (DC) combiner:** A device used in the PV source and PV output circuits to combine
23 two or more DC circuit inputs and provide one DC circuit output.

24
25 **Diversion charge controller:** Equipment that regulates the charging process of a battery by diverting
26 power from energy storage to direct-current or alternating-current loads or to an interconnected utility
27 service.

28
29 **Electric supply stations:** Locations containing the generating stations and substations, including their
30 associated generator, storage battery, transformer, and switchgear areas.

31
32 **Electrical production and distribution network:** A power production, distribution, and utilization
33 system, such as a utility system and connected loads, that is external to and not controlled by the PV
34 power system.

35
36 **Electrolyte.** Liquid solution of dilute sulfuric acid in which battery elements are immersed for the
37 lifetime of the cell.

38
39 **Functional grounded PV system:** A PV system that has an electrical reference to ground that is not
40 solidly grounded. *Note: A functional grounded PV system is often connected to ground through a fuse,*
41 *circuit breaker, resistance device, non-isolated grounded AC circuit, or electronic means that is part of a*
42 *listed ground-fault protection system. Conductors in these systems that are normally at ground potential*
43 *may have voltage to ground during fault conditions.*

44
45 **Generating capacity:** The sum of the parallel-connected inverter rated maximum continuous output
46 power at 40°C in kilowatts (kW).

1 **Generating station:** A plant wherein electric energy is produced by conversion from some other form
2 of energy (e.g., chemical, nuclear, solar, wind, mechanical, or hydraulic) by means of suitable apparatus.

3
4 **Grid-connected:** Generation that operates in parallel with the electric utility grid.

5
6 **Incident angle:** Orientation angle of the sun with respect to the horizon, expressed in degrees.

7
8 **Insolation:** The average solar energy that reaches the earth's surface at a given location per day,
9 expressed as kilowatt-hours-per-square-meter per day (kWh/m²/day).

10
11 **Interactive inverter.** An inverter capable of operating in parallel with an electrical production and
12 distribution network to supply common loads and that may deliver power to the utility, that contains
13 controls necessary to regulate power conversion from DC to AC, monitor bus voltage and frequency,
14 synchronize and connect to and disconnect from the electric utility grid, and provide protection in the
15 event of a fault, failure, or abnormal operating condition.

16
17 **Interactive inverter output circuit:** The conductors between the interactive inverter and the service
18 equipment or another electric power production source, such as a utility or microgrid.

19
20 **Interactive PV system.** A PV system that operates in parallel with and may deliver power to an
21 electrical production and distribution network.

22
23 **Inverter:** Equipment that is used to change voltage level or waveform, or both, of electrical energy.
24 Commonly, an inverter is a device that changes DC input to an AC output. Inverters may also function as
25 battery chargers that use alternating current from another source and convert it into direct current for
26 charging batteries. See Figure 2.4 for an example of a small inverter installed for a PV system.



1
2 Figure 2.4 Typical photovoltaic inverters for a smaller PV system (Courtesy of Central Florida Electrical
3 JATC)
4

5 **Inverter controls:** Controls that regulate power conversion from DC to AC, monitor bus voltage and
6 frequency, synchronize to the electric utility grid, and provides protection in the event of a fault, failure,
7 or abnormal operating condition.
8

9 **Inverter input circuit:** Conductors connected to the DC input of an inverter.
10

11 **Inverter output circuit:** Conductors connected to the AC output of an inverter.
12

13 **Microgrid Interconnect Device (MID):** A device that allows a microgrid system to separate from
14 and reconnect to a primary power source.
15

16 **Microgrid system:** A premises wiring system that has generation, energy storage, and load(s), or any
17 combination thereof, that includes the ability to disconnect from and parallel with the primary source.
18

19 **Module:** A complete, environmentally protected unit consisting of solar cells, optics, and other
20 components, exclusive of tracker, designed to generate DC power when exposed to sunlight.
21

22 **Monopole subarray:** A PV subarray that has two conductors in the output circuit, one positive (+) and
23 one negative (-). Two monopole PV subarrays are used to form a bipolar PV array.
24

25 **Multimode inverter:** Equipment having the capabilities of both an interactive inverter and a stand-
26 alone inverter.
27

28 **Net-metering:** Utility billing practice that permits power delivery from distributed generation sources,
29 such as an interactive PV system, to the electric utility grid across the utility revenue meter.
30

31 **Non-continuous load:** A load where the maximum current is expected to continue for less than 3
32 hours.
33

34 **Nonlinear load:** A load where the wave shape of the steady-state current does not follow the wave
35 shape of the applied voltage.
36

37 **Peak sun hours.** The equivalent measure of total solar irradiation in a day. See Insolation, and Solar
38 Irradiation.
39

40 **Point of connection:** Location in the electrical distribution system where a source of distributed
41 generation, such as an interactive PV system, is connected.
42

43 **Power buy-back:** Utility purchase of excess power from customer-owned distributed generation, such
44 as an interactive PV system.
45

46 **Power production equipment:** The generating source, and all distribution equipment associated with
47 it, that generates electricity from a source other than a utility supplied service.
48

1 **PV output circuit:** Circuit conductors between the PV source circuit(s) and the inverter or DC
2 utilization equipment.
3

4 **PV power source:** An array or aggregate of arrays that generates DC power at system voltage and
5 current.
6

7 **PV source circuit:** Circuits between modules and from modules to the common connection point(s) of
8 the DC system.
9

10 **PV system:** The total components and subsystem that, in combination, convert solar energy into electric
11 energy for connection to a utilization load.
12

13 **PV system DC circuit:** Any DC conductor supplied by a PV power source, including PV source
14 circuits, PV output circuits, inverter input circuits, DC-to-DC converter source circuits, or DC-to-DC
15 converter output circuits.
16

17 **Qualified person:** One who has skills and knowledge related to the construction and operation of the
18 electrical equipment and installations and has received safety training to recognize and avoid the hazards
19 involved. *NOTE: Refer to NFPA 70E, Standard for Electrical Safety in the Workplace, for electrical*
20 *safety training requirements.*
21

22 **Reactive power:** Power consumed by induction machines such as motors and transformers in
23 establishing and maintaining the electric and magnetic fields necessary for their operation, expressed as
24 kilovolt-amperes reactive (kVAR).
25

26 **Rectifier:** Device that converts 60-Hertz AC voltage waveform into a DC voltage.
27

28 **Separately derived system:** An electrical source, other than a service, having no direct connection(s)
29 to circuit conductors of any other electrical source other than those established by grounding and bonding
30 connections.
31

32 **Solar cell:** The basic PV device that generates electricity when exposed to light.
33

34 **Solar irradiation:** The total amount of solar energy accumulated on an area over time, typically
35 expressed as kilowatt-hours-per-square-meter (kWh/m²). Solar irradiation is the principle measurement
36 used to quantify solar energy production over time. See Insolation, and Peak Sun Hours.
37

38 **Solar module:** Several solar cells that are electrically interconnected and encapsulated.
39

40 **Stand-alone inverter:** An inverter capable of operating independently of an electrical production and
41 distribution network, that contains controls necessary to regulate power conversion from DC to AC,
42 monitor and independently control bus voltage, frequency, and reactive power generation, if needed, and
43 provide protection in the event of a fault, failure, or abnormal operating condition.
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Figure 2.5 Typical stand-alone photovoltaic system (Photo by NECA Copyright® Rob Colgan)

Stand-alone PV system: A solar PV system that supplies power independently of an electrical production and distribution network. See Figure 2.5 as an example of a stand-alone system.

Subarray: An electrical subset of a PV array.

Synchronization: Process of matching the operating voltage, frequency, and phase angle of one source to another source prior to paralleling the sources together.

Tilt angle: The orientation angle of the solar array with respect to the horizon, expressed in degrees.

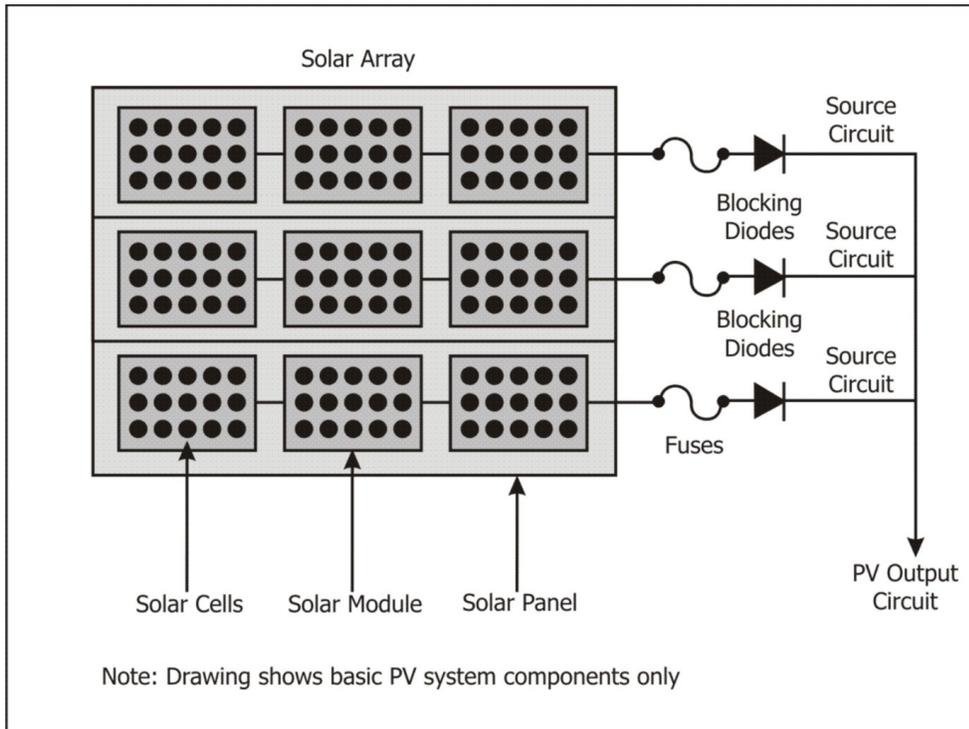
3. Overview

3.1 General

Photovoltaic (PV) power systems convert solar energy to electric energy. Individual solar cells convert light into a direct-current (DC) voltage. Solar cells are electrically and mechanically interconnected to form solar modules or solar panels. Solar panels are connected in series and parallel to form solar arrays. Series solar panel connections are used to increase operating voltage, and parallel solar panel connections are used to increase ampacity. A solar array of virtually any operating voltage and power rating can be

1 designed by careful selection and interconnection of solar panels. See Figure 3.1.1 showing the basic
2 components of a PV system.

3



4

5

6 Figure 3.1.1 Basic components of a photovoltaic system [illustration is intended as a concept only].

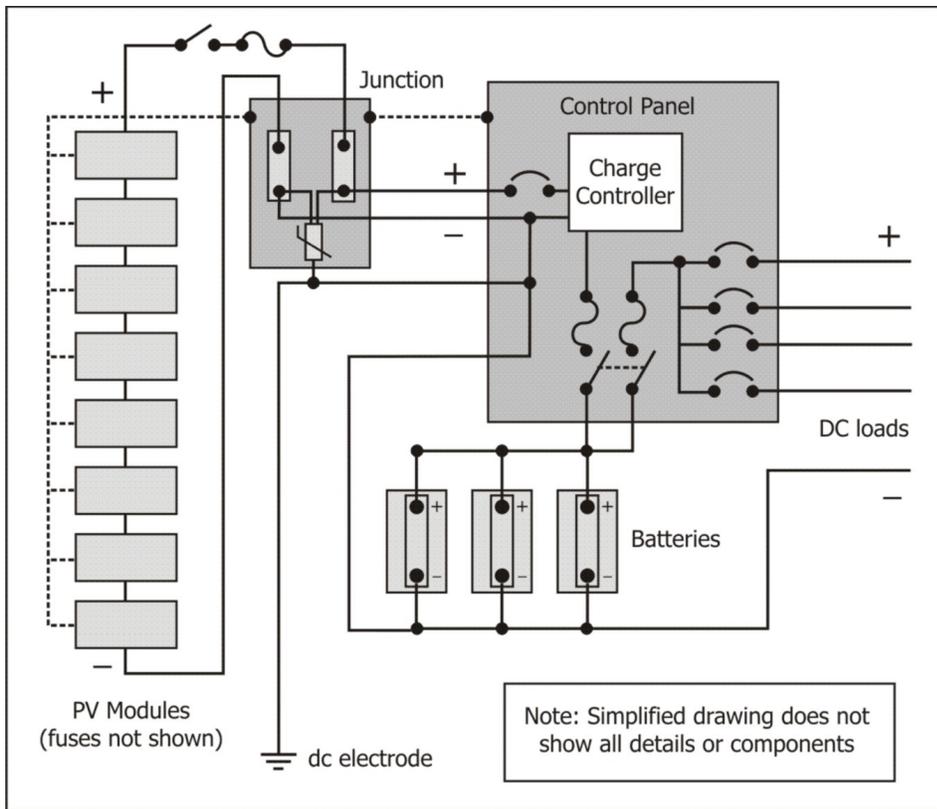
7

8 The DC output conductors from each string of solar panels are connected to an overcurrent protective
9 device in a combiner box. One set of DC output conductors from the combiner box are connected to the
10 DC disconnecting means and ultimately connected to the DC input of the inverter.

11

12 The DC voltage generated by solar arrays can be used to directly power DC loads or to charge energy
13 storage batteries. See Figure 3.1.2 as an example of a DC stand-alone system with batteries connected
14 and DC output only. When a solar array is used to charge energy storage batteries, a charge controller is
15 used to regulate the charging voltage and current for the batteries and to protect the batteries from
16 damaging voltages, currents, and temperatures.

17



1
2
3 Figure 3.1.2 Typical photovoltaic system with battery storage (DC system output) [Note: This is a
4 simplified diagram concept and is not intended to show all wiring, grounding, bonding, overcurrent
5 protection, and so forth.]
6

7 More often, however, solar arrays are used to power alternating-current (AC) loads or for interconnection
8 to the electric utility grid. Interactive inverters convert the DC voltage into an AC waveform that is
9 compatible with AC loads and are used to connect the solar array to the electric utility grid. When a solar
10 array is used to supply AC power, the inverter controls the power transfer from the solar array to the AC
11 loads or the utility grid, protects the solar array from the utility, and protects the utility from the solar
12 array. The inverter monitors the electric utility grid to ensure the one-way transfer of power from the
13 solar array to the connected loads and to the utility.
14

15 PV power generated in excess of local loads can be delivered to the electrical utility grid through the
16 revenue meter of the customer. When PV power generated is less than the local loads, power is drawn
17 from the electric utility provider. PV power systems are frequently an integral component of a microgrid.
18 See NECA 417 for additional information regarding microgrids.
19

20 Grid-connected PV power systems are comprised of one or more solar arrays, one or more utility-
21 interactive inverters, the mechanical balance-of-system components, and the electrical balance-of-system
22 components. PV power systems that operate independently of the electric utility grid must have either
23 energy storage batteries or one or more alternative power generation sources, or both, to supply power to
24 the loads when solar power is not available, such as at night. See NECA 416 for energy storage systems.
25 See NECA 417 for microgrids.
26
27

3.2 PV Power System Operation

PV power is a passive generation technology. Solar power generation is a function of sunlight magnitude and duration. When the sun shines, PV power systems generate power. When the sun does not shine, no power is produced.

In general, solar panels must be located clear of obstructions and shadows that can significantly reduce solar power production. Solar panels must be located in areas with sun exposure for most of the daylight hours in the day. Solar panels must be oriented towards the sun and should be tilted at an angle that maximizes solar power production.

As a passive generation technology, solar power generation cannot be increased in response to an increase in the load. Once a PV power system is installed and activated, there is no control over how much solar power is generated. Solar power generation, however, can be accurately estimated over a relatively long period of time.

Several factors affect solar power production, including atmospheric conditions, such as cloudy, overcast skies, high humidity or pollution in the air, and the thickness of the atmosphere due to elevation, ambient temperature, and ground snow cover. Typical PV power output ramps up during morning hours as the sun rises, peaks during the middle of the day, and declines as the sun sets.

Power output from a PV array is greatest on a bright, sunny day with low ambient temperature as cooler conductors and equipment, such as solar panels and inverters, operates more efficiently, and drops off with increasing operating temperature. Ground snow cover can increase solar power production by reflecting solar energy from the ground towards solar panels.

Solar power output drops off with sunlight intensity, such as at sun up or dusk and during cloudy days, or when solar panels are shaded in some way, and at other times when the solar panels are not exposed to direct sunlight. Solar power production also drops off as solar panels heat up, such as on a very hot summer day.

For a stand-alone PV power system, the array must be designed very closely to the size of the load. An array that is too small cannot power the load, and one too large can overheat, causing protective devices, such as the utility-interactive power inverter, to disconnect the array from the system. Typically, one or more alternative sources of power, such as energy storage batteries or an engine-generator, is required to power loads at night and when the load exceeds the output of the array. Solar arrays with energy storage batteries should be sized slightly larger than the connected load to charge the batteries during the day to allow for nighttime operation.

For grid-connected systems, sizing the solar array is not as critical as for a stand-alone PV system, namely because the electric utility grid is available to supply power to the customer load in excess of power generated by the PV array, and is available to absorb power generated by the PV array in excess of the customer load. A grid-connected PV system connects to the electric utility grid through one or more utility-interactive inverters. The controls and interlocks within a utility-interactive inverter only permit PV power transfer when the utility source voltage is present, and automatically stops PV power transfer upon an electric utility power interruption.

Hybrid PV power systems typically have battery energy storage and are capable of both grid-connected operation and stand-alone operation when the electric utility grid is not available.

3.3 Equipment Ratings

PV systems and equipment have voltage, current, and power ratings that are used to size equipment and conductors.

3.3.1 Voltage Ratings

The open-circuit voltage rating is the voltage rating of the module when open-circuited and exposed to full, direct sunlight. When a solar array is disconnected from the load during daylight hours, the array generates DC voltage somewhat higher than the nominal operating voltage of the array under load, although no current or power is drawn from the array. The maximum system voltage is the sum of the rated open-circuit voltages of the series-connected modules corrected for the lowest expected ambient temperature. *NOTE: The maximum open-circuit voltage of a solar array can exceed the voltage ratings of conductors, inverters, and equipment. Conductors and equipment must be carefully sized considering the maximum open-circuit voltage of the array.*

Maximum system voltage must be corrected for ambient temperature in accordance with the NEC for Crystalline and Multicrystalline Silicon Modules, and in accordance with manufacturer instructions where ambient temperature is below -40°C (-40°F), or where other than crystalline or multi-crystalline silicon PV modules are used. The temperature-corrected maximum system voltage must also be used in determining the voltage rating of conductors, cables, overcurrent protective devices, disconnects, and similar equipment.

The operating voltage rating is the nominal voltage rating of the module, which is typically a multiple of 12 Volts DC.

The maximum permissible system voltage is the peak operating voltage of the module.

The maximum voltage of PV system DC circuits is the highest voltage between any two circuit conductors or any conductor and ground. PV system DC circuits on or in one- and two-family dwellings are permitted to have a maximum voltage of 600 volts or less. PV system DC circuits on or in other types of buildings are permitted to have a maximum voltage of 1000 volts or less.

Where not located on or in buildings, listed DC PV equipment, rated at a maximum voltage of 1500 volts or less, shall not be required to comply with Parts II and III of NEC Article 490.

The maximum voltage is used to determine the voltage rating of conductors, cables, disconnects, overcurrent devices, and other equipment. In a DC PV source circuit or output circuit, the maximum PV system voltage for that circuit is calculated in accordance with one of the following methods:

- The sum of the PV module-rated open-circuit voltage of the series connected modules corrected for the lowest expected ambient temperature using the open-circuit voltage temperature coefficients in accordance with the instructions included in the listing or labeling of the module
- For crystalline and multi-crystalline silicon modules, the sum of the PV module-rated open-circuit voltage of the series connected modules corrected for the lowest expected ambient temperature using the correction factor provided in NEC Table 690.7(A)

- For PV systems with a generating capacity of 100 kW or greater, a documented and stamped PV system design, using an industry standard method and provided by a licensed professional electrical engineer, shall be permitted.

For two-wire DC circuits connected to bipolar PV arrays, the maximum voltage is the highest voltage between the two-wire circuit conductors where one conductor of the two-wire circuit is connected to the functional ground reference (center tap). To prevent overvoltage in the event of a ground-fault or arc-fault, the array must be isolated from the ground reference and isolated into two two-wire circuits.

3.3.2 Current Ratings

The operating current rating is the current rating at maximum power and maximum permissible system voltage. The short-circuit current rating is the maximum current that the module can deliver to a short-circuit at the terminals of the module.

3.3.3 Power Ratings

The maximum power rating is the power output of the module at the maximum permissible system voltage and operating current. The maximum power rating is typically the same as the rated power and peak power ratings of the module.

4. Receiving, Handling and Storage

4.1 Receiving

Visually inspect packaging upon delivery. Examine shipping boxes for visible damage, punctures, dents or any other sign of possible internal damage. Carefully unpack materials to inspect for concealed damage resulting from shipping and handling. While unpacking, be careful not to discard any equipment, parts or manuals. If damage has occurred, notify the delivering carrier and the manufacturer in writing immediately, and note the condition of the shipment on all copies of the delivery receipt. Request a carrier inspection and file a claim with the carrier. Failure to properly file a claim for shipping damages may void warranty service for any physical damages later reported for repair. Save original packaging as it will have to be used in case the equipment has to be shipped out for repairs, or the responsible inspector requires it.

Compare components and accessories received with the bill of materials to verify that the shipment is complete. If the shipment is not complete, notify the manufacturer in writing immediately. Verify that equipment and accessories received conform to approved submittals and manufacturer quotations.

If components and accessories are to be stored prior to installation, reuse the original packing materials. Leave the packing materials intact until equipment and accessories are ready for installation, when possible.

Battery racks are typically shipped dismantled in separate rail, frame, and brace packages. Check packages to ensure that the necessary assembly hardware is included.

1
2 Inspect the seals of batteries that have been shipped dry and charged. Renew any seals that are damaged
3 in accordance with the manufacturer's instructions. Inspect electrolyte levels of lead-acid batteries that
4 have been shipped wet when batteries are received at the site. Electrolyte should be added to the proper
5 level in accordance with manufacturer recommendations, if any has been lost.
6
7

8 **4.2 Handling**

9
10 Handle PV power system equipment and components in accordance with manufacturer instructions in
11 order to avoid damage to components and accessories. Verify that lifting equipment has adequate
12 capacity when handling palletized shipments. Avoid dropping, impact, jolting, jarring, and rough
13 handling.
14

15 During handling and transporting, do not bend inverters parts or change insulation distances of parts and
16 components. Do not allow electronic parts to contact terminals. Protect inverter parts from mechanical
17 damage.
18
19

20 **4.3 Storage**

21
22 Store equipment and components in a clean, warm, dry, well-ventilated room with a moderate
23 temperature ranging between 4°C and 40°C (40°F and 100°F).
24

25 Provide suitable protection until final assembly is complete. Protect from weather, rain, snow, dirt,
26 corrosive gases or fumes, dust, foreign objects, and rodents. Moisture in combination with cement dust is
27 very corrosive to electronic equipment.
28

29 Store components and accessories in a monitored area to discourage vandalism and theft, and out of the
30 way of construction traffic.
31

32 Store batteries indoors, in a dry place. Give batteries a refreshing charge three months after date of
33 shipment from the factory, and every three months thereafter. Restore batteries to manufacturer
34 recommended voltage in accordance with manufacturer instructions. Do not exceed the manufacturer
35 recommended charging rate or overcharge the batteries. Store other types of batteries that have been
36 shipped wet per the manufacturer's instructions.
37
38

39 **5. PV Power System Safety**

40 **5.1 General**

41
42 For PV power systems to work properly, the components must be handled carefully and installed,
43 commissioned, operated, and maintained correctly. Neglecting fundamental installation and maintenance
44 requirements may lead to personal injury or death, as well as damage to electrical equipment or other
45 property. All work and actions must conform to the requirements of NFPA 70E, Electrical Safety in the
46 Workplace. See Figures 5.1.1 and 5.1.2 for examples of manufacturer danger labels and field-applied
47 warnings required.
48

1



2
3
4
5

Figure 5.1.1 Typical danger/safety labels provided on electrical equipment by manufacturers.



6
7

Figure 5.1.2 Typical warning label that is field applied in accordance with NEC 110.16. See ANSI Z535 for information related to danger, warning, and caution markings and signage.

10

Hazards associated with PV power systems include electrical hazards from independent power generation, high voltage AC and DC electricity, high voltage DC from open-circuited solar arrays, and the potential for backfeeds. Where batteries are installed, additional hazards include corrosive liquids such as sulfuric acid or battery electrolyte, sulfur vapors from cracked or leaky batteries, fire and explosion hazard from hydrogen gas generated during the battery charging cycle, and hazardous fumes or vapors resulting from the products of combustion due to fire.

17

Solar power systems and utility-interactive power inverters have multiple sources of power, both AC and DC, and capacitors with stored electric charge. High voltage DC is present even with AC input power disconnected. Expect hazardous voltages in all interconnecting components and lines.

21

When operating disconnecting means for PV power systems, open the AC disconnect first to stop the transfer of power from the solar power system to the electric utility grid before opening the DC disconnect. By operating the AC disconnect first, the inverter automatically senses the disconnection from the electric utility grid and shuts down PV power generation in an orderly manner.

26

Do not touch inverter or charge controller surfaces during operation. Hazards associated with inverter and charge controller operation may include energized, uninsulated components, moving and rotating parts, and hot surfaces.

29

30

1 Follow manufacturer’s instructions and recommendations for electrically isolating PV power systems and
2 components. Open all external disconnects or circuit breakers to completely isolate the inverter or charge
3 controller and the solar array from all AC and DC power sources. Open DC circuit breakers to
4 completely isolate the solar array from the inverter, and to completely isolate batteries from charge
5 controllers. Check equipment terminals, conductors, and components for AC and DC voltages to ensure
6 that equipment is electrically safe before performing any inspections, maintenance, testing, or repairs.
7

8 PV power system components are frequently installed at elevation on roofs or elevated ground-mounted
9 racks. Comply with applicable Codes for fall protection and worker safety when working at elevation.
10

11 **5.2 Safe Work Practices**

12 Perform preliminary inspections and tests prior to beginning work to determine existing conditions.
13 Check existing conditions against available record documents.
14

15 Visually verify all cable connections to equipment. Confirm that supply cables and load cables are
16 connected properly. Keep in mind that transposed cables may be connected to different terminals than
17 expected.
18

19 Resolve discrepancies between installed conditions and electrical drawings. Have drawings corrected, if
20 required. Provide warning labels on equipment and cables where necessary to indicate unexpected and
21 potentially hazardous conditions.
22

23 Maintain as much distance as practical from equipment and devices that may arc during operation or
24 handling, but not less than the arc flash protection boundary specified in NFPA 70E, Electrical Safety in
25 the Workplace.
26

27 Use appropriate Personal Protective Equipment (PPE) and established safety procedures when working on
28 or near energized electrical equipment or equipment that has not been de-energized, tested, grounded, and
29 tagged in accordance with NFPA 70E, Electrical Safety in the Workplace. See Figure 5.2.1 for an
30 example of typical personal protective equipment necessary when performing justified energized work
31 such as troubleshooting procedures.
32
33
34



35
36

1 Figure 5.2.1 Use appropriate personal protective equipment (PPE) for justified energized work. (Courtesy
2 of NJATC)

3
4 Use insulated hand tools when working on or in close proximity to energized equipment. Use only
5 properly rated tools for the energy present. Maintain tool inventories to ensure that all tools are accounted
6 for prior to energizing equipment.
7

8 9 **5.3 Electrical Hazards**

10
11 Consider all ungrounded and grounded metal parts of equipment and devices to be energized at the
12 highest voltage to which they are exposed unless they are de-energized, tested, locked, and red tagged in
13 accordance with OSHA requirements. Keep in mind that high voltage DC is always present when solar
14 panels are exposed to sunlight, and because of the nature of batteries. Consider covering solar panels
15 with tarpaulins, opaque sheeting, or covers to minimize open-circuit DC voltages created by opening DC
16 disconnecting means with solar arrays exposed to sunlight. Employ proper safeguards.
17

18 Do not work on energized conductors or equipment. Do not enter solar power system equipment or
19 enclosures with components are energized. Using established safety procedures, guard energized
20 conductors and equipment in close proximity to work.
21

22 Render equipment electrically safe. Disconnect all sources of AC and DC power to solar power system
23 equipment and components, including batteries, before opening any compartments. Follow lock-out/tag-
24 out procedures. After compartments are opened, test for the presence of voltage and apply locks and tags
25 in accordance with NFPA 70E, Electrical Safety in the Workplace. Leave locks and tags in place until the
26 work is completed and the equipment is ready to be put into service.
27

28 Verify that circuit breakers and switches are open. Verify by testing that desired cables and equipment
29 are de-energized. Use electrical testing equipment rated for the operating voltage of the system. Test
30 voltage sensing equipment on a known, energized source immediately before and after testing the
31 equipment to be tested to ensure that voltage sensing equipment is operating properly. Secure circuit
32 breakers and switches with locks and tags.
33

34 Do not make any modifications to the equipment or operate the system with interlocks or safety barriers
35 removed. Engage lock-bars for compartment doors so equipped to prevent doors from accidentally
36 closing.
37

38 Protect against accidental energization of automatic or remotely controlled equipment by identifying,
39 opening, locking, and tagging starting devices. Remove locks and tags only after work is complete and
40 tested, and all personnel are clear of the area.
41

42 Carefully inspect work area and remove any tools and objects left inside equipment before energizing PV
43 power systems. Install all devices, doors, and covers before energizing solar power system equipment
44 and components.
45

46 Wait a minimum of five minutes after disconnecting both AC and DC inverter disconnects before opening
47 access covers to allow all energy to discharge from ungrounded solar panels, transformer-less solar
48 modules, and system capacitance and to avoid the risk of electric shock.
49
50

5.4 Battery Systems

Follow manufacturer's installation, servicing, and maintenance instructions. Voltages present can cause injury and death. Batteries connected in series have high voltage and current capacities. Exposing skin and eyes to electrolyte can cause severe burns and blindness. During activation and operation, batteries can produce and emit a highly volatile mixture of hydrogen and oxygen.

Wear appropriate safety equipment as deemed necessary by the task being performed while in rooms containing batteries or when working near batteries. Personal protective equipment includes, but is not limited to, goggles, face shields, safety glasses with side shields and splash protection, head protection appropriate for environments with electrical hazards, insulated rubber gloves and sleeves suitable for the voltage class of equipment present, acid- or alkali-resistant gloves, protective or impermeable aprons, acid- or alkali-resistant boots or overshoes, and (acid or alkali) neutralizing solution.

Ensure that egress from the work area is unobstructed. Ensure that fire extinguishers approved for use in electrical fires and fires involving batteries and battery acids are readily available. Use fire extinguishers recommended by the battery manufacturer. *NOTE: Some battery manufacturers do not recommend the use of CO₂ Class C fire extinguishers due to the potential of thermal shock, and the possibility of cracking battery containers.*

Check that appropriate chemical protective equipment and approved air-purifying respirators (full-face APR with combination acid gas, organic vapor, and HEPA cartridges - magenta/yellow) are available for clean-up of a low-risk spill of sulfuric acid, along with sulfuric acid spill control and clean-up materials, such as absorbent pillows, lime, crushed limestone, sodium bicarbonate, and/or soda ash.

5.4.1 DC Electricity

Do not place tools or metal objects on battery cells, racks, or tiers. Use insulated tools when working on or near batteries to protect against shorting of cells. Wear rubber gloves and boots. Discharge static electricity from the body before touching cell terminal posts by first touching a grounded surface such as the grounded battery racks.

Wear 100 percent natural fiber clothing or flame-resistant apparel. Do not wear conductive articles such as watches or rings. Disconnect the charging source prior to connecting or disconnecting battery terminals.

Check the battery for inadvertent grounding during installation and maintenance. Contact with any part of a grounded battery can result in electrical shock. Remove inadvertent grounds to reduce the likelihood of such shock.

5.4.2 Sulfuric Acid

Sulfuric acid is a colorless, odorless liquid that can form a mist during battery charging or by explosion or fire. Sulfuric acid in contact with some metals may form corrosive sulfur dioxide fumes and flammable hydrogen gas. Water applied directly to sulfuric acid causes evolution of heat and splattering. Refer to battery material safety data sheets shipped with the system for further information.

Sulfuric acid contact with the eyes or skin will cause severe burns. Exposure to sulfuric acid mist or vapors severely irritates eyes, the respiratory tract, and skin. Sulfuric acid will concentrate if not removed

1 from contaminated clothing or skin, dehydrating and destroying tissue. If electrolyte comes in contact
2 with skin or eyes, flush the affected area immediately with copious amounts of water and obtain medical
3 assistance immediately.

4
5 Wear personal protective equipment, including a full-face shield, when preparing electrolyte. Pour acid
6 into water; never pour water into acid. Exercise the utmost caution to avoid spilling electrolyte.
7 Bicarbonate of soda solution in a concentration of one pound per gallon of water will neutralize acid
8 spilled on clothing or material. Apply the solution until bubbling stops, then rinse with clear water.
9

10 **5.4.3 Hydrogen Gas**

11
12 As batteries charge, hydrogen (H₂), a colorless, odorless, and tasteless gas, which is non-toxic under
13 normal conditions, may be released. Hydrogen may displace oxygen and cause asphyxiation in confined
14 spaces and is a severe fire and explosion hazard when exposed to heat, flame, or oxidizers. The explosive
15 range for hydrogen is very wide with a lower explosive limit of 4.1 percent by volume and the upper limit
16 of 74.2 percent.

17
18 Check that rooms containing batteries and compartments with lead-acid batteries are adequately
19 ventilated to prevent hydrogen levels from exceeding a one percent concentration by volume of the space.
20 An essentially fully charged battery will generate a maximum of 0.016 cubic feet of hydrogen (measured
21 at 25 degrees C and 760 mm Hg absolute pressure) per hour from each cell for each ampere of charging
22 current. Additional ventilation may be required during activation charging cycle.

23
24 Do not allow open flames, sparks, hot plates, smoking, or any other ignition sources near batteries, gas
25 ventilation paths, or anywhere hydrogen can accumulate. Discharge static electricity from body before
26 touching batteries by first touching a grounded metal surface.
27
28

29 **6. Pre-Installation Considerations**

30 **6.1 General**

31
32
33 All equipment shall be approved for the intended use. Equipment, such as inverters, PV modules, PV
34 panels, AC modules, DC combiners, DC-to-DC converters, and charge controllers intended for use in PV
35 systems shall be listed or field labeled for PV applications. Utility interactive inverters shall be listed and
36 or field labeled for the intended use of interconnection service PV application.
37

38 The installation of equipment and all associated wiring and interconnections for PV systems, including
39 the installation of utility-interactive systems, shall be performed only by qualified persons.
40

41 PV system equipment and disconnecting means are not permitted to be installed in bathrooms.
42
43

44 **6.2 Local Solar Resource**

45
46 PV power is a passive generation technology. Solar power generation is a function of sunlight magnitude
47 and duration. Once a PV power system is installed and activated, there is no control over the amount of
48 solar power generated. Consequently, solar power generation cannot be predicted at any given point in
49 time. Conversely, solar power generation can be accurately estimated over a relatively long period of
24

1 time.

2
3 To accurately estimate solar power generation over time, the local solar resource, or the average sunlight
4 available per day over the course of a year must be evaluated at the proposed installation site. Solar
5 irradiation is the total amount of solar energy accumulated on an area over time, typically expressed as
6 kilowatt-hours-per-square-meter (kWh/m^2). Insolation is the average solar energy density at a given
7 location, expressed as kilowatt-hours-per-square-meter per day ($\text{kWh}/\text{m}^2/\text{day}$), and is one estimate of the
8 average solar energy available at any given installation site. Peak sun hours is the total solar irradiation in
9 one day, and 1 peak-sun-hour is defined as $1 \text{ kWh}/\text{m}^2/\text{day}$.

10
11 Insolation or peak-sun-hours are used to calculate the average annual energy output of a given PV array
12 and are used to calculate the minimum-sized PV array necessary to produce a desired annual solar energy
13 output.

14
15 Insulation information for various locations throughout the world is available from numerous on-line
16 sources. See Annex A for calculations using insolation or peak-sun-hours in estimating annual solar
17 energy output and for sizing PV arrays.

18 19 20 **6.3 Environmental Conditions**



22
23
24 Figure 6.3.1 Photo of a typical ground-mounted photovoltaic array (Courtesy of Central Florida
25 Electrical JATC)

26
27 Environmental considerations for PV power systems include:

- 28
29 • Rain, snow, sleet and hail. Many PV modules or solar panels are relatively immune to damage
30 from rain, snow, sleet and hail. See Figure 6.3.1 for an example of a ground-mounted PV system.
31 Because many solar panels are mounted at some angle from horizontal, rain, snow and sleet do
32 not typically accumulate on the panels, and hail is deflected from the panel upon impact. Thin-
33 film PV modules, however, can be installed on horizontal surfaces and may be damaged by hail.

- Elevation. PV arrays located at higher elevations from sea level produce higher levels of solar power because the sunlight travels through thinner layers of atmosphere to reach the array.
- Temperature. PV power systems generate energy more efficiently in lower temperatures, and solar power production is increased. Likewise, inverters used for solar power are adversely affected by heat and sunlight. Inverters should be located out of direct sunlight in a relatively cool location.

6.4 Building Codes, Permits and Inspections

Check local building codes, fire codes, and zoning requirements as applicable to PV power systems. Such codes typically include requirements for firefighter safety and for solar panel and solar array placement, arrangement and access to disconnect switches, overcurrent protection, and safety and warning labels.

Obtain the necessary building and electrical permits prior to installing PV power systems. PV power systems on new structures should be included in the overall valuation of the project and typically do not require separate permits but must comply with installation criteria and local codes. New PV power systems on existing structures require a separate permit and should comply with installation criteria and local codes.

Typically, any system larger than 5 kW or a residential solar array that will occupy more than 50% of the roof area will require a submittal for code review. Any system incorporating battery storage or another alternative energy source will typically require full plan review. PV plan review typically includes electrical wiring and configuration, system disconnects, signage, placement of equipment and solar panels with associated access and pathways, equipment type, listing, and testing agency approvals.

Submittal requirements may include general information such as the name of the applicant, address of project, name of licensed contractor, and size of system. Plans must be signed by the responsible party and should include a roof plan drawn to scale with the following information, North arrow, direction to street frontage, location of service lateral conductors, main electric meter and panel, DC disconnect, inverter, AC disconnect, roof slope, material of roof covering, roof dimensions, access locations, and dimension of solar arrays, all skylights, roof ventilation openings or other mechanical equipment on the roof, clearance around arrays for access and pathways, and approximate locations of conduit and where conduits turn down to go to the service panel.

Submittals may require a single-line diagram of electrical equipment showing the size of the main panel, any sub panels, PV power system equipment including make, model and size of units, disconnects, associated electrical devices, conduit size and type, and wire size and type. Include mounting information and specific mounting details of solar panels to roofs or other assemblies. Show actual proposed labels with approximate dimensions of the labels as require by Code and by policy, identifying where labels are to be located on equipment, conduits, disconnects, boxes, and similar equipment. Plans should include a general statement that the installation will comply with all applicable Codes.

6.5 Utility Interconnection Requirements

PV power systems that are interconnected to the local electrical utility grid have special requirements, which may include additional disconnecting means that are accessible to utility company personnel,

1 labeling, metering, overcurrent protection, and automatic disconnection to prevent the PV power system
2 from backfeeding the utility during an outage, among others.

3
4 Contact the local electric utility company for interconnection requirements, required forms, fees and
5 permits. Review the local electric utility company interconnection requirements and submit the required
6 application forms. Connection to the distribution system may be completed only after receiving approval
7 from the local electric utility company as required by national and state interconnection regulations.

8
9 PV systems may be permitted by the electric utility company to be connected to the supply side of the
10 service disconnecting means as permitted in NEC Section 230.82(6). For equipment connected on the
11 supply side of the service disconnecting means, the sum of the ratings of all overcurrent devices
12 connected to power production sources must not exceed the rating of the service.

13
14 Utility-interactive power inverters for PV power systems can be connected on the load side of the service
15 disconnecting means at any distribution equipment on the premises. Additional requirements for
16 connecting inverters to backfed distribution equipment such as switchgear, switchboards, and panelboards
17 include:

- 18 • Each source must have a dedicated circuit breaker or fusible disconnecting means.
- 19 • Ampacity calculations for feeders, taps, and busbars must be made based on 125% of the power
20 source output circuit current and equipment sized in accordance with NEC Section 705.12(B)(2).
- 21 • The sum of ampere ratings of source overcurrent protective devices to a common busbar or
22 conductor cannot exceed 120% of the ampacity of the busbar or conductor.
- 23 • The inverter interconnection point must be on the line side of all ground-fault protection
24 equipment unless ground fault protection is provided for all sources and ground-fault protective
25 devices are identified and listed as suitable for backfeeding.
- 26 • Equipment must be marked to indicate the presence of all sources of power.
- 27 • A permanent warning label must be applied to the distribution equipment with the following or
28 equivalent wording: “Warning—inverter output connection. Do not relocate this overcurrent
29 device.”

30
31 It is also important to note that circuit breakers that are backfed must be suitable for backfeed operation.
32 Circuit breakers that are marked “line” and “load” have not been evaluated for backfeed operation.
33 Circuit breakers without “line” and “load” designations are suitable for backfeed operation. Supplemental
34 fasteners are not required for panelboards with listed plug-in type circuit breakers that are backfed from
35 listed utility-interactive inverters.

36
37 In addition, for panelboards sized for the connected loads but with ampere ratings less than the sum of all
38 of the source overcurrent protective devices, the utility-interactive inverter output connection must be at
39 the load end of the panelboard opposite the main lugs or main circuit breaker. Where panelboards are
40 connected in series, such as main-lug-only panelboards, the rating of the overcurrent protective device
41 directly connected to the output of the utility-interactive inverter must be used in the calculations for all
42 busbars and conductors.

43 44 45 **6.6 Locating Solar Arrays**

46
47 Solar arrays must be carefully located to ensure maximum power production. Solar panels and solar
48 arrays must be located in areas of full sun exposure with no shading and should be generally oriented
49 towards solar south (azimuth of 0°). Solar south is determined empirically by the location of the sun at

1 the time halfway between sunrise and sunset. Fixed arrays in the northern hemisphere should be oriented
2 toward solar south to maximize the average daily exposure to sunlight. Solar panels can be oriented
3 slightly east (positive azimuth angle) or west (negative azimuth angle) of solar south but should not be
4 oriented to the north. See Figure 6.6.1 for an example of a large roof-mounted photovoltaic array.
5



6
7
8 Figure 6.6.1 Photo of a typical roof-mounted photovoltaic array (Courtesy of NEC Copyright Rob
9 Colgan)

10
11 Solar arrays can be mounted on pivoting structures that can track the sun using rotation on one or two
12 axes or can be fixed mounted. Both one- and two-axis tracking solar arrays have the ability to rotate from
13 east to west to follow the path of the sun across the daytime sky. A two-axis tracking solar array also has
14 the ability to change the tilt angle to maintain the optimal exposure of the face of the solar array to match
15 the height of the sun in the sky from season to season.

16
17 Tracking solar arrays have the disadvantage of moving parts that require maintenance and repair, have
18 more complex structural and mounting components, and are more expensive to install, which is offset
19 somewhat by the increased solar power generation. See Figure 6.6.2 and 6.6.3 for examples of a PV with
20 a solar tracking system. The selection of a one- or two-axis tracking array must be carefully weighed with
21 the additional complexity and cost.
22



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Figure 6.6.2 Typical pole-mounted photovoltaic solar tracking system (Courtesy of IBEW Local 26 Electrical JATC Training Center)



7
8
9
10

Figure 6.6.3 Photovoltaic system that tracks the sun and secured to a single pole (Courtesy of IBEW Local 26 Electrical JATC Training Center)

11

Fixed-mounted solar arrays may be surface-mounted or tilt-up. A surface-mounted solar array is typically installed on a roof. A tilt-up solar array is typically installed on a structural support or framework that can be constructed on a roof or the ground or can be installed on a pole base.

12

Power output from a PV power system is reduced when the solar panels are shaded. Ensure the installation location is clear of obstructions, trees, other structures, and shading. Identify and remove any obstruction to sunlight that may shade the solar array. Trim trees or locate solar arrays away from trees, utility poles, buildings or structures, or any obstacle that may cast a shadow on the array. Trace the path of the sun in the sky to determine whether any object may cast a shadow on the array.

13
14
15
16
17
18
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20
21

1 The structural integrity of the mounting method must be evaluated for the weight of the solar array,
2 conductors, conduits, electrical boxes, and similar equipment. Solar arrays that are roof mounted must
3 also be located and arranged in accordance with local codes to provide access and required clearances for
4 firefighting, including areas for access aisle ways and smoke ventilation.

6.5.1 *Thin-Film PVs*

7
8 Thin-film PV modules use various technologies to reduce the amount of light absorbing material within
9 each individual solar cell. While slightly less efficient, thin-film PV modules are less expensive, lighter
10 weight and more flexible than solar panels that use traditional solar cell technology. Thin-film PVs can
11 be designed as solar panels or can be integrated into construction materials such as exterior walls
12 treatments, windows, and roofing materials. Some thin-film PV modules are self-ballasting and do not
13 require attachment to flat roofs, reducing installation time and cost. Due to the variety of different
14 materials and components that are available, contact the manufacturer for recommendations for installing
15 thin-film PV modules.

6.7 Access and Required Clearances

19
20 Roof mounted conduits, pipes, and braces crossing walkways or pathways should be clearly marked by
21 red/white reflective tape or other fire department approved identifying material. Any item higher than 45
22 cm (18 inches) must typically have steps up and down on either side.

23
24 All arrays shall be mounted per the listing installation instructions of the system. Pathways should be
25 established in the design of the solar installation and clearly indicated on the plans.

26
27 Sharp edges of PV equipment and components, and fastener tips should be covered or crimped over as to
28 not provide a sharp edge where emergency responders or any other individual accessing the rooftop may
29 be injured.

6.7.1 *Residential Buildings*

30
31
32 For hip roofs, solar panels should be placed in a manner that provides at least one 1-meter (36-inch) wide
33 clear access pathway from the eave to the ridge on each roof slope where solar panels are located. The
34 access pathway should be located at a structurally supported location on the building, such as at a bearing
35 wall. Residential buildings with a single ridge require two 1-meter (36-inch) wide access pathways from
36 the eave to the ridge on each slope where solar panels are located.

37
38 For roofs with hips and valleys, solar panels should be located no closer than 45 cm (18 inches) to a hip
39 of valley if solar panels are to be placed on both sides of the hip or valley. If solar panels are only to be
40 located on one side of a hip or valley that is equal length, solar panels can be placed directly adjacent to
41 the hip or valley. Solar panels should be located no higher than 1-meter (36-inch) below the ridgeline of
42 residential roofs to permit smoke ventilation.

6.7.2 *Commercial Buildings and Residential Housing of Three or More Units.*

43
44 Provide a minimum 1.2 meter (48 inch) wide clear perimeter around the edges of the roof. Pathways
45 should be established during the design process and prior to installation. Pathways should be over
46
47
48
49

1 structural members. Centerline axis pathways should be provided in both axis of the roof. Pathways
2 should be in straight lines not less than 1.2 meter (48 inch) clear to skylights and/or ventilation hatches,
3 and not less than 1.2 meter (48 inch) clear to roof standpipes.
4

5 Pathways should provide not less than 1.2 meter (48 inch) wide clearance around roof access hatches with
6 at least one not less than 1.2 meter (48 inch) clear pathway to parapet of roof edge. For smoke
7 ventilation, arrays should be no greater than 46 meters (150 feet) in distance in either axis. Ventilation
8 options between array sections should be either a pathway 2.5 meters (96 inches) or greater in width, 1.2-
9 meter (48 inch) or greater in width pathway and bordering on existing roof skylights or ventilation
10 hatches, or 1.2-meter (48 inch) or greater in width pathway and boarding 1.2-meter (48 inch) by 2.5
11 meters (96 inches) venting cutouts every 6 meters (20 feet) on alternating sides of the pathway.
12
13

14 **6.8 Structural Systems**

15
16 Solar array structural mounting systems must be selected and evaluated for the application. Solar array
17 mounting options include:

- 18 • Surface-mounted roof-mounted arrays.
- 19 • Universal tilt-up structural supports suitable for either roof or ground mounting.
- 20 • Pole-mounted ground installed arrays.
- 21 • Tracking arrays (special configuration of pole-mounted arrays).

22
23 Because roof-mounted solar panels require mounting holes through the roof, the best time to install roof-
24 mounted solar panels is during the installation of the roof. Roof-mounted solar panels are more likely to
25 be surface-mounted to the roof than installed on a structural framework due to aesthetic reasons. Surface-
26 mounted roof systems are installed in the same plane as the roof and are less conspicuous than a bulky
27 structural framework mounted on a roof. See Figure 6.8.1 for an example of a typical roof-mounted
28 photovoltaic array.
29



1 Figure 6.8.1 Roof-mounted solar photovoltaic array attached to structural members in building (Roof
2 penetrations should be sealed by a qualified contractor).
3

4 Flush roof-mounted solar arrays are the least expensive and most simple approach to mounting solar
5 panels. Metal brackets are installed on each side of a solar panel and secured to the roof. The metal
6 brackets raise the solar panels off of the roof, providing the required clearance between the solar panel
7 and the roof material for necessary air circulation. Flush roof-mounted solar array brackets are installed
8 through the roof material into the structural supports or rafters using stainless steel bolts and hardware or
9 using J-bolts around the rafters. Check that such penetrations do not void the roof warranty, and seal roof
10 penetrations using approved materials and methods. Flush-mount roof systems offer no flexibility in the
11 orientation of the solar array and are typically used for smaller PV power systems.
12

13 Solar panels can be mounted on a structural framework that is anchored to the ground or to a roof.
14 Because of the weight and bulk of the structural framework, such installations are more difficult to install
15 on a roof and are more likely to be installed on the ground than on a roof. Structural framework and
16 supports are more expensive than flush roof-mounted systems, greatly increase the wind resistance of the
17 array and the structure, and typically have issues with local codes when installed on a roof. Structural
18 supports are typically non-moving, or static, and are used for larger solar arrays.
19

20 Solar arrays can also be mounted on a structural framework that is bolted to a sleeve that is set on a pole
21 embedded in concrete or the earth. Large top of pole mounts can be heavy and/or can present substantial
22 wind resistance. Tracking systems are special top-of-pole mount systems. An active solar tracking
23 system consists of solar panels mounted on a motorized rotating and/or tilting structural support with
24 controls to point the solar panels toward the sun during daylight operation.
25

26 A passive solar tracking system consists of solar panels mounted on a non-motorized rotating structural
27 support that uses solar energy to heat liquid contained in tubes and tanks on the support, allowing the
28 difference in weight to rotate the solar panels using gravity with no motors, gears, bearing or controls.
29 Either type of tracking system will increase solar power production by orienting the solar panels toward
30 the sun during daylight hours.
31

32 Some PV modules installed on flat roofs are self-ballasting and do not require attachment to the roof.
33 Consult with the manufacturer for recommendations for installing self-ballasting solar panels.
34
35

36 **6.9 Electrical Systems and Equipment**

37

38 The PV power system electrical configuration and equipment must be selected and evaluated. Possible
39 electrical configurations and types of PV power systems include:

- 40 • Utility interactive system. Operated in parallel with the local electrical utility grid.
- 41 • Stand-alone system. Operates fully independently of the local electrical utility grid. Stand-alone
42 systems typically require one or more forms of energy storage, such as batteries, and one or more
43 forms of backup generation, such as an engine-generator, to supply power when PV power is not
44 available, such as at night.
- 45 • Bimodal system. Capable of both utility interactive and stand-alone operation. Operating in
46 stand-alone mode, a bimodal system typically requires energy storage batteries and a second form
47 of generation.
- 48 • Hybrid system. Contains PV power generation along with a minimum of one other form of
49 generation, such as a wind turbine, engine-generator, or microturbine, and may or may not be

1 utility interactive. A stand-alone or bimodal system with a second form of generation is also
2 known as a hybrid system.

- 3 • Direct-coupled system. PV power system that supplies DC loads with or without energy storage
4 batteries.
- 5 • Microgrids. PV power systems are frequently used as distributed generation as part of a
6 microgrid. A microgrid is a distinct type of hybrid system that includes interconnected loads and
7 distributed energy resources, such as distributed generation, energy storage devices, or
8 controllable loads, within clearly defined electrical boundaries that acts as a single controllable
9 entity with respect to the electric utility grid. See NECA 417 for additional information and
10 guidance for microgrids.

11
12 A utility interactive PV power system is fully supported by the electric utility grid during normal
13 operation. Consequently, the design of a utility interactive PV power system provides tremendous
14 latitude.

15
16 For any other type of PV power system, the electrical system and equipment, including the solar array,
17 inverter or charge controller, batteries, and other forms of generation, must be carefully evaluated, sized
18 and selected for the load.

19 20 21 **6.10 Power Requirements**

22
23 The power requirements of the PV power system must be evaluated. For PV systems that include energy
24 storage batteries, the energy required to charge the batteries must be factored into the solar power
25 generation calculation.

26
27 Some PV power systems supply power to a sub-set of the electrical system. When designing such as
28 system, the power requirements of this sub-set of electrical loads should be evaluated and used when
29 designing the solar power system, energy storage battery system and alternate energy source. See NECA
30 406 for a discussion of what are considered essential loads and non-essential loads.

31 32 33 **6.11 Performance Estimate**

34
35 The performance estimate for a PV power system is a calculation of the expected average annual power
36 output for the system. See Annex A for estimating PV power system energy production performance.

37 38 39 **6.12 PV Power System Components**

40
41 PV power systems are made up of solar panels, inverters or charge controllers, mechanical balance-of-
42 system components, and electrical balance-of-system components.

43 44 ***6.12.1 Solar Panels***

45
46 The basic building block of a PV power system is the solar cell. A solar cell creates a direct current (DC)
47 voltage when exposed to light. Solar cells are interconnected and grouped together in a solar panel or
48 solar module.

1 Solar panels are interconnected to form solar arrays. Solar panels are connected in series to increase the
2 operating voltage and connected in parallel to increase the available operating current. By connecting
3 solar panels using series and parallel connections, solar arrays can be designed to deliver virtually any
4 power, voltage and current requirement. See Figure 6.12.1 for an example of interconnected photovoltaic
5 modules that form an array.
6



7
8
9 Figure 6.12.1 Typical photovoltaic solar panel used to connect with other modules when forming an
10 array.
11

12 ***6.12.2 Inverters***

13
14 The inverter is used to convert DC power produced by the solar array into a 60 Hertz AC waveform that
15 is compatible with AC loads and with the electric utility grid. A utility-interactive inverter also regulates
16 power delivered to the electrical utility grid and protects both the solar array and the electric utility grid
17 from abnormal operating conditions by automatically disconnecting from the grid during a utility outage.
18 See Figure 6.12.2 for an example of inverters installed as part of a photovoltaic system.
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Figure 6.12.2 Typical inverters for a small photovoltaic system (Courtesy of Central Florida Electrical JATC)

The inverter contains protection for the PV power system, including anti-islanding, which shuts down the inverter during an electric utility outage to prevent the PV power system from backfeeding the utility, and panel ground-fault protection, which continuously monitors the system and shuts the system down if the DC portion of the PV power system becomes inadvertently grounded.

Additional protection and control features include continuously monitoring the grid voltage and frequency to ensure that values are within operational tolerances. When the grid voltage and frequency are outside of operational tolerances, the inverter disconnects the solar array from the grid.

Solar panels that have an integral inverter are known as alternating-current (AC) modules. An AC module is a complete, environmentally protected solar panel consisting of solar cells, optics, and inverter, that is designed to generate ac power when exposed to sunlight. For the purposes of this Standard, the output of an AC PV module (solar panel) is considered to be an inverter output circuit, as the PV source circuit, conductors, and inverter are considered to be internal wiring of an AC module. The requirements for AC output of utility-interactive inverters apply to the output of AC modules.

6.12.3 Charge Controllers

Charge controllers are used in a PV power system with energy storage batteries. A charge controller regulates the battery charging voltage and current from the solar array while supplying a load. The charge controller maintains the battery system at the highest possible state of charge while protecting batteries from overcharging or over discharging.

6.12.4 Mechanical Balance-of-System Components

1
2 Mechanical balance-of-system components are all of the remaining mechanical components necessary to
3 install a PV power system, including brackets, supports, fasteners, connectors, racks, enclosures, and
4 structural attachments, along with building components such as fencing, ladders for access, and handrails.
5

6 ***6.12.5 Electrical Balance-of-System Components***

7
8 Electrical balance-of-system components are all of the remaining electrical components necessary to
9 install a PV power system, including conductors, cables and wires, conduits and raceways, boxes and
10 enclosures, connectors and terminations, disconnect switches, fuses and circuit breakers, grounding
11 components, instrumentation, controls and monitoring, and surge protective devices, if installed.
12
13

14 **6.13 Energy Storage Batteries**

15
16 Most PV power systems are utility-interactive, meaning that the solar power system operates in parallel
17 with the electric utility. The electric utility establishes the operating voltage and frequency of the system,
18 and the solar power system delivers real power, expressed in kilo-Watts (kW) to the system. Utility-
19 interactive solar power systems typically do not have energy storage batteries simply because batteries are
20 not required for system operation.
21

22 The purpose of energy storage batteries is to supply power to the load when PV power generation is less
23 than the connected load, such as during peak electrical energy usage or during a cloudy day, or when solar
24 power generation is not available, such as at night. A utility-interactive solar power system does not
25 require batteries because the electric utility grid can supply power in excess of solar power generation and
26 at times when solar power is not available.
27

28 Energy storage batteries are typically installed for stand-alone, bimodal or hybrid PV power systems that
29 supply a load apart from the electric utility grid. Stand-alone, bimodal and hybrid PV power systems
30 require additional controls to enable voltage and frequency regulation independently of the electric utility
31 grid.
32

33 Such systems many times include one or more alternative generation sources, such as a wind turbine or
34 engine-generator. A system with energy storage batteries typically requires a charge controller that
35 controls the charging and discharging cycles of battery operation and protects the batteries from damage
36 from excessive voltage, current and temperature.
37

38 When power generation exceeds the connected load, the excess power is used to charge the energy
39 storage batteries. When the connected load exceeds solar power generation, the energy storage batteries
40 deliver power to the load as needed.
41

42 Batteries require maintenance, have a finite life expectancy based on the operating temperature and
43 charging and discharging cycle, and typically must be replaced every five to ten years. See Section 10 for
44 battery maintenance requirements.
45
46

47 **6.14 Utility Interactive Systems**

48
49 Utility-interactive PV power systems operate in parallel with the electric utility grid, and typically require

1 an inverter that performs several control and protection functions. Utility-interactive inverters monitor
2 the electric utility grid voltage and frequency to ensure stable operation. The inverter will only deliver
3 power to the system when the electric utility source is on-line and grid voltage and frequency is stable.
4

5 The inverter controls the delivery of solar power to the electric utility grid. The inverter controls the
6 conversion of DC power generated by one or more solar arrays to AC power, using the reference AC
7 voltage and frequency from the electric utility grid to create an AC waveform that is compatible with the
8 electric utility grid.
9

10 Utility-interactive power inverters protect the solar array from abnormal electric utility operation by
11 automatically disconnecting the solar array from the electric utility grid when there are variations in
12 voltage or frequency that could adversely affect or damage the solar array. Utility-interactive power
13 inverters protect the electric utility grid by automatically disconnecting the solar array from the electric
14 utility grid when there are abnormal operating conditions within the solar array.
15

16 Utility-interactive power inverters also protect the electric utility grid from backfeed by automatically
17 disconnecting the solar array from the electric utility grid when there is an electrical utility outage.
18

19 Many electric utility companies offer a net metering agreement for customers with PV power systems.
20

21 ***6.14.1 Net Metering***

22
23 Net metering is when a PV power system is interconnected to the electric utility grid through one electric
24 utility meter that monitors the two-way power transfer between the utility and the customer. When the
25 on-site solar power generation exceeds the customer's connected load, power is delivered from the
26 customer to the utility. When the customer's connected load exceeds the on-site solar power generation,
27 power is delivered from the utility to the customer.
28

29 Electric utility billing is based on the net difference between the power delivered from the utility to the
30 customer, and the power delivered from the customer to the utility. The customer is charged or credited
31 for the net flow of energy across the electric utility meter. Frequently, net metering agreements do not
32 provide for electric utility company payments for power exported to the electric utility grid but provide a
33 credit for excess power delivered to the grid that will expire if not used within a contractually-specified
34 period of time.
35

36 Not all electric utility companies offer net metering. When net metering is not offered, it may be
37 necessary to install a second electric utility meter for the PV power system (dual metering) to measure the
38 amount of energy produced by the system, and to make special arrangements with the electric utility
39 provider to receive credit for excess energy produced by the PV power system.
40

41 ***6.14.2 Dual Metering***

42
43 Dual metering is when the utility-interactive PV power system is connected to the electric utility grid
44 through a separate electric utility meter that monitors the one-way flow of power from the on-site solar
45 power system to the electric utility grid. Dual metering systems are used more frequently for large-scale
46 PV power systems. The use of separate metering provides the ability to assign different monetary values
47 to the electricity monitored by the different meters.
48
49

1 **6.15 Stand-Alone Systems**
2

3 All equipment used in a stand-alone PV system must be listed or field labeled for the intended use.
4

5 Premises wiring systems must be adequate to meet the requirements of the NEC for similar installations
6 supplied by a feeder or service. The wiring on the supply side of the building or structure disconnecting
7 means shall comply with the requirements of the NEC, except as modified below:

- 8 • Power supply to premises wiring systems shall be permitted to have less capacity than the
9 calculated load. The capacity of the stand-alone supply shall be equal to or greater than the load
10 posed by the largest single utilization equipment connected to the system. Calculated general
11 lighting loads shall not be considered as a single load.
- 12 • The circuit conductors between a stand-alone source and a building or structure disconnecting
13 means shall be sized based on the sum of the output ratings of the stand-alone sources.
- 14 • Stand-alone systems shall be permitted to supply 120 volts to single-phase, 3-wire, 120/240-volt
15 service equipment or distribution panels where there are no 240-volt outlets and where there are
16 no multiwire branch circuits. In all installations, the sum of the ratings of the power sources shall
17 be less than the rating of the neutral bus in the service equipment. This equipment shall be
18 marked with the following words or equivalent:

19
20 **WARNING:**
21 **SINGLE 120-VOLT SUPPLY. DO NOT CONNECT MULTIWIRE**
22 **BRANCH CIRCUITS!**
23

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

- 25 • Energy storage or backup power supplies are not required.
- 26 • Plug-in type back-fed circuit breakers connected to an interconnected supply shall be secured in
27 accordance with NEC Section 408.36(D). Circuit breakers marked “line” and “load” shall not be
28 back-fed.
- 29 • The stand-alone supply shall be controlled so that voltage and frequency remain within suitable
30 limits for the connected loads.

31
32
33 **6.16 Utility-Interactive Inverters**
34

35 Utility-interactive power inverters are solid-state devices that control and regulate the conversion of DC
36 power into a 60-Hertz AC voltage waveform in parallel with another AC source. Interactive inverters
37 have integral protection and control functions, including:

- 38 • Regulating the conversion of DC power through static switching of the rectifier to establish a
39 compatible 60-Hertz AC output voltage waveform.
- 40 • Synchronizing to the electric utility grid and maintaining a one-way power flow from the source
41 to the electric utility grid.
- 42 • Monitoring the bus voltage and frequency.
- 43 • Protecting the source and the grid from any faults, failures, or abnormal operating conditions,
44 including over- and under-voltage, over- and under-frequency, over-current, and over-
45 temperature.

46
47 Single-phase inverters must not be connected to three-phase power systems unless the system is designed
48 to prevent significant voltage imbalance. Likewise, three-phase inverters must automatically de-energize
49 upon the loss of one or more phases, or the imbalance of one or more phases unless the system is

1 designed to prevent significant voltage imbalance.
2

3 Utility-interactive power inverters have several operational limitations. First, inverters have a maximum
4 open-circuit voltage rating for passive sources that continue to generate voltage when they are
5 disconnected from the grid, such as PV modules. Second, because utility-interactive power inverters are
6 current-limited, they may not be capable of delivering sufficient short-circuit current to cause overcurrent
7 protective devices to operate to clear a fault and may shut down due to an under-voltage condition caused
8 by the fault. Additionally, sources connected to utility-interactive power inverters must be sized smaller
9 than the maximum DC current rating of the inverter.

10
11 Utility-interactive power inverters may be mounted on roofs or other exterior areas that are not readily
12 accessible. In these installations, the inverter must have DC disconnecting means and AC disconnecting
13 means mounted within sight of or within the inverter. An additional AC disconnecting means is required
14 to ensure that fuses, if installed, can be de-energized when disconnecting means are backfed.

15
16 Single-phase inverters for hybrid systems and AC modules in interactive hybrid systems shall be
17 connected to three-phase power systems in order to limit unbalanced voltages to not more than 3 percent.
18 Three-phase inverters and three-phase AC modules in interactive systems shall have all phases
19 automatically de-energized upon loss of, or unbalanced, voltage in one or more phases unless the
20 interconnected system is designed so that significant unbalanced voltages will not result.

21
22 Utility-interactive power inverters are limited by their voltage, current, and power ratings, and have
23 specific installation requirements for compliance with the National Electric Code.
24
25

26 ***6.16.1 Inverter Ratings*** 27

28 Inverters have both AC and DC voltage, current, and power ratings. The DC ratings are known as input
29 ratings, and the AC ratings are known as output ratings. Inverters also have a maximum open-circuit
30 voltage rating for PV sources that continue to generate voltage when they are disconnected from the grid.
31

32 The DC voltage rating of the inverter is typically a nominal voltage with a wide operating range,
33 sometimes of hundreds of volts, because of the variety of DC sources that can be connected to the electric
34 utility grid. For example, solar arrays will generate voltage near their peak voltage rating in full sunlight
35 but generate much lower levels during cloudy or overcast days or times when less light is available. Since
36 inverters have a wide operating range for DC voltage, they continue to deliver power to the grid when the
37 source voltage is low but still within the operating range of the inverter.
38

39 The AC voltage rating of the inverter is the nominal system voltage, including tolerances. The output AC
40 voltage waveform must be compatible with the electric utility grid. Similar to the grid, inverters typically
41 have operating tolerances of +10% and -5% of the nominal system voltage.
42

43 The DC current rating includes the maximum input current and short-circuit current ratings. Unlike many
44 AC sources used for distributed generation applications, DC sources are not capable of delivering high
45 short-circuit current. Consequently, the maximum input current and short-circuit current ratings of the
46 inverter are typically within a few percentage points of each other.
47

48 The output of a utility-interactive power inverter is considered continuous. A continuous load or source is
49 a load or source where the maximum current is expected to continue for three hours or more. A non-
50 continuous load or source is a load or source where the maximum current is expected to continue for less

1 than three hours.

2
3 The AC current rating of the inverter is the maximum continuous output current rating. Because solar
4 modules are current-limited, utility-interactive power inverters are current-limited. Consequently, the
5 available short-circuit current of a utility-interactive power inverter is limited to the continuous output
6 current rating of the inverter, and the inverter does not have a short-circuit current rating.

7
8 The DC power rating is determined using the maximum DC current rating and the minimum DC
9 operating voltage of the operating voltage range. The AC power rating is based on the maximum AC
10 continuous output current at the nominal voltage rating. The continuous power rating is the total power
11 that the inverter can supply indefinitely.

12
13 Inverters also typically have surge power ratings. The surge power rating is the amount of power that the
14 inverter can supply for brief periods of time for motor and transformer inrush currents. The surge power
15 rating is less critical for grid-connected distributed generation applications than for stand-alone operation.

16 17 18 **6.17 Sizing Conductors**

19
20 The size of ungrounded (or phase) conductors is determined from the maximum circuit current, which
21 includes multipliers such as for continuous loading, where applicable, and applying adjustment and
22 correction factors in accordance with the NEC.

23
24 The maximum input circuit current of a utility-interactive power inverter is the input current rating of the
25 inverter, and the maximum output circuit current is the continuous rated output current of the inverter.
26 PV sources must be rated less than the maximum DC current rating of the inverter.

27
28 Utility-interactive power inverter circuits are considered continuous when sizing conductors and
29 overcurrent protective devices. Circuit conductors and overcurrent devices must be sized to carry not less
30 than 125% of the maximum input and output current ratings of the inverter before applying adjustment
31 and correction factors. Circuit breakers that are listed for continuous operation can be applied at 100% of
32 their rating. Additionally, circuits containing an assembly, together with overcurrent devices, that is listed
33 for continuous operation at 100 percent of its rating is permitted to be used at 100 percent of its rating.

34
35 Size conductors in accordance with the NEC when applying adjustment and correction factors for
36 derating conductor ampacity due to ambient temperature, for more than three current carrying conductors
37 in a cable (or bundling or stacking of cables), and for rooftop installations where the distance above the
38 roof to the bottom of the raceway or cable is less than 23 mm (7/8 inch).

39
40 Conductors with temperature ratings higher than specified for the terminations may be used for ampacity
41 adjustment, correction, or both. The NEC permits conductor ampacities to be adjusted or corrected from
42 the 90°C column of NEC Table 310.15(B)(16) when applying adjustment and correction factors, provided
43 the derated ampacity is not less than the 60°C (140°F) ampacity of the conductor for equipment and
44 circuits rated 100 Amperes and less and the 75°C (167°F) ampacity of the conductor for equipment and
45 circuits rated over 100 Amperes. The grounded or neutral conductor is permitted to be increased in size
46 proportionately to the ungrounded or phase conductors when making ampacity adjustments, corrections,
47 or both.

48
49 PV power system circuits are considered continuous, and circuit conductors must be sized to carry not
50 less than 125% of the maximum circuit currents. The maximum current for the PV source circuit

1 currents, such as individual modules or modules connected in series, is the sum of parallel module rated
2 short-circuit currents multiplied by 125%. The maximum current for parallel source circuits is the sum of
3 the parallel source circuit maximum currents.
4

5 The inverter output circuit current rating is the continuous current output rating of the inverter. The
6 maximum stand-alone inverter input circuit current is the continuous input current rating of the inverter
7 when producing rated power at the lowest input voltage.
8

9 For a PV power source that has multiple output circuit voltages and employs a common-return conductor,
10 the ampacity of the common-return conductor must be sized not be less than the sum of the ampere
11 ratings of the overcurrent devices of the individual output circuits. Where a single overcurrent device is
12 used to protect a set of two or more parallel-connected module circuits, the ampacity of each of the
13 module interconnection conductors must be sized not be less than the sum of the rating of the single fuse
14 plus 125% of the short-circuit current from the other parallel-connected modules.
15

16 Flexible cords and cables are permitted to be used to connect moving parts of tracking solar arrays. The
17 allowable ampacities of such cords and cables must be in accordance with the NEC and must be derated
18 by the appropriate factors given in NEC Table 690.31(C) for ambient temperatures exceeding 30°C
19 (86°F).
20

21 The neutral conductor for a single-phase, two-wire inverter output connected to the neutral and one
22 ungrounded conductor (only) of a three-wire system, or of a three-phase four-wire wye-connected system
23 must be not less than the maximum load connected between the neutral and any one ungrounded
24 conductor, and the inverter output rating must not exceed the ampacity of the neutral conductor.
25

26 In general, the grounded conductor of a utility-interactive power inverter should be the same size as the
27 ungrounded conductors. In all cases, the output current of an inverter should not exceed the ampacity of
28 the grounded conductor.
29

30 The grounded or reference conductor of a bipolar PV array should be the same size as the ungrounded
31 conductors. For a PV power source that has multiple output circuit voltages and employs a common-
32 return conductor, the ampacity of the common-return conductor must not be less than the sum of the
33 ampere ratings of the overcurrent devices of the individual output circuits.
34

35 The grounded conductor is permitted to be increased in size proportionately to the ungrounded conductors
36 when the ungrounded conductors are increased in size in accordance with the cross-sectional area to
37 compensate for heating effects from continuous loading, more than three current-carrying conductors in a
38 common raceway, roof-top heating effects, and/or high ambient temperature (see Section 6.4).
39

40 For PV systems with a generating capacity of less than 100 kW, maximum PV source circuit currents are
41 calculated from the sum of the parallel-connected PV module rated short-circuit currents multiplied by
42 125 percent.
43

44 For PV systems with a generating capacity of 100 kW or greater, a documented and stamped PV system
45 design is permitted to determine PV source circuit currents. The calculated maximum current value shall
46 be based on the highest 3-hour current average resulting from the simulated local irradiance on the PV
47 array accounting for elevation and orientation. The current value used by this method shall not be less
48 than 70 percent of the value calculated for PV systems with a generating capacity of less than 100 kW.
49

1 The maximum PV output circuit current is the sum of parallel source circuit maximum currents as
2 calculated above.

3
4 The maximum DC-to-DC converter source circuit current is the DC-to-DC converter continuous output
5 current rating.

6
7 The maximum DC-to-DC converter output circuit current is the sum of parallel connected DC-to-DC
8 converter source circuit currents as calculated above.

9
10 Circuit conductors shall be sized to carry not less than the larger of the maximum calculated PV source
11 circuit currents or the maximum calculated PV output circuit current, or where protected by a listed
12 adjustable electronic DC overcurrent protective device in accordance NEC Section 690.9(B)(3), not less
13 than the maximum calculated inverter output circuit current.

14 15 16 **6.18 Disconnecting Means**

17
18 In general, disconnecting means are required to de-energize and isolate equipment for maintenance,
19 testing, and repairs at the location where the work is to be performed. Disconnecting means are usually
20 installed in circuits with a one-way flow of electricity from the electric utility source toward the load.
21 Because PV power systems have the possibility of backfeeding circuits and equipment, disconnecting
22 means for PV power system applications have special requirements.

23
24 In addition to the requirements for service disconnecting means for the electric utility supply, PV power
25 systems are required to have disconnecting means to simultaneously disconnect all ungrounded
26 conductors of the PV source from all other conductors. In short, separate disconnecting means are
27 required for PV supply conductors and for utility source supply conductors to de-energize and isolate
28 equipment connected to the electrical power distribution system between those separate sources.

29
30 The disconnecting means for ungrounded conductors of a PV power source shall consist of manual or
31 power operated switches or circuit breakers that comply with the following:

- 32 • Located where readily accessible
- 33 • Externally operable without exposing the operator to contact with live parts and, if power
34 operated, of a type that is opened by hand in the event of a power-supply failure
- 35 • Clearly indicate whether in the open (off) or closed (on) position
- 36 • Have ratings sufficient for the maximum circuit current, available short-circuit current, and
37 voltage that is available at the terminals
- 38 • Where the line and load terminals are capable of being energized in the open position, marked in
39 accordance with the warning in NEC Section 690.13(B). *NOTE: In parallel generation systems,*
40 *some equipment, including knife blade switches and fuses, is likely to be energized from both*
41 *directions.*
- 42 • Simultaneously disconnect all ungrounded conductors of the circuit
- 43 • Be lockable in the open (off) position.

44
45 In addition, the disconnecting means must be suitable for the installed environment and identified as a PV
46 system disconnect.

47
48 When the PV system is connected to the supply side of the service disconnecting means as permitted by
49 the NEC, the PV system disconnecting means shall be listed as suitable for use as service equipment.

1 The local electrical utility company may have additional requirements for disconnecting means for PV
2 power system applications.

3
4 The disconnecting means for PV power generation systems have the potential hazard of both the line and
5 load terminals being energized with the disconnecting means open. Disconnecting means energized from
6 both the line and load sides must have a marking to indicate that all contacts of the disconnect equipment
7 might be energized when in the “open” or “off” position. Additional disconnecting means are required to
8 de-energize and isolate equipment subject to backfeeds.

9 10 11 **6.19 Overcurrent Protection**

12
13 Provide overcurrent protection of PV power system circuits in accordance with NEC Article 240, NEC
14 Article 690, and NEC Article 705.

15
16 PV power system circuits are considered to be continuous. Therefore, overcurrent protective devices are
17 sized for not less than 125% of the maximum current ratings of the circuits. Circuit breakers that are
18 listed for continuous operation can be applied at 100% of their rating. Series-connected solar modules are
19 permitted to be protected by a single overcurrent protective device. Supplementary overcurrent protective
20 devices are permitted within PV source circuits, such as between solar modules, series-strings of modules,
21 and parallel-connected modules.

22
23 Equipment and conductors connected to more than one electrical source must have a sufficient number of
24 overcurrent devices located so as to provide protection from all sources.

25
26 Overcurrent protection for electric power production source conductors, such as PV source circuits,
27 connected to the supply side of the service disconnecting means shall be located within 3 m (10 ft) of the
28 point where the electric power production source conductors are connected to the service. *NOTE: This*
29 *overcurrent protection protects against short-circuit current supplied from the primary source(s) of*
30 *electricity.*

31
32 Where ground-fault protection is used, the output of an interactive system shall be connected to the
33 supply side of the ground-fault protection. Connection is permitted to the load side of ground-fault
34 protection if there is ground-fault protection for equipment from all ground-fault current sources.

35
36 Overcurrent protection of a transformer supplied by a PV power system on one side and another electric
37 power production source on the other must have overcurrent protection; the overcurrent protection must
38 be evaluated by considering each side of the transformer as the primary source of power. With a few
39 exceptions, this requirement essentially means that transformers installed in distributed generation
40 applications will have both primary and secondary overcurrent protection.

41
42 Overcurrent devices, either fuses or circuit breakers, used in any DC portion of a utility-interactive
43 inverter power system must be listed for use in DC circuits and must have the appropriate voltage,
44 current, and interrupt ratings.

45
46 Install ground-fault protection for PV power systems in accordance with the NEC.

47 48 49 **6.20 Grounding and Bonding**

1
2 Ground PV systems in accordance with manufacturer recommendations and applicable NEC requirements
3 for system grounding. Unless installing an ungrounded PV system, one conductor of a two-wire system
4 with a PV system voltage of over 50 volts, and the reference (center tap) conductor of a bi-polar system
5 must be solidly grounded or must use other methods that accomplish equivalent system protection in
6 accordance with NEC Article 250 and Article 690, and must use equipment listed and identified for the
7 purpose. Interconnected battery cells are considered grounded when the PV power source is grounded in
8 this manner.

9
10 The equipment grounding conductors for the PV array and structure, where installed, must be contained
11 within the same raceway or cable or otherwise run with the PV array circuit conductors when those
12 conductors leave the vicinity of the PV array.

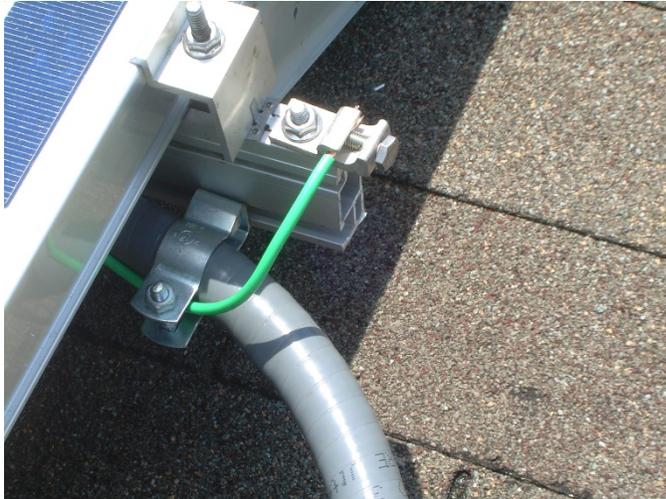
13
14 The connection to ground is permitted at any single point on the PV output circuit. Locating the
15 grounding connection as close as is practical to the PV source provides improved system protection from
16 lightning voltage surges. The grounding connection is permitted to be made at the ground-fault protection
17 equipment location, when installed. Do not provide an external grounding connection when the
18 grounding connection is internal to ground-fault equipment.

19
20 Ground all non-current-carrying metal components of PV systems, including PV module frames,
21 electrical equipment and conductor enclosures. Provide an equipment grounding conductor between each
22 PV array and other equipment.

23
24 The metallic frames of PV modules or other equipment are permitted to be bonded to exposed metal
25 surfaces or other equipment to mounting structures. Metallic mounting structures other than building
26 steel used for grounding purposes must be identified as equipment grounding conductors or must have
27 identified bonding jumpers or devices connected between the separate metallic sections, and must be
28 bonded to the grounding system. Use only devices listed and identified for grounding and bonding. See
29 Figures 6.20.1 and 6.20.2 for examples of equipment grounding and bonding connections.
30



31
32
33 Figure 6.20.1 Grounding is required for photovoltaic systems and metal parts of equipment associated
34 with a photovoltaic installation.
35



1
2
3 Figure 6.20.2 Use grounding terminals and means of connection suitable for the environment where they
4 are installed.

5
6 Size PV equipment grounding conductors in accordance with NEC Article 250. The equipment
7 grounding conductor must be no smaller than 14 AWG and is not required to be increased in size for
8 voltage drop considerations. Where no overcurrent protective device is provided, size equipment
9 grounding conductors in accordance with NEC Article 250 considering the PV short circuit rating as the
10 overcurrent protective device rating.

11
12 Where ground-fault protection is not provided in other than dwelling units, size equipment grounding
13 conductors a minimum of twice as large as the ungrounded conductor ampacity after applying adjustment
14 and correction factors.

15
16 Protect PV equipment grounding conductors smaller than 6 AWG from physical damage by an identified
17 raceway or cable armor unless within hollow spaces of the framing members of building or structures and
18 where not subject to physical damage where PV equipment grounding conductors are not routed with
19 circuit conductors.

20
21 Provide DC ground-fault protection for grounded DC PV arrays in accordance with the NEC. Ground-
22 fault protection must be capable of detecting ground-fault current, interrupting the flow of current, and
23 providing an indication of the fault. If the grounded or neutral conductor is opened to interrupt the
24 ground-fault current, all conductors of the faulted circuit must open simultaneously. PV DC ground fault
25 detection must be listed for providing PV ground-fault protection.

26
27 Manual operation of the main PV DC disconnect must not activate the ground-fault protection system or
28 cause grounded conductors to become ungrounded. Isolation of faulted circuits is permitted to be by
29 automatic disconnection of the ungrounded conductors or by automatic shutdown of the inverter or charge
30 controller. Ground-fault protection systems must be labeled at the batteries, if installed, and at the
31 inverter or near the ground-fault indicator at a visible location, stating, "WARNING: ELECTRIC
32 SHOCK HAZARD IF A GROUND FAULT IS INDICATED, NORMALLY GROUNDED
33 CONDUCTORS MAY BE UNGROUNDED AND ENERGIZED."
34

35 Ungrounded PV systems also require a ground-fault protection system that detects a ground fault,
36 provides indication that a ground fault has occurred, and automatically disconnects all conductors or

1 causes the inverter or charge controller connected to the faulted circuit to automatically cease supplying
2 power to output circuits.

3
4 Alternating-current (AC) PV modules are permitted to use a single ground-fault detection device to detect
5 only AC ground faults and to disable the array by removing AC power to the AC modules.

6
7 Provide an AC grounding electrode system for buildings or structures supporting a PV array in
8 accordance with NEC Article 250. Provide a DC grounding electrode system in accordance with NEC
9 Article 250 for grounded and ungrounded systems. Install grounding electrode conductors in accordance
10 with NEC Article 250. Connect the AC and DC grounding electrodes together with a suitably sized
11 bonding jumper. See Figure 6.20.3 for an example line diagram (concept only).
12

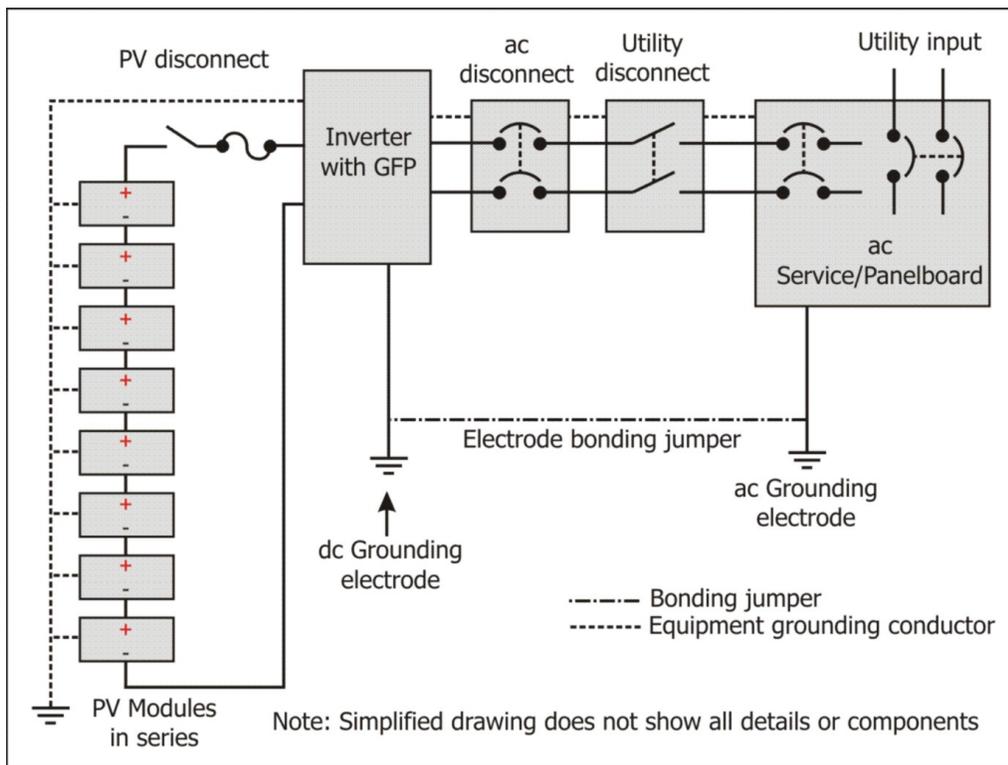


Figure 6.20.3 Bond DC system electrode(s) to AC system grounding electrode(s) [Note: Simplified drawing provides concepts only and is not intended to serve as a complete schematic for every system]

A common DC grounding electrode is permitted to server multiple inverters provided the grounding electrode conductor and grounding electrode tap conductors are sized in accordance with NEC Article 250. Grounding electrode tap conductors must be connected to the common grounding electrode conductor by exothermic welding or with listed grounding and bonding connectors in such a manner that the common grounding electrode conductor remains without a splice or joint.

Provide a DC grounding electrode system where PV systems have both DC and AC circuits where there is no direct connection between the DC grounded conductor and the AC grounded conductor. Bond the DC grounding electrode system to the AC grounding electrode system. The bonding jumper between the AC and DC grounding electrode systems is sized as the larger of the DC requirement for the PV

1 equipment grounding conductor, the AC requirement for the inverter AC output overcurrent protective
2 device, and NEC Table 250.122.

3
4 Supplemental grounding electrodes are permitted at the location of ground and pole-mounted PV arrays
5 and as close as practicable to the location of roof-mounted PV arrays, unless the structures, poles, and
6 metal frames of buildings are considered grounding electrodes. Supplemental electrodes are permitted to
7 be connected directly to the frames and supporting structures of the array.

8
9 The equipment grounding conductor is permitted to serve the multiple functions of DC grounding, AC
10 grounding, and bonding between AC and DC systems, provided that the conductor is sized for the
11 maximum applied current from the functions served.

12
13 A common ground bus is permitted to be used for both the AC and DC systems. Likewise, a common
14 grounding electrode is permitted to be used for both systems. In this instance, the grounding electrode
15 conductor must be connected to the AC ground system bonding point. The grounding electrode must be
16 sized to meet the requirements of both AC systems and DC systems.

17 18 19 **6.20.1 Surge Protective Devices (SPDs)**

20
21 Surge protection of PV systems is optional equipment that is selected as part of the design. When
22 installing SPDs, follow the manufacturer's installation instructions.

23 24 25 **6.20.2 Ungrounded Solar Photovoltaic Power Systems**

26
27 Ungrounded solar photovoltaic power systems are permitted to have ungrounded sources and output
28 circuit conductors, provided the system has:

- 29 • Disconnecting means for all solar photovoltaic sources and output circuit conductors
- 30 • Overcurrent protection for solar photovoltaic sources and output circuit conductors
- 31 • Ground-fault protection for solar photovoltaic sources and output circuits that detects a ground
32 fault, indicates that a ground fault has occurred, and automatically disconnects all conductors or
33 causes the inverter or charge controller connected to the faulted circuit to automatically cease
34 supplying power to output circuits

35
36 Ungrounded solar photovoltaic source conductors must be non-metallic-jacketed multiconductor cables,
37 conductors installed in raceways, or conductors listed and identified as solar photovoltaic (PV) wire when
38 installed as exposed, single conductors. Ungrounded DC solar photovoltaic power systems are permitted
39 to be operated with ungrounded battery systems.

40
41 An ungrounded solar photovoltaic power source must be labeled with the following or an equivalent
42 warning at each junction box, combiner box, disconnect, and device where energized, ungrounded circuits
43 may be exposed during service: "Warning – electric shock hazard. The DC conductors of this solar
44 photovoltaic system are ungrounded and may be energized." The inverters or charge controllers used in
45 ungrounded solar photovoltaic source and output circuits must be listed for the purpose.

46 47 48 **6.21 Rapid Shut Down**

1 PV system circuits installed on or in buildings are required to have a rapid shutdown function to reduce
2 shock hazard for emergency responders, with the exception that ground mounted PV system circuits that
3 enter buildings, of which the sole purpose is to house PV system equipment, are not required to have a
4 rapid shutdown function. PV circuit conductors supplied by the PV system are required to be controlled
5 by the rapid shutdown system.
6

7 Controlled PV circuit conductors located outside a boundary of 3 m (1 ft) from the array in all directions
8 or more than 1 m (3 ft) from the point of entry inside a building is limited to not more than 30 volts within
9 30 seconds of rapid shutdown initiation. Voltage is measured between any two conductors and between
10 any conductor and ground.
11

12 Controlled PV circuit conductors located inside a boundary of 3 m (1 ft) from the array in all directions
13 must comply with one of the following:

- 14 • The PV array must be listed or field labeled as a rapid shutdown PV array. Such a PV array must
15 be installed and used in accordance with the instructions included with the rapid shutdown PV
16 array listing or field labeling. *NOTE: A listed or field labeled rapid shutdown PV array is*
17 *evaluated as an assembly or system as defined in the installation instructions to reduce but not*
18 *eliminate risk of electric shock hazard within a damaged PV array during fire-fighting*
19 *procedures. Rapid shutdown PV arrays are designed to reduce shock hazards by methods such*
20 *as limiting access to energized components, reducing the voltage between energized components,*
21 *limiting the electric current that might flow in an electrical circuit involving personnel with*
22 *increased resistance of the conductive circuit, or by a combination of such methods.*
- 23 • Controlled conductors located inside the boundary or not more than 1 m (3 ft) from the point of
24 penetration of the surface of the building must be limited to not more than 80 volts within 30
25 seconds of rapid shutdown initiation. Voltage is measured between any two conductors and
26 between any conductor and ground.
- 27 • PV arrays with no exposed wiring methods, no exposed conductive parts, and installed more than
28 2.5 m (8 ft) from exposed grounded conductive parts or ground are not required to comply with
29 NEC 690.12(B)(2). *NOTE: The requirement of NEC 690.12(B)(2) become effective January 1,*
30 *2019.*
31

32 The initiation device(s) initiate the rapid shutdown function of the PV system. The device “off” position
33 indicates that the rapid shutdown function has been initiated for all PV systems connected to that device.
34 For one-family and two-family dwellings, an initiation device(s) is located at a readily accessible location
35 outside the building. The rapid shutdown initiation device(s) consist of at least one of the following:

- 36 • Service disconnecting means
- 37 • PV system disconnecting means
- 38 • Readily accessible switch that plainly indicates whether it is in the “off” or “on” position
39

40 Equipment that performs the rapid shutdown functions, other than initiation devices such as listed
41 disconnect switches, circuit breakers, or control switches, shall be listed for providing rapid shutdown
42 protection. *NOTE: Inverter input circuit conductors often remain energized for up to 5 minutes with*
43 *inverters not listed for rapid shutdown.*
44
45

46 **7. Installing PV Power Systems**

47 **7.1 General**

1
2 Review installation instructions for each component to become familiar with the installation process.
3 Comply with all warning and safety labels.
4
5 Determine the physical size and dimensions of the PV array and its primary components (See Annex A)
6 to determine where the array and ancillary equipment will be mounted. Examine location options for
7 mounting the array.
8
9 Develop a preliminary drawing or sketch of the solar panel lay out on the roof or other structure.
10 Determine any potential conflict with the proposed solar panel locations from any existing or potential
11 plumbing, ventilation, or electrical penetrations of the roof. Determine the locations of any plumbing or
12 combustible appliance vents that will impact the placement or shading of any solar panels.
13
14 Where such conflicts exist, determine whether it is possible to relocate obstructions to another portion of
15 the roof. Ensure that the layout of the solar array provides the required space for circulation around solar
16 panels, for access for firefighting and smoke ventilation and for emergency egress from the roof in
17 accordance with local codes. Locate roof access points where the building is structurally sound, where
18 not in conflict with overhead obstructions, such as power lines or tree limbs, and where ladders are not
19 placed over openings, such as doors or windows.
20
21 Where possible, configure solar panels following the dimensional shape of the roof, such as providing a
22 rectangular array layout for rectangular roofs. Arrange solar panels symmetrically and group connection
23 points for ease of installation and wiring.
24
25 Solar panels will develop DC open circuit voltage at connecting cable terminations when exposed to
26 sunlight. Considering using open circuit or short-circuiting methods to disable an array or portions of an
27 array for installation and service. For very small systems, cover solar panels with dark opaque sheeting
28 before making connections to prevent the possibility of high DC open circuit voltages at the connecting
29 cable terminations. For larger systems, open all disconnects and fuse holders, and remove all fuses in the
30 photovoltaic system.
31
32 Examine the main electrical service panel to determine if the panel has sufficient space or spare circuit
33 breakers to install the circuit breaker for the PV power system. If adequate space is not available, consult
34 the panel manufacturer for alternatives to replacing the panel. If the system includes a critical load sub-
35 panel, such as for a standby battery system, determine which circuits are considered to be essential (See
36 NECA 406 for a discussion of determining what are considered to be essential loads and sizing critical
37 load sub-panels). The critical load sub-panel must be adequately designed to handle the anticipated
38 electrical loads. Determine the location of the critical load sub-panel. Install the critical sub-panel and
39 relocate the essential circuits to the sub-panel.
40
41 Check that the open-circuit voltage of the solar panels connected in series does not exceed the DC
42 operating voltage range of the inverter. See Annex A. Do not exceed the inverter manufacturer's
43 recommended maximum voltage. For two-wire circuits connected to a bipolar PV system, the maximum
44 system voltage is considered the highest voltage between the conductors of the two-wire circuit if one
45 conductor of a bipolar subarray is solidly grounded, each circuit is connected to a separate subarray, and
46 the equipment is clearly marked with a label stating as indicated in Figure 7.1.1.
47



1
2
3 Figure 7.1.1 Typical warning label identifying a bipolar photovoltaic array or system

4
5 Check that the total current of the array is within the power ratings of the inverter. Additional inverters
6 may be required to increase the power capacity of the solar photovoltaic power system.

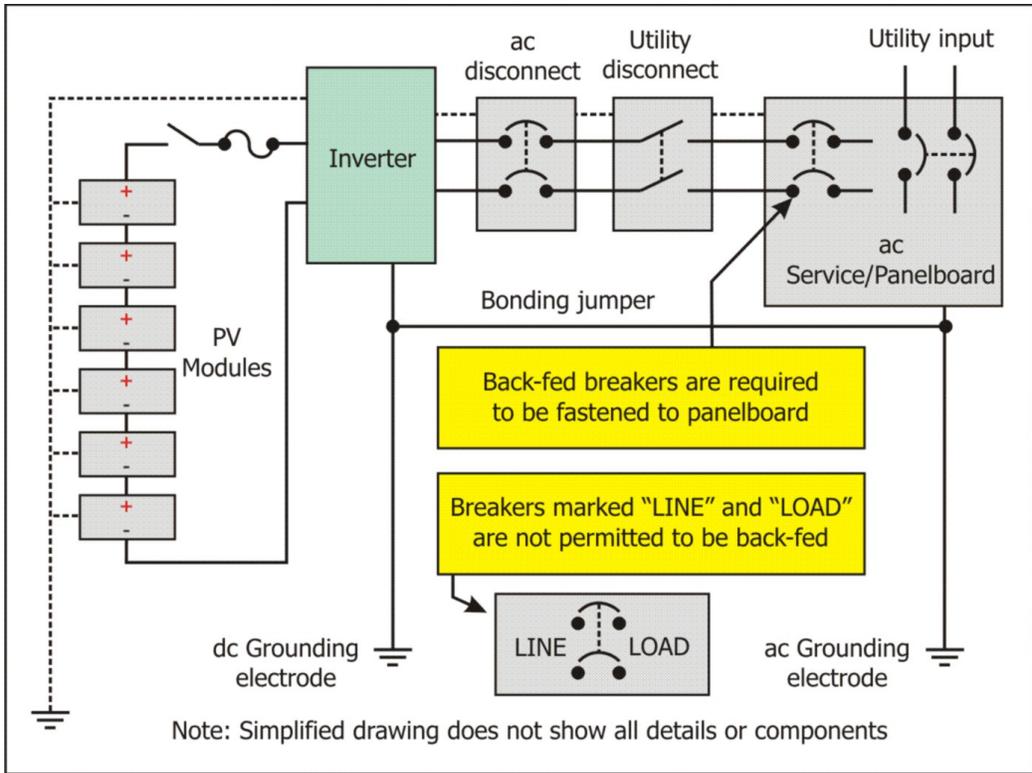
7
8 Arrange the connections to solar modules or panels so that removal of a module or panel from a PV
9 source circuit does not interrupt a grounded conductor or neutral to other PV source circuits during
10 operation. Note that during construction, service, or maintenance, it may be necessary to temporarily
11 open grounded circuits, but these circuits should not be left in an open state.

12
13 Photovoltaic system currents are considered to be continuous where the maximum load current is
14 expected to continue for more than 3 hours. The maximum circuit current for PV source and PV output
15 circuits is 125 percent of the sum of the parallel module rated short-circuit currents. The maximum
16 inverter output circuit current is the inverter continuous output current rating. For standalone inverters,
17 the maximum input circuit current is the standalone continuous inverter input current rating when the
18 inverter is producing rated power at the lowest input voltage.

19
20 Install conductors with ampacity of 125 percent of the maximum circuit current without any additional
21 correction factors for conditions of use, or with ampacity equal or greater than the maximum currents
22 calculated after conditions of use have been applied. Where a common return conductor is installed for
23 PV systems with multiple output circuit voltages, the ampacity of the common return conductor must be
24 not less than the sum of the ampere ratings of the overcurrent devices of the individual output circuits.

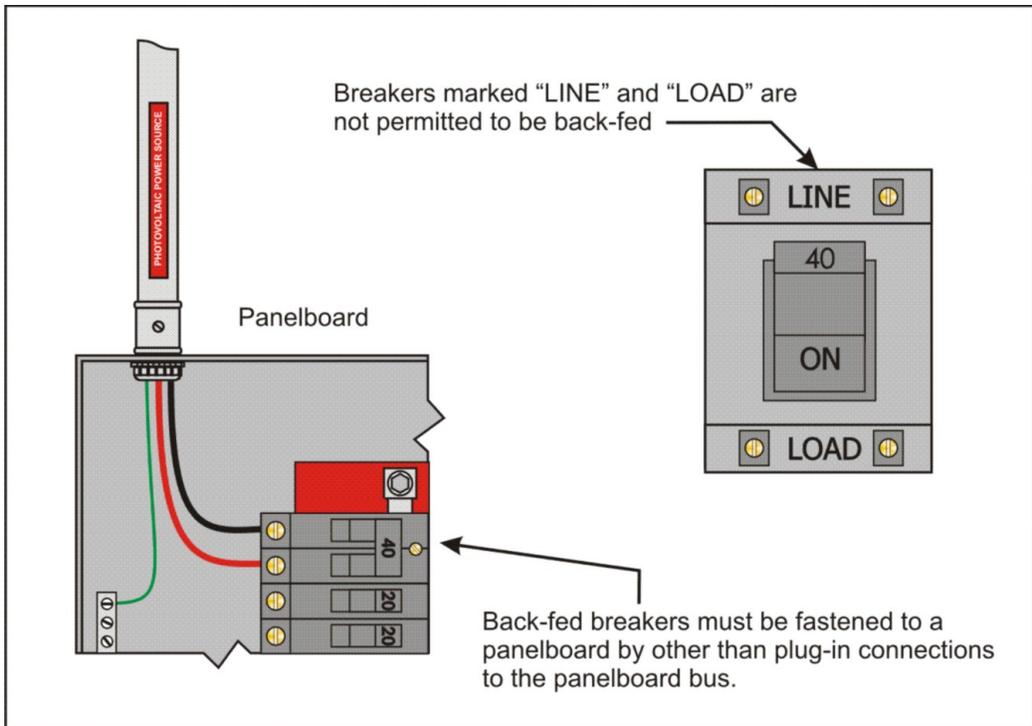
25
26 Overcurrent protective devices must be rated to carry not less than 125 percent of the maximum circuit
27 current, unless the device is rated for continuous operation at 100 percent of its rating. Observe the
28 terminal temperature limitations and apply the manufacturer's temperature correction factors when
29 operated at temperatures greater than 40°C. Install overcurrent protection to protect PV conductors within
30 their ampacity. Overcurrent protective devices must be listed for use in DC circuits when used in any DC
31 portion of a PV system, and must have appropriate voltage, current and interrupt ratings.

32
33 Secure plug-in type overcurrent protective devices that are back-fed and used to terminate field-installed
34 ungrounded supply conductors using an additional fastener that requires other than a pull to release the
35 device from the mounting means on the panel. Do not backfeed circuit breakers that are marked "LINE"
36 and "LOAD." See Figures 7.1.2 and 7.1.3 for examples of back-fed circuit breakers and use
37 requirements.
38



1
2
3
4

Figure 7.1.2 Back-fed breakers must be securely fastened to panelboards.



5
6
7

Figure 7.1.3 Breakers marked "LINE" and "LOAD" are not permitted to be back-fed.

1
2 Provide a listed DC arc-fault circuit protection, PV type, or other system components listed to provide
3 equivalent protection for PV systems with DC source circuits and/or DC output circuits that operate at
4 80VDC or greater that penetrate a building. The DC arc-fault protection system must detect and interrupt
5 arcing faults resulting from a failure in the intended continuity of a conductor, connection, module or
6 other system component in the DC PV source and output circuits.
7

8 The arc-fault protection system is permitted to disable or disconnect inverters or charge controllers
9 connected to the faulted circuit when the fault is detected, or to disable or disconnect system components
10 within the arcing circuit. The arc-fault protection system must be manually reset and must have a visual
11 indication that the circuit interrupter has operated that must also be manually reset. Note at the time of
12 publication, there are no listed devices for this purpose.
13

14 Label each junction box, combiner box, disconnect and device where energized, ungrounded circuits of
15 the PV power source may be exposed during service with, "WARNING. ELECTRIC SHOCK HAZARD.
16 THE DC CONDUCTORS OF THIS PHOTOVOLTAIC SYSTEM ARE UNGROUNDED AND MAY
17 BE ENERGIZED."
18

19 Photovoltaic systems with a maximum system voltage over 600VDC must comply with NEC Article 490
20 for equipment rated over 600 V nominal.
21
22

23 **7.2 Installing PV Arrays** 24

25 *NOTE: The design and installation of the foundation and structural support for PV power systems is*
26 *beyond the scope of this Standard.*
27

28 PV array foundation and support depends on the type of mounting, either ground- or roof-mounted, the
29 size of the array, local wind and snow loading conditions, the tilt of the array, and whether a tracking
30 system is installed. *NOTE: Tracking systems are typically required for a flat-plate collector array,*
31 *which incorporates optical components to direct and concentrate light onto the solar cells to maximize*
32 *PV power production. Concentrator arrays use only direct sunlight and must directly face or track the*
33 *sun. Concentrator arrays are more complex to design than flat-plate arrays because of the necessity of a*
34 *tracking system, but because concentrator arrays intensify direct sunlight, a much smaller concentrator*
35 *array can be installed than if installing a flat-plate array for a given application.*
36

37 Install foundation and structural supports in accordance with manufacturer instructions and contract
38 documents, drawings and specifications.
39

40 Inspect roofs for flatness when installing roof-mounted solar panels. Any noticeable concave sections of
41 a roof may be an indication of underlying structural and support defects in the roof and should be
42 investigated and repaired prior to installing solar panels.
43

44 Coordinate the installation of roof-mounted solar panels with the roofing installer for the installation of
45 anchors and supports during new roof installation, and to repair and weather seal penetrations on an
46 existing roof.
47

48 Ensure that ground-mounted PV arrays are located a minimum of ten feet away from low-level shrubs,
49 brush, and trees.
50

1 Install mounts and supports for solar arrays in accordance with manufacturer recommendations. For roof-
2 mounted arrays, use the minimum number of attachment points and roof penetrations necessary for
3 structural loading. When possible, install roof mounts before the roof is installed. Locate rafters or roof
4 joists using a stud finder or similar method. Install mounts and supports approximately 48 inches on
5 center and aligned directly over rafters or joists. Where rafters or joists are not available, install wood
6 blocking on the underside of the roof plywood sheathing to secure mounts and supports. Do not attach
7 mounts and supports directly to the plywood sheathing of the roof. Ensure that mounts and supports are
8 installed in a straight line using a chalk line, laser sight or similar method. Drill pilot holes for mounting
9 hardware to prevent rafters and joists from splitting.

10
11 Secure mounting and support bases to the roof using stainless steel hardware, such as lag bolts bolted
12 through the rafters or "J-bolts" that hook around the rafters. Install metal flashings around each mount to
13 prevent leaks in the roof. Attached the structural supports to the roof mounts with stainless steel bolts,
14 washers and nuts.

15
16 The structural supports for surface-mounted solar arrays are typically two perpendicular sets of metal
17 rails. The first set of rails provides the structural connection to the roof. The second set of rails provides
18 the proper width spacing for attaching the solar panels. The combination of the two sets of rails ensures
19 that the solar panels will be mounted a minimum of three to six inches off of the roof for ventilation and
20 free circulation of air, which improves the operational efficiency of surface-mounted solar panels. Secure
21 the solar panels to the structural support system using the specially-designed restraining hardware and
22 clamps supplied with the panels. Test each solar panel to ensure that they are securely anchored.

23
24 For structural supports and pole-mounted solar arrays located on the ground, provide foundation pads or
25 pole supports in accordance with manufacturer recommendations.

26
27 Adjust the tilt angle of adjustable PV arrays in accordance with manufacturer instructions, contract
28 documents, drawings and specifications, and owner requirements. In the absence of such guidance, for
29 maximum solar power generation, adjust the tilt angle of the solar panels to receive the maximum amount
30 of sun. The optimal tilt angle of the array depends upon the site latitude of the installation location. In
31 general, for solar arrays installed between 0 and 15 degrees site latitude, the recommended tilt angle of
32 the array is 15 degrees. For solar arrays installed between 15 and 40 degrees site latitude, the
33 recommended tilt angle of the array is the same angle as site latitude. For solar panels installed at site
34 latitudes of greater than 40 degrees, the recommended tilt angle is 60 degrees.

35
36 Check solar panels for damage prior to installation, such as cracks, dents, and discoloration. Measure the
37 open circuit voltage and short circuit current of each solar panel to ensure proper operation prior to
38 installation.

39
40 Install solar panels to structural supports in accordance with manufacturer instructions.

41 42 43 **7.3 Installing Inverters and Charge Controllers**

44
45 Utility-interactive inverters are permitted to be installed in not readily accessible locations, such as on a
46 roof or other exterior location. When inverters are installed in not readily accessible locations, mount
47 both the DC and AC disconnecting means within sight of the inverter, and install a permanent plaque or
48 directory that denotes all electric power sources on or in the premises at each service equipment location
49 and at locations of all electric power production sources capable of being interconnected.



1
2
3 Figure 7.3.1 Typical inverter nameplate information for small photovoltaic system

4
5 Check that the maximum voltage and current ratings of each array are within the ratings of the inverter or
6 charge controller. See Figure 7.3.1 for an example of an inverter nameplate for a PV system. Check that
7 the impedance at the inverter AC terminals is within manufacturer's recommended tolerances. *NOTE:*
8 *Some manufacturers require 1 ohm or less impedance for proper operation.*

9
10 Install inverters and charge controllers in a location sheltered from direct sunlight that provides adequate
11 ventilation. *NOTE: Environmental factors that influence inverter and charge controller operating*
12 *temperature include ambient temperature, airflow, exposure to sunlight, input voltage, input power, and*
13 *orientation of the heatsink fins. Inverters and charge controllers lose efficiency and operate at reduced*
14 *capacity when exposed to sunlight or excessive heat, such as from insufficient ventilation.* Install
15 inverters and charge controllers in a suitable location, away from the elements, such as excessive dust,
16 rain, and snow. Check that the ambient temperature in the installed location does not exceed the
17 manufacturer recommended operating temperature range of the inverter or charge controller.

18
19 Mount inverters and charge controllers to maintain the manufacturer recommended clearances for proper
20 airflow and with sufficient space for the installation of conduits, cables, and conductors, and for
21 maintenance. Install inverters and charge controllers at a suitable height to facilitate reading of the front
22 display and the status LED's.

23
24 Install inverters and charge controllers in a vertical position using a mounting template, if provided.
25 Derate inverters and charge controllers for installation other than vertical in accordance with
26 manufacturer instructions, when permitted. Mount inverters and charge controllers to a structural surface
27 using stainless steel mounting hardware. Follow manufacturer instructions for installing anchors and
28 fasteners.

1 Install multiple inverters or charge controllers in accordance with manufacturer recommendations,
2 keeping in mind that some manufacturers do not recommend mounting multiple devices side-by-side, but
3 staggered in rows where no device is installed directly above another.

4
5 Mount inverters and charge controllers before terminating any conductors. Remove access covers to
6 expose wiring terminal blocks and conduit access locations. Connect solar array conductors to the
7 inverter or charge controller in accordance with manufacturer recommendations.

8
9 Connect the inverter or charge controller to the electrical power distribution system only after receiving
10 authorization from the local electrical utility provider.

13 7.4 Disconnecting Means

14
15 Provide disconnecting to disconnect all current-carrying DC conductors of the PV system, such as
16 inverters, batteries, charge controllers, and the like, from all other conductors of all sources.
17 Disconnecting means are not normally permitted to switch the grounded or neutral conductor if the
18 operation of the disconnecting means leaves the grounded or neutral conductor in an ungrounded and
19 energized state. See Figure 7.4.1 for an example of a disconnecting means that does not switch the
20 grounded conductor.



22
23
24 Figure 7.4.1 Disconnecting means typically not permitted to break the grounded (usually the neutral)
25 conductor. (Courtesy of NJATC)

26
27 Disconnecting means are required:

- 28 • To disconnect a PV power system from the electric utility grid.
- 29 • To disconnect batteries, when installed, from the charge controller.
- 30 • To disconnect each solar array from the inverter or charge controller. See Figure 7.4.2 for an
31 example of an array disconnect ahead of the inverter.

- To de-energize fuses that are supplied from each side and are accessible to unqualified personnel. Frequently, overcurrent protective devices are used as disconnecting means. In the case where a fused disconnect switch is used on a PV power system, the fuses may remain energized due to a backfeed when the switch is opened. In this case, a second safety switch is required to disconnect the fuses from the backfeed source of energy.



Figure 7.4.2 Disconnect means to disconnect the inverter from the array (Courtesy of Central Florida Electrical JATC)

Each PV system disconnecting means must plainly indicate whether in the open (off) or closed (on) position and must be permanently marked “PV SYSTEM DISCONNECT” or equivalent.

Local codes may require additional disconnecting means for the protection of emergency personnel, such as a separate emergency disconnect on the roof to disconnect each solar array, or a main separate emergency disconnect to disconnect interior and exterior wiring running to the inverter. Emergency disconnects should be accessible to the fire department and located together, when possible.

Many times, the inverter is located near the main service panel and the AC circuit breaker where the inverter connects to the service panel serves as the AC disconnect for the PV power system where acceptable to the Authority Having Jurisdiction. AC disconnecting means must be accessible to the local electric utility company personnel to operate to isolate the PV system when utility work is required.

Where solar panels have integral inverters, the output of the AC solar panel is considered the AC output of an inverter and requires a disconnect.

Install a DC disconnect switch with overcurrent protection between the inverter or charge controller and the solar array. When fusible disconnect switches are used as overcurrent protection, an additional switch may be required to ensure that the fuses are not backfed while the fusible disconnect switch is open.

Install the DC disconnect in a readily accessible location at the point where the DC conductors from the solar array first enter (penetrate) the structure. While not required, it is recommended that each series-

1 connected solar panel string connected in parallel to form an array have a separate disconnecting means to
2 allow an individual PV string to be taken out of service without disabling the entire solar array.

3
4 For bipolar PV systems, provide separate enclosures for the disconnecting means and overcurrent
5 protective devices for each monopole subarray output.

6 7 8 **7.5 Energy Storage Batteries** 9

10 Install energy storage batteries connected to PV systems in accordance with NEC Article 706 and NECA
11 417. The PV source circuit shall be considered to comply with the energy storage system charge control
12 requirements of NEC Section 706.23 if the PV source circuit is matched to the voltage rating and charge
13 current requirements of the interconnected battery cells and the maximum charging current multiplied by
14 1 hour is less than 3 percent of the rated battery capacity expressed in ampere-hours or as recommended
15 by the battery manufacturer.

16
17 Check that battery types are compatible with the battery charger and charge controller following
18 manufacturers instructions.

19
20 When working with energy storage batteries, ensure that battery acid neutralizer, such as baking soda, is
21 available to mitigate spills. Ensure adequate ventilation of hazardous gases generated by batteries during
22 charging.

23
24 Install battery racks and cells in accordance with manufacturer instructions, battery and rack data,
25 mounting information, and charging instructions.

26
27 Use lifting belts and spreaders when lifting battery cells with mechanical equipment such as a crane or
28 hoist. Position battery cells such that hydrometer tubes are located on the aisle side of each cell.

29
30 Locate energy storage batteries as close as practical to battery charging equipment. Clean battery cell
31 contact surfaces, apply non-oxidizing grease, if applicable, and connect cells in accordance with the
32 manufacturer instructions. Apply non-oxidizing grease only on connection surfaces. See Figures 7.5.1
33 and 7.5.2 for an example of a battery installation. *NOTE: Spill containment is required for wet cell*
34 *battery installations.*



36
37
38 Figure 7.5.1 Locate storage batteries in a dry location (secure from public access in cases where not

1 installed in an enclosure) and provide spill containment as required.
2
3



4
5
6 Figure 7.5.2 Do not exceed the manufacturers charge rates (secure from public access in cases where not
7 installed in an enclosure)
8

9 Ensure that cables are sized to limit voltage drop to acceptable levels in accordance with manufacturer's
10 recommendations. Use manufacturer recommended flexible cables for all inter-rack and inter-tier
11 connections. Ensure that battery cables have a long bending radius to avoid excessive stress at
12 terminations. Ground battery racks and battery disconnecting means to the system with a separate
13 equipment grounding conductor.
14
15

16 **7.6 Wiring Methods**

17

18 All raceway and cable wiring methods included in the NEC, other wiring systems and fittings specifically
19 listed for use on PV arrays, and wiring as part of a listed system are permitted for use with PV
20 components and systems. For ambient temperatures exceeding 30°C (86°F), conductor ampacities
21 must be corrected in accordance with NEC Table 690.31(A).
22

23 Comply with manufacturer instructions for wiring methods, keeping in mind that communication cables
24 and wiring may require non-metallic protective raceways. Do not install photovoltaic source circuits and
25 PV output circuits in the same raceway, cable tray, outlet or junction box, or similar fitting as conductors
26 of other non-PV systems unless the conductors of the different systems are separated by a partition.
27

28 Guard PV source and output circuits or install in raceways or use Type MC cable when operating with a
29 maximum system voltage greater than 30 volts when installed in readily accessible locations. Provide
30 sufficient length of conductors, wires and cables to facility future replacement of wiring devices with
31 integral enclosures, if needed.
32

33 Single conductor cable type USE-2 and single conductor cable listed and labeled as photovoltaic (PV)
34 wire is permitted in exposed outdoor locations in PV source circuits for PV module interconnections with
35 the PV array, although raceways are required when the maximum system voltage exceeds 30 volts when
36 installed in readily accessible locations. Install PV wire in accordance with NEC Sections
37 338.10(B)(4)(b) and 334.30. Calculate raceway fill using Table 1 of Chapter 9 of the NEC.
38

1 PV source circuits and PV output circuits using single-conductor cable listed and identified as
2 PV wire of all sizes, with or without a cable tray marking/rating, is permitted in cable trays
3 installed in outdoor locations, provided that the cables are supported at intervals not to exceed
4 300 mm (12 in.) and secured at intervals not to exceed 1.4 m (4-1/2 ft). *NOTE: PV wire and PV*
5 *cable have a nonstandard outer diameter. NEC Table 1 of Chapter 9 contains the allowable*
6 *percent of cross section of conduit and tubing for conductors and cables.*
7

8 When used to connect the moving parts of tracking PV arrays, flexible cords and cables must be of a type
9 identified as a hard service cord or portable power cable, suitable for extra-hard usage, listed for outdoor
10 use and water and sunlight resistant. Flexible PV cord and cable ampacity must be in accordance with
11 NEC Article 400.5. The ampacity of PV flexible cords and cables must be derated in accordance with
12 NEC Table 690.31(C) when they are applied in ambient temperatures exceeding 30°C. Stranded copper
13 PV wire is permitted to be connected to moving parts of tracking PV arrays in accordance with the
14 minimum number of strands specified in NEC Table 690.31(E).
15

16 Single conductor cables, sizes 16 AWG and 18 AWG, that are listed for outdoor use and are sunlight and
17 moisture resistant are permitted for module interconnections. Ampacity adjustment and correction factors
18 must be made in accordance with NEC Article 310.15. Terminate flexible, fine stranded cables only in
19 terminals, lugs, devices or connectors in accordance with NEC Article 110.14(A).
20

21 Flexible cables as identified in NEC Article 400 in sizes 2/0 AWG and larger are permitted within the
22 battery enclosure from battery terminals to a nearby junction box where they are connected with an
23 approved wiring method. Flexible cables are also permitted between batteries and cells within the battery
24 enclosure. Flexible cables must be listed for hard service use and identified as moisture resistant.
25 Flexible, fine-stranded cables must only be terminated with terminals, lugs, devices or connectors in
26 accordance with NEC Article 110.14(A).
27

28 Direct-current (DC) PV source or output circuits from a building integrated or other PV system that are
29 run inside a building or structure must be installed in metal raceways, Type MC cable or metal enclosures
30 from the point where the circuits enter the building or structure to the first readily accessible
31 disconnecting means. When installed beneath a roof, PV source or output circuits must be installed on
32 supports not less than 10 inches from the roof decking or sheathing except where installed directly below
33 the PV modules and associated equipment to prevent accidental damage from saws used by firefighters
34 for roof ventilation during a structure fire.
35

36 Protect PV source and output circuits installed in flexible metal conduit (FMC) smaller than 3/4 inch and
37 Type MC cable smaller than 1 inch in diameter with substantial guard strips when installed across
38 ceilings or floor joists. Where run exposed, FMC and Type MC cable must closely follow the building
39 surface or be protected from physical damage by approved means, other than within 1.8 m (6 ft) of their
40 connection to equipment.
41

42 Install junction, pull, and outlet boxes located behind solar modules or panels so that the wiring
43 contained in them can be rendered accessible directly or by displacement of a module or panel
44 secured by removable fasteners and connected by a flexible wiring system.
45

46 Route PV source and PV output conductors, either cable or conductors in raceway, along interior building
47 structural members such as beams, rafters, trusses, and columns where the location of those structural

1 members is observed. Clearly mark circuits that are imbedded in built-up, laminate or membrane roofing
2 materials in roofs not covered by PV modules or associated equipment
3

4 Group and identify PV system conductors in accordance with NEC requirements. Identify PV source
5 circuits, PV output circuits, and inverter input and output circuits at all points of termination, connection
6 and splices. Identify the conductors of each system at all termination, connection and splice points where
7 more than one PV system occupies the same junction box, raceway or equipment.
8

9 Group AC and DC conductors of each system by cable ties or similar means at least once, and then at
10 intervals not exceeding 1.8 m (6 ft) where the conductors of more than one PV system occupy the same
11 junction box or raceway with a removable cover. If the identification and grouping of conductors is
12 obvious, additional identification or grouping is not required.
13

14 Only PV system circuit conductors that are solidly grounded in accordance with NEC Section
15 690.41(A)(5) must be marked in accordance with NEC Section 200.6, except where the
16 identification of the conductors is evident by spacing or arrangement.
17

18 For bipolar PV systems, install all conductors from each separate monopole subarray in the same raceway
19 or cable. Where the sum of two monopole subarrays of a bipolar PV system exceeds the rating of the
20 conductors and the connected equipment, install the electrical output circuits from each monopole
21 subarray in separate raceways until connected to the inverter.
22

23 Terminate flexible whips (pre-made or field fabricated cable with connectors to match the PV module
24 connectors) at the combiner box, where provided. Connect the solar panels together in the series strings
25 utilizing factory installed leads with connectors, where provided, and connect to the combiner box
26 flexible whips.
27

28 Fittings and connectors that are intended to be concealed at the time of on-site assembly are permitted for
29 on-site interconnection of modules or other array components where those fittings and connectors are
30 listed for such use. Such fittings and connectors must be equal to the insulation, temperature rise, and
31 fault-current withstand as the wiring method used, and must be suitable for the installed environment.
32

33 Connectors used for PV systems must be polarized with a non-interchangeable configuration with other
34 connectors or receptacles in other electrical systems on the premises. Connectors must be constructed and
35 installed to guard against inadvertent contact with live parts. Connectors must be of the latching or
36 locking type. Connectors that are readily accessible and are used in circuits operating at over 30 volts AC
37 or over 30 volts DC nominal maximum circuit voltage must require a tool for opening. The grounding
38 contact of connectors must be the first to make and the last to break contact with the mating connector.
39 For non-load-break type connectors, the connector must be labeled "Do Not Disconnect Under Load" or
40 "Not for Current Interrupting" and must require a tool to open.
41

42 Install PV circuits, conduits and conductors, located on the roof as close as possible to the ridge or hip or
43 valley and from the hip or valley as directly as possible to an outside wall to reduce trip hazards and
44 maximize locations for firefighting ventilation.
45

46 Install conduits for solar module interconnections and inverter conductors using proper, listed
47 components and correct tightening torque. Use raceway approved for the location for underground
48 installations. Use proper, listed damp/wet wiring methods for underground circuits and circuits exposed
49 to damp/wet conditions. Use watertight wiring methods when making inverter connections. Seal off
60

1 unused conduit openings in inverter enclosures and make watertight. Ensure that minimum wire bending
2 radius is maintained.

3
4 Conductors for ungrounded PV power systems must be nonmetallic jacketed multiconductor cable,
5 conductors installed in raceways, or conductors listed and identified as Photovoltaic (PV) Wire where
6 installed as exposed, single conductors. Jacketed multiconductor cable assemblies listed and
7 identified for the application are permitted in outdoor locations. Secure cables at intervals not
8 exceeding 1.8 m (6 ft).

9
10 Fittings and cable clamps for the attachment of conduit, electrical metallic tubing, armored cable,
11 nonmetallic flexible tubing, nonmetallic-sheathed cable, service cable or equivalent, must be listed by a
12 Nationally Recognized Testing Laboratory to comply with UL 514B, Conduit, Tubing and Cable Fittings,
13 UL 2239 Hardware for the Support of Conduit, Tubing and Cable, or other appropriate standard.

14
15 Install solar panel and output conductors consisting of sheathed or jacketed multi-conductor cables or
16 cables in raceway in accordance with manufacturer recommendations. DC PV conductors should be
17 installed in metallic raceways on roofs and when located within enclosed spaces of a building and should
18 be routed along the bottom of load bearing structural members to the greatest extent possible to minimize
19 the hazard of cutting energized circuits during firefighting roof-venting operations.

20
21 Follow manufacturer minimum ampacity and temperature rating recommendations. Check the ampacity
22 of solar panels and solar arrays to determine the minimum wire size for current flow. Determine required
23 correction and adjustment factors for conductor ampacity. Increase conductor size for temperature,
24 voltage drop, conduit fill and raceways installed on rooftops in accordance with the NEC.

25
26 Estimate the two-way length of circuit conductors from series-connected strings of solar panels to
27 combiner boxes and to inverters, and calculate the voltage drop across the length of conductors. Size
28 conductors for a maximum of 3% voltage drop from the array to the inverter. If the array combiner box is
29 located remote from the inverter, spread the voltage drop accordingly between the PV array-to-combiner
30 wiring and the combiner-to-inverter wiring for a maximum of a 3% voltage drop.

31
32 Locate DC combiner boxes to minimize conduit lengths from series-connected solar panel strings and
33 from solar arrays to combiner boxes, generally taking the shortest path from arrays to combiner boxes.

34
35 To prevent DC voltage from developing on conductors, install conductors working from the utility toward
36 the solar array. Do not switch the neutral conductor unless the neutral conductor is switched with the
37 phase conductors simultaneously. Terminate the solar array conductors in the combiner box before
38 completing the final connections to each solar array. Terminate the battery conductors at the battery
39 disconnect before completing the final connections at the batteries.

40
41 Interconnect solar panels by opening the junction box at the back of each panel and attaching the wires to
42 the appropriate positive and negative terminal screws in the box, removing one-half inch of insulation
43 from the ends of the wires first. Route conductors between panels through the knockouts in each box.
44 Run the wire from the first panel to the next electrical component of the system, such as the combiner
45 box, inverter or charge controller. Install solar panels using modular plug connectors where listed
46 products are available, to simplify installation. Close all junction boxes.

1 Make electrical connections to the inverter only after the inverter is securely mounted in its final location.
2 Do not connect the inverter to the electrical distribution system until receiving proper authorization from
3 the local electric utility company.
4

5 Connect the inverter only to a dedicated feeder circuit. Connect the inverter to a primary AC disconnect
6 switch with overcurrent protection. Connect the solar array to a DC disconnect switch with overcurrent
7 protection.
8

9 Ground the PV power system in accordance with manufacturer recommendations and the NEC. Keep in
10 mind that some manufacturers require the solar array to operate ungrounded or floating with the negative
11 conductor not grounded. Ground battery racks and battery disconnecting means to the system with a
12 separate equipment grounding conductor.
13

14 **7.7 Labels and Warning Signs**

15 Numerous safety labels and warning signs are required for PV power systems because of multiple sources
16 of power and the likelihood of equipment backfeeds. PV power systems, interior and exterior DC
17 conduits, raceways, enclosures, cable assemblies, disconnect switches, combiner boxes and junction
18 boxes must be marked to provide emergency responders with appropriate warnings and guidance for
19 safely working around and isolating the PV power system. Warning sign(s) or label(s) shall comply with
20 NEC Section 110.21(B). Plaques or directories shall be installed in accordance with NEC Section 705.10.
21
22

23 Energized conductors, such as from solar arrays to inverters or charge controllers, should not be cut when
24 venting for smoke removal from a burning structure. Suitable labels should be installed on all interior and
25 exterior DC conduit, raceways, enclosures, cable assemblies and junction boxes to alert the fire
26 department to avoid cutting them. See Figure 7.7.1 for an example of photovoltaic power source
27 markings on wiring conduits and boxes.
28
29

1



2
3

4 Figure 7.7.2 Cautionary or warning marking is required to indicate that the line and load side of switches
5 and circuit breakers could be energized

6

7 Direct current PV power sources are required to be labeled at an accessible location at the disconnecting
8 means, stating the operating current, operating voltage, maximum system voltage and short-circuit current
9 of the source.

10

11 The main service disconnect must be marked with a label placed adjacent to main service disconnect at a
12 location clearly visible from the location where the disconnect is operated. If the main service disconnect
13 is operable with the panel closed, the marking should be placed on the outside cover.

14

15 Each disconnecting means for any portion of a solar array must state the maximum kW of power
16 generated by that portion of the array.

17

18 For ungrounded PV power systems, the PV power source must be labeled with the following or similar
19 warning: “Warning—electric shock hazard. The DC conductors of this PV system are ungrounded and
20 may be energized.” This warning should appear at each junction box, combiner box, disconnect, and
21 device where energized, ungrounded circuits may be exposed during service.

22

23 Solidly grounded bipolar PV systems must be clearly marked with a permanent, legible warning notice
24 indicating that the disconnection of the grounded conductor(s) may result in overvoltage on the
25 equipment. Listed switchgear rated for the maximum voltage between circuits and containing a physical
26 barrier separating the disconnecting means for each monopole subarray is permitted to be used instead of
27 disconnecting means in separate enclosures.

28

29 Provide a permanent label for the DC PV power source at the PV disconnecting means for each source
30 indicating the rated maximum power-point current, the maximum rated power-point voltage, maximum
31 system voltage, short-circuit current, and maximum rated output current of the charge controller or DC-
32 to-DC converter, if installed.

33

34 Provide a label at the point of interconnection of all interactive PV systems with another source at an
35 accessible location at the disconnecting means identifying the PV system as a power source, and include
36 the rated AC output current and the nominal operating AC voltage of the PV system. The disconnecting
37 means for PV power systems that have energy storage batteries must be labeled with the maximum
38 operating voltage, including any equalization voltage and the polarity of the grounded circuit conductor.

39

40 Any building or structure with a standalone PV system is required to have a permanent plaque or
41 directory installed on the exterior of the building or structure at a readily visible location acceptable to the
42 authority having jurisdiction indicating the location of the system disconnecting means and that the
43 structure contains a standalone electrical power system.

44

1 Buildings or structures with an interactive PV system are required to have a permanent plaque or
2 directory installed on the exterior of the building or structure at a readily visible location acceptable to the
3 authority having jurisdiction indicating the location of the service disconnecting means and the PV
4 system disconnecting means if it is not in the same location as the service disconnecting means.
5

6 Where multiple PV systems are installed in or on a single building or structure and are remotely located
7 from each other, provide a permanent plaque or directory denoting the location of all electric power
8 source disconnecting means on or in the premises at each service equipment location and at each PV
9 system disconnecting means, including utility-interactive power inverters mounted in not-readily-
10 accessible locations such as on roofs or other exterior areas that are not readily accessible. It is permitted
11 to designate installations with large numbers of power production sources, such as PV power systems, by
12 groups.
13

14 Buildings with rapid shutdown PV systems shall have permanent labels as described below:

- 15 • For PV systems that shut down the array and conductors leaving the array:
16

17 SOLAR PV SYSTEM IS EQUIPPED WITH RAPID SHUTDOWN.
18 TURN RAPID SHUTDOWN SWITCH TO THE “OFF” POSITION
19 TO SHUT DOWN PV SYSTEM AND REDUCE SHOCK
20 HAZARD IN ARRAY.
21

22 The title “SOLAR PV SYSTEM IS EQUIPPED WITH RAPID SHUTDOWN” shall utilize
23 capitalized characters with a minimum height of 9.5 mm (3/8 in.) in black on yellow background,
24 and the remaining characters shall be capitalized with a minimum height of 4.8 mm (3/16 in.) in
25 black on white background. [See Figure 690.56(C)(1)(a).]
26

- 27 • For PV systems that only shut down conductors leaving the array:
28

29 SOLAR PV SYSTEM IS EQUIPPED WITH RAPID SHUTDOWN
30 TURN RAPID SHUTDOWN SWITCH TO THE “OFF” POSITION
31 TO SHUT DOWN
32 CONDUCTORS OUTSIDE THE ARRAY. CONDUCTORS IN
33 ARRAY REMAIN
34 ENERGIZED IN SUNLIGHT.
35

36 The title “SOLAR PV SYSTEM IS EQUIPPED WITH RAPID SHUTDOWN” shall utilize
37 capitalized characters with a minimum height of 9.5 mm (3/8 in.) in white on red background, and
38 the remaining characters shall be capitalized with a minimum height of 4.8 mm (3/16 in.) in black
39 on white background. Include a simple diagram of a building with a roof. The diagram shall
40 have sections in red to signify sections of the PV system that are not shut down when the rapid
41 shutdown switch is operated. The rapid shutdown label shall be located on or no more than 1 m
42 (3 ft) from the service disconnecting means to which the PV systems are connected and shall
43 indicate the location of all identified rapid shutdown switches if not at the same location.
44

45 For buildings that have PV systems with both rapid shutdown types or a PV system with a rapid
46 shutdown type and a PV system with no rapid shutdown, a detailed plan view diagram of the roof shall be
47 provided showing each different PV system and a dotted line around areas that remain energized after the
48 rapid shutdown switch is operated.
49

1 A rapid shutdown switch shall have a reflective label with all letters capitalized and having a minimum
2 height of 9.5 mm (3/8 in.), in white on red background located on or no more than 1 m (3 ft) from the
3 switch that includes the following wording:
4

5 RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM
6
7

8 **7.8 Large-Scale PV Electric Power Production Facilities**
9

10 Large scale PV electric power production facilities are defined as PV electric power production facilities
11 with a generating capacity of not less than 5000 kW and not under exclusive utility control. See NEC
12 Article 691 for additional information. *NOTE: Facilities covered by NEC Article 691 have specific*
13 *design and safety features unique to large-scale PV facilities and are operated for the sole purpose of*
14 *providing electric supply to a system operated by a regulated utility for the transfer of electric energy.*
15

16 Large-scale PV electric supply stations are accessible only to authorized personnel and must comply with
17 the following:

- 18 • Electrical circuits and equipment are maintained and operated only by qualified personnel.
- 19 • Access to PV electric supply stations is restricted by fencing or other adequate means in
20 accordance with NEC Section 110.31. Field-applied hazard markings are installed in accordance
21 with NEC Section 110.21(B).
- 22 • The connection between the PV electric supply station and the system operated by a utility for the
23 transfer of electrical energy is made through medium- or high voltage switchgear, substation,
24 switch yard, or similar methods whose sole purpose is to safely and effectively interconnect the
25 two systems.
- 26 • The electrical loads within the PV electric supply station are only used to power auxiliary
27 equipment for the generation of the PV power.
- 28 • Large-scale PV electric supply stations must not be installed on buildings.
29

30 All electrical equipment shall be approved for installation by listing and labeling, field labeling, or
31 engineering review validating that the equipment is tested to relevant standards or industry practice
32

33 Documentation of the electrical portion of the engineered design of the electric supply station must be
34 prepared and stamped by a licensed professional electrical engineer retained by the system owner or
35 installer, and provided upon request of the AHJ. Additional stamped independent engineering reports
36 detailing compliance of the design with applicable electrical standards and industry practice must be
37 provided upon request of the AHJ. This design documentation must include details of conformance of the
38 design with NEC Article 690, and any alternative methods to NEC Article 690, or other articles of the
39 NEC, including documentation of DC operating voltage calculations, details of fire mitigation plans to
40 address DC arc-faults, and fence grounding requirements and details.
41

42 Documentation that the construction of the electric supply station conforms to the electrical engineered
43 design must be provided upon request of the AHJ. Additional stamped independent engineering reports
44 prepared by a licensed professional electrical engineer retained by the system owner or installer detailing
45 that construction conforms with the NEC, applicable standards and industry practice must be provided
46 upon request of the AHJ. This documentation, where requested, must be available prior to commercial
47 operation of the station.
48

1 Isolating devices are permitted to be more than 1.8 m (6 ft) from the equipment where written safety
2 procedures and conditions of maintenance and supervision ensure that only qualified persons service the
3 equipment.
4

5 Buildings whose sole purpose is to house and protect supply station equipment is not required to comply
6 with the Rapid Shutdown requirements of NEC Article 690. Written standard operating procedures must
7 be available onsite detailing necessary shutdown procedures in the event of an emergency.
8
9

10 **8. Start-Up and Commissioning**

11 **8.1 General**

12 Observe safe working practices. See Section 5.
13

14 Check that connections between the inverter (or charge controller and batteries), the solar array and the
15 main service panel have been made correctly.
16
17
18
19

20 **8.2 Connecting the Inverter or Charge Controller**

21
22 Open the AC disconnect switch or circuit breaker and lockout the AC disconnecting means to isolate the
23 inverter or charge controller from the electric utility grid. Open the DC disconnect switch and lockout the
24 DC disconnecting means to isolate the inverter or charge controller from the solar array. Verify that there
25 is no voltage on the connection terminals.
26

27 Connect the grounding electrode conductor to the inverter or charge controller using the grounding means
28 provided. Tighten connections to manufacturer recommended torque using a calibrated torque wrench or
29 torque screwdriver.
30

31 Connect the inverter or charge controller to the AC disconnect switch or circuit breaker. Use proper, low
32 impedance cables to connect the inverter or charge controller to the AC disconnect switch, and between
33 the disconnecting means and the grid. Connect the conductors to the appropriate terminals, first in the
34 inverter or charge controller, then in the AC disconnect switch or circuit breaker. Tighten terminals to
35 manufacturer recommended torque value.
36

37 Connect the inverter or charge controller to the DC disconnect switches, keeping in mind that each solar
38 array requires a separate DC disconnect switch, and the inverter or charge controller manufacturer may
39 recommend two independent solar arrays be wired and connected separately to the DC input sections.
40

41 Follow the manufacturer's recommendations for installing jumper wires to connect a single array that
42 exceeds the current ratings of one of the DC input sections. Follow manufacturer's recommendations for
43 short-circuiting the DC input section when a single array is installed that does not exceed the current
44 rating of one of the DC input sections, if applicable.
45

46 Check polarity when connecting the solar array to the inverter or charge controller. Verify that all
47 connections are correct and properly tightened and install the terminal cover on the inverter. Connect the
48 battery conductors to the charge controller and install the terminal cover.
49

8.3 Starting the Inverter or Charge Controller

Do not place any object on the inverter or charge controller during operation, and do not touch heat sinks during operation. The inverter and charge controller are extremely hot during operation.

Remove the opaque covering from the solar panels, if installed. Close the DC disconnecting means. Close the AC disconnecting means.

The inverter or charge controller should start operating automatically, verifying that the electric utility voltage, impedance and frequency parameters are within the operating range of the inverter in accordance with UL 1741 requirements. After a period of time that may last several minutes, depending upon the condition of the utility operating parameters, the inverter or charge controller may display countdown timer, voltage status, or frequency status screens or indicator lights.

If the operating parameters are not acceptable, the inverter or charge controller will repeat the check until utility operating parameters are acceptable. If parameters are not acceptable after an extended period of time, measure the voltage and frequency of the electric utility grid, and verify that the configuration of the inverter or charge controller is appropriate for the electrical connection to the utility grid.

If the operating parameters are acceptable, the inverter or charge controller will perform a self-diagnostic, during which time the inverter or charge controller may emit audible sounds. If the self-check is successful, the inverter or charge controller will begin exporting power to the grid, provided there is sufficient sunlight for the solar array to generate solar power to export to the grid. If the inverter or charge controller does not begin exporting power to the grid, check that the solar array operating voltage is high enough for the inverter or charge controller to start-up and initiate the grid connection sequence. If the operating voltage is other than the default setting, reconfigure the inverter or charge controller AC section using the communication software supplied by the manufacturer.

Verify that all PV circuits are operating properly and that the system is performing as designed and as expected. Shut down the system and coordinate the final inspections from the Authority Having Jurisdiction and from the local electric utility company. Once approval to operate in parallel with the electric utility company is received from the utility, the system can be set in operation.

8.3.1 Monitoring and Data Transmission

Inverters and charge controllers provide operational data in several ways, including LED indicators, LCD displays and data transmission via power line modem or data cable to data loggers or personal computers equipped with manufacturer's monitoring software.

LED indicators and LCD displays may provide redundant information, with the combination of solid and blinking indicator lights showing various operational statuses and/or fault conditions while the LCD display shows a message related to the operation being carried out or to an operational fault.

Provide data cabling, installation, connections and programming in accordance with manufacturer instructions.

Configure inverter and charge controller addresses and dipswitches for monitoring and data transmissions in accordance with manufacturer instructions. Do not exceed the manufacturer recommended maximum

1 number of inverters or charge controllers connected on the same serial data line. Do not exceed
2 manufacturer recommended maximum length of monitoring and data cabling.

3
4 When using power line modem, ensure that the inverter or charge controller and the receiving equipment
5 are connected to the same phase conductor. Observe the manufacturer recommendations for maximum
6 length of power line transmission, considering that high electromagnetic interference may limit the
7 transmission length below the recommended maximum.

10 **8.4 Batteries**

11 Charge and operate batteries in accordance with manufacturer recommendations and instructions. Make
12 final battery connections in accordance with manufacturer recommendations and instructions.

13
14 Check DC power, control power, and battery connections including cell-to-cell, tier-to-tier, rack-to-rack,
15 and charge controller to battery module connections, for correct polarity. Torque battery rack connections
16 to manufacturer recommendations.

17
18 Inspect battery racks and insulating covers for physical damage, loose connections, cracking, dielectric
19 leaks, dirt, corrosion, and seismic parts and spacers. Check battery jars and covers for cracking,
20 distortion, dielectric leaks, dirt, and corrosion. Inspect jar and post seals. Check electrolyte levels, if
21 applicable. Check vented lead-acid batteries and vented Nickel-Cadmium batteries for clogged flame
22 arresters. Inspect vented lead-acid battery cells, and check plates for cracks, sulfate, and hydration.

23
24 Measure resistance at each battery cell and across all DC connections with a digital low-resistance
25 ohmmeter. Investigate readings that deviate from other readings by 25 percent or more.

26
27 Check for liquid contamination such as battery electrolyte. De-energize equipment and make corrections
28 or repairs for any abnormal operating conditions in accordance with manufacturer recommendations.

29
30 Close the battery circuit breaker. Measure and record the battery charging voltage and current.

31
32 Allow the charge controller to run until the batteries are fully charged, or for a minimum of 24 hours,
33 whichever is less. Record the time. Measure and record the battery float voltage and current and battery
34 charge controller output voltage and current every 4 hours.

35
36 After charging, check batteries for signs of vibration. Check vented lead-acid batteries for signs of
37 excessive gassing, which is an indication of overcharging.

38
39 Add electrolyte to batteries as required to fill cells up to the bottom of the high-level line using
40 manufacturer recommended materials and methods. Equalize non-valve regulated batteries in accordance
41 with manufacturer instructions.

42
43 Check that battery connections are properly torqued to manufacturer's specifications. Measure and record
44 cell-to-cell and terminal connections resistance. Remake connections having a resistance of more than 10
45 percent above the average.

46
47 Remove and dispose of empty, partially full, and excess acid drums, including shipping containers, and
48 obsolete batteries in accordance with local laws and regulations regarding disposal of hazardous material.
49 Do not dispose of batteries in a fire.

8.5 Troubleshooting

If an abnormal operating condition is encountered, check the inverter or charge controller to observe which type of fault is detected. Follow the manufacturer's instructions for identifying and correcting the type of fault detected.

When the inverter or charge controller indicates that there is a ground fault, the most likely cause is an insulation failure or defect in the solar array wiring or in one or more connections. Press the "Reset" button on the inverter or charge controller to clear the fault. If the fault will reset, the inverter or charge controller will continue in operation. If the fault will not reset, inspect the solar array conductors and connections for water seepage, condensation, or other indication of insulation breakdown. Repair or replace damaged conductors, connections and components.

Troubleshoot solar panels by measuring the operating voltage and current of each solar module. Disconnect an individual solar panel and orient towards the sun. Measure the voltage of the solar panel when exposed to direct sunlight. The measured voltage should be close to the rated voltage of the panel or slightly less. Short-circuit the solar panel and expose to direct sunlight. Measure the short-circuit current generated by the solar panel. Calculate the power by multiplying the measured voltage times the measured current. The calculated voltage should be close to the rated power output of the solar panel of slightly less. For example, a 200 W solar panel might measure 26.0 VDC and 7.5 A, with a calculated power output of 195.0 W.

9. Site Cleanup

9.1 General

Use materials compatible with construction materials and methods. Caulk around conduit penetrations. Patch and paint any holes in drywall. Use firestopping for penetrations in fire-rated assemblies. Seal roof penetrations and make watertight.

9.2 Test Data and Operating Manuals

Provide contractually required test data and operating manuals. Deliver manufacturer data and operation manuals, which are an integral part of, and shipped with PV power system components, to the owner. Provide factory test data, battery specifications, vendor certificates of compliance to the specifications, and records of field acceptance testing to the owner.

In lieu of contractual requirements, provide two sets of operating manuals for solar panels, inverters or charge controllers, and related equipment. Provide a detailed explanation of the operation of the system, an electrical one-line diagram of the electrical system showing PV power sources and connections, schematic wiring diagrams, functional block diagrams, battery data including specifications, maintenance, and wiring diagrams, instructions for routine maintenance, recommended spare parts list with part numbers and sources, and routine troubleshooting procedures.

1
2 **9.3 Training**
3

4 Provide contractually required training. Use operating manuals as training materials.
5
6

7 **9.4 Spare Parts and Special Tools**
8

9 Provide contractually required spare parts and special tools. In lieu of contractual requirements, provide
10 one set of manufacturer-supplied special tools.
11
12

13 **10. Maintenance**
14

15 **10.1 General**
16

17 Monitor power on a weekly basis using the inverter display, through a free web account from the inverter
18 manufacturer or through a third-party monitoring service to identify potential maintenance issues. If
19 weekly monitoring identifies operational issues, troubleshoot in accordance with Section 8.5, and perform
20 biennial maintenance. See Section 10.3.
21

22 When performing maintenance, follow all manufacturer safety precautions and established safety
23 procedures using appropriate tools, test equipment, and safety equipment. See Section 5.
24

25 Exercise caution when servicing PV power systems to prevent unscheduled outages. Schedule
26 inspections and maintenance at times that will least affect operations. Do not initiate inspections and
27 maintenance until all users have been notified.
28

29 Recommended intervals for operational inspection, testing, and maintenance should be adjusted
30 accordingly for the operating environment, such as duty cycle and exposure to temperature, dust, and
31 chemicals, age and condition of the equipment, manufacturer recommendations, and trends established
32 through testing.
33

34 Maintain written records of all inspections, maintenance, testing, and repairs for future reference and to
35 establish trends. Records should include complete log notations, test results, meter readings, details of
36 any unsatisfactory conditions, corrective actions taken, parts replaced, identification of servicing
37 personnel, and documentation of satisfactory tests of the PV power system immediately following any
38 repair or battery replacement. Correct battery data for temperature variations to 77°F (25°C).
39

40 Whenever the shutdown of the system is required for maintenance, open the inverter AC output
41 disconnecting means before opening the inverter DC input disconnecting means. Place opaque sheets,
42 cloths, or tarpaulins over the solar panels, or use short circuit or open circuit techniques when taking the
43 solar panels out of service. Open battery disconnecting means to isolate energy storage batteries from the
44 system, where installed.
45

46 Take corrective action for any inspection item found to be deficient. Follow manufacturer instructions for
47 inspecting, maintaining, repairing, and replacing equipment and components. Replace batteries in
48 accordance with manufacturer recommendations. Replacement and disposal of batteries is governed by

1 federal, state, and local regulations and must be carried out by licensed recyclers/disposers following
2 prescribed methods.
3
4

5 **10.2 Periodic Maintenance**

6
7 Inspect solar panels for accumulations of dust. Rinse off regular accumulations of dust with clean water
8 approximately every two weeks, depending upon the frequency of rain. In desert regions, construction
9 areas with dust, or similar conditions, rinse solar panels more often. Rinse off solar panels during the
10 cool of the day to prevent thermal shock to the surface of the panel.

11
12 Inspect solar panels and solar arrays for accumulations of leaves, tree branches and other debris
13 periodically. Remove leaves, tree branches, and other debris from solar panels immediately.

14
15 Check the appearance and cleanliness of PV power system equipment and the areas immediately around
16 the inverter or charge controller and the solar array. Remove accumulations of dust and debris as needed
17 in accordance with Section 10.3.
18
19

20 **10.3 Biennial Maintenance**

21 *10.3.1 Inspections*

22
23
24 Check for evidence of problems by evaluating sounds, smells, and detrimental environmental conditions
25 such as heat, moisture, and chemicals.
26

27 Inspect solar panels for cracks or broken glass. Replace solar panels with cracked or broken glass.
28

29 Check inverter and charge controller indicator lamps using the “lamp test” feature. Check all meters to
30 ensure they are operating properly. Scroll through all of the monitoring and metering parameters of the
31 inverter or charge controller. Record meter readings for input and output voltage, current, and frequency.
32

33 Visually inspect the inverter or charge controller, solar array, combiner boxes, disconnecting means, and
34 other components externally. Check inverter and charge controller air intakes, vents, heatsinks, and
35 filters, where installed. Check ventilation fans for proper operation and ensure that ventilation openings
36 are clean and clear of obstructions. Brush debris and dust out of the inverter or charge controller heatsink
37 or fan screen.
38

39 Inspect areas under and around solar panels and solar arrays and inverters or charge controllers for plant
40 growth and for accumulations of debris. Remove plants or accumulations of debris under or around solar
41 panels that could restrict airflow around panels and could cause water to pool during periods of severe
42 rain. Remove plants or accumulations of debris around inverters and charge controllers.
43

44 Check the ambient temperature in the area around the inverter or charge controller. Ensure that the
45 inverter or charge controller is not exposed to direct sunlight during operation. Install a sunshade or
46 relocate the inverter or charge controller out of direct sunlight during operation.
47

1 Open access doors and covers and inspect internal parts and components for evidence of overheating, and
2 for physical and thermal damage, including worn insulation, and corrosion. Inspect terminals for loose or
3 broken connections, frayed conductors, and burned insulation.

4
5 Check inverters and charge controllers for signs of leaking fluid from the wave-forming capacitors.
6 Check for evidence of liquid contamination, battery electrolyte, and oil from capacitors. Check capacitors
7 for swelling or discoloration.

8
9 Check the torque of ground connections using a calibrated torque wrench. Check electrical connections
10 with a digital low-resistance ohmmeter, measure voltage drop across all electrical connections, or perform
11 infrared scanning under load to identify possible loose or corroded connections. Clean and retighten
12 electrical connections as necessary.

13
14 Check that mounting supports and hardware are tight and secure. Tighten loose supports and hardware.
15 Replace any missing hardware with stainless steel components.

16
17 On a sunny day near noon on March 21 and September 21 each year, record the power output of the PV
18 power system with the solar panels clean, noting the weather conditions, whether full sun, partial sun or
19 overcast. Compare the measurements with previous readings to determine whether the system's
20 performance is declining. Maintain a log of these readings to identify if the system's performance is
21 consistent, relative to the environmental conditions at the time, or is inconsistent or declining, indicating a
22 problem with the system.

23 24 ***10.3.2 Cleaning***

25
26 Wash solar panel using a sponge or squeegee with a mild soap solution to remove accumulations of tree
27 sap, and bird droppings. Wash solar panels during the cool of the day to prevent thermal shock to the
28 surface of the panel or array.

29 30 ***10.3.3 Batteries and Charge Controllers***

31
32 Check battery racks for corrosion, cleanliness, and structural integrity. Inspect battery rack and rack
33 insulating covers for physical damage, loose connections, cracking, leaks, dirt, corrosion, and seismic
34 parts and spacers. Re-torque battery rack connections.

35
36 Check ventilation and condition of electrical equipment in the vicinity of the batteries. Evaluate battery
37 proximity to combustibles and sources of ignition and heat. *NOTE: Local sources of heat can create cell*
38 *temperature differentials that can cause battery damage.*

39
40 Check battery cable connections. Examine interconnection cables, cell connectors, and other conductors
41 for wear, contamination, corrosion, and discoloration.

42
43 Measure and record charge controller input and output voltage, current, and frequency, and battery float
44 voltage and charging current. Check solar power generation and transfer to the electric utility grid to
45 ensure that it is within the inverter or charge controller rating.

46
47 Check intercell and terminal connection resistances in a sample of batteries in accordance with
48 manufacturer recommendations. If the sample shows an increase in resistance, check the resistance of all
49 connections. Check cell impedance, conductance, and resistance of valve-regulated lead-acid batteries.

1
2 Check battery jars, covers, and post seals for cracks, structural damage, dielectric leaks, dirt, and
3 corrosion. Remove all corrosion and dirt, clean battery cell tops, terminals, and intercell connectors, and
4 check terminal connections, battery posts, and cable ends. Clean battery posts in accordance with
5 manufacturer recommendations. Replace damaged units and vent caps.
6

7 Clean lead-acid battery surfaces with water and sodium bicarbonate to avoid leakage currents caused by
8 electrolyte on the battery. Clean Nickel-Cadmium battery surfaces with a boric acid solution. Do not use
9 cleaners, soaps, or solvents to clean battery jars and covers. Reapply non-oxidizing grease to battery
10 terminals and intercell connectors, if necessary.
11

12 Check plates of clear jars for buckling, warping, scaling, swelling, or cracking, and for changes in color.
13 Replace damaged cells. Check batteries for vibration. Excessive vibration can be detected by observing
14 vibration of plates and sediment in the jar. Note the condition of plates and sediment of free-electrolyte,
15 lead-acid batteries in transparent containers. Determine if electrolyte and cells are clear with minimal
16 deposits, gassing, or rings, and that there is only minor sediment below the plates.
17

18 Check for spilled electrolyte. Neutralize lead-acid battery spills using bicarbonate of soda solution. Use
19 boric acid solution to neutralize Nickel-Cadmium battery spills. Check battery electrolyte levels, where
20 applicable, and refill as necessary using manufacturer recommended materials and methods. Measure and
21 record amounts of water added to cells as excessive water consumption can be a sign of overcharging.
22 For lead-antimony batteries, water should be used unless otherwise recommended by the battery
23 manufacturer.
24

25 Perform infrared scanning of batteries under load. Torque intercell connectors or links to manufacturer
26 recommended values. Correct deficiencies in accordance with manufacturer recommendations.
27

28 ***10.3.4 Adjustments***

29
30 Adjust the tilt angle of adjustable arrays every three months to maintain an optimum orientation to the
31 sun, as needed.
32
33

34 **10 4 Post-Repair Testing**

35
36 Check the battery and associated charger/control equipment immediately following any repair or battery
37 replacement to verify that they are in a clean and satisfactory condition with no exceptional
38 environmental or other conditions that could damage or affect performance.
39

40 When applicable, check electrolyte levels and refill as necessary. Clean and re-grease battery terminals
41 and intercell connectors as necessary. Clean cell tops. Check and record individual cell voltages where
42 practical. Check and record the specific gravity of pilot cells where applicable. Note the condition of the
43 plates and sediment of free-electrolyte, lead-acid batteries in transparent containers.
44

45 Check that all indicator lamps, meters, and controls are operating correctly. Check the solar power
46 generation and transfer to the electric utility grid to ensure that it is within the inverter rating.
47
48

1 (This annex is not part of the standard)
2

3 **Annex A: Sizing PV Power Systems** 4

5 One step in sizing PV power systems is to perform an energy audit. An energy audit is a collection of
6 information about the energy use of the facility. A minimum of 12 months of past electrical energy bills
7 should be reviewed to determine seasonal demand and energy consumption for use in sizing the PV
8 power system.
9

10 Utility energy consumption can peak in summer months with significant air conditioning loads, or in
11 winter months for customers with electric heat in cooler climates. The tilt angle of solar panels and solar
12 arrays can be adjusted to maximize summer or winter solar power generation in response to energy
13 consumption trends. Understanding the seasonal energy consumption of the customer can help maximize
14 the benefit of solar power production.
15

16 As mentioned earlier, PV power systems are a passive generation technology. While there is no way to
17 predict how much solar power will be generated at any given time, the average power generation of a PV
18 power system can be estimated using the formula:
19

$$20 \quad P_{\text{AEO}} = 365(I_{\text{PSH}})(P_{\text{SAR}})(0.77)$$

21 Where

22 P_{AEO} is the annual energy output of the solar array expressed in kilo-Watt-hours,

23 365 is the number of days in a year,

24 I_{PSH} is the average daily solar energy density, or insolation at the installation location expressed in
25 kW/m²/day,

26 P_{SAR} is the power output rating of the solar array expressed in kilo-Watts, and

27 System efficiency is approximately 77%, with system losses accounting for 25 to 30% of the
28 system output.
29

30 For example, an 18-kW solar power system with a fixed tilt angle of site latitude installed in a location
31 with an average annual insolation of 4.4 peak-sun-hours will generate an average of 20,236 kWh per year.
32 Solar power generation can be improved by installing a larger array, by adjusting the tilt angle quarterly
33 to maintain a better sun exposure during each season, or by installing a tracking array.
34

35 The solar panels used to form the solar array, and the system wiring must be configured in such a way
36 that the maximum open circuit voltage developed from the type, number and operating condition of the
37 selected solar panels is less than the maximum inverter voltage rating. As the maximum open circuit
38 voltage of each solar panel depends upon the ambient operating temperature, the number of panels per
39 string must be chosen according to the minimum ambient temperature for the installation location in
40 accordance with the manufacturer's recommendations, and with NEC recommended derating factors for
41 minimum temperature.
42

43 The open circuit voltage of the solar panels is affected by the ambient temperature with open circuit
44 voltage increasing as temperature decreases. Ensure that the minimum temperature estimated for the
45 installation does not cause the panels to exceed the maximum upper voltage limit of equipment and
46 conductors. The maximum number of solar panels that can be connected in series is a function of the
47 minimum ambient temperature in which the system can reasonably be expected to operate. Consult the
48 solar panel manufacturer for temperature correction coefficients before calculating the voltage rating of
49 the solar array.

1
2 As an example, the solar panels selected to form the 18kW solar array from the previous example have a
3 power rating of 150 Watts, nominal voltage rating of 24VDC, peak current rating of 5.3A, an open circuit
4 voltage rating of 35.5VDC, and a short circuit current rating of 5.9 A.
5

6 An 18-kW array requires one hundred twenty (120) 150W solar panels (120 x 150W = 18,000W).
7 Typically, inverters used for PV power systems have power output ratings less than 11 kW.
8 Consequently, the example 18 kW array should be divided into two 9kW arrays of 60 solar panels each.
9 It is important to determine what the configuration of the 60 solar panels can be, namely how many solar
10 panels can be connected in series without exceeding the maximum operating voltage of the inverter.
11

12 To ensure that the open-circuit voltage of the array does not exceed 600V, the maximum expected
13 operating voltage of the inverter and the maximum expected insulation voltage for the DC conductors for
14 this example, the open-circuit voltage must be adjusted for ambient temperature, keeping in mind that
15 solar panels operate with greater efficiency at lower temperatures. Use the manufacturer recommended
16 temperature adjustment factors when determining the maximum open-circuit voltage of a given solar
17 panel. In the absence of manufacturer recommendations, use the ambient temperature adjustment factors
18 found in Table 690.7 of the NEC.
19

20 Assuming that the maximum permissible open-circuit voltage is 600V, and using the lowest ambient
21 temperature in the example location as 2 degrees below zero Fahrenheit, the maximum number of solar
22 panels that can be connected in series is determined using the following ambient temperature correction
23 formula for open-circuit voltage:
24

$$V_{O-C} = (C_F)(N_{SM})(V_{O-C/SM})$$

26
27 Where

28 V_{O-C} is the maximum open circuit voltage of the array,
29 C_F is the correction factor of 1.18 from NEC Table 690.7 for -2°F,
30 N_{SP} is the number of solar panels in the array, and
31 $V_{O-C/SP}$ is the maximum open circuit voltage of each solar panel.
32

33 Solving the equation using from the above example results in:
34

$$600V = (1.18)(N_{SM})(35.5V)$$

36
37 Solving for the maximum number of solar panels that can be connected in series without exceeding 600V
38 is 14.3 panels. Consequently, the 60 panels cannot be configured as an array of four parallel rows of 15
39 series-connected panels. The solar array can, however, be configured as an array of five rows of 12
40 panels connected in series. The 12 panels in series would have an operating voltage of 288VDC (12 x
41 24VDC = 288VDC), with a peak operating current of 5.3A. The five strings in the array would have a
42 total peak operating current of 26.5A with a short-circuit current of 29.5A.
43
44

1 (This annex is not part of the standard)
2

3 **Annex B: List of Figures** 4

5 Notice: The photos and illustrations included in this standard are intended to show examples of
6 components and systems described in the text. The illustrations are conceptual in nature only.
7 Photovoltaic systems must be installed according to design drawings and in accordance with the
8 equipment manufacturer’s installation instructions and specific wiring diagrams.
9

10 **Section 1** 11

12 Figure 1.1 Typical roof-mounted array of a photovoltaic power system (I-Stock Photo Courtesy of
13 NECA)
14

15 **Section 2** 16

17 Figure 2.1 Typical roof-mounted photovoltaic array (I-Stock Photo Courtesy of NECA)

18 Figure 2.2 Basic diagram of bipolar photovoltaic array [Note: Simplified drawing shows concepts of a
19 bipolar array only; it does not include all details or components and is intended to help visualize a bipolar
20 array]

21 Figure 2.3 Photo of typical building integrated photovoltaic modules as part of clay roofing materials.
22 (Photo Courtesy of Rick Maddox, Clark County, NV)

23 Figure 2.4 Typical photovoltaic inverter for a smaller PV system. (Courtesy of Central Florida Electrical
24 JATC)

25 Figure 2.5 Typical stand-alone photovoltaic system (Photo by NECA Copyright® Rob Colgan)
26

27 **Section 3** 28

29 Figure 3.1.1 Basic components of a photovoltaic system [illustration is intended as a concept only].
30 (Concept drawing by NECA)

31 Figure 3.1.2 Typical photovoltaic system with battery storage (DC system output) [Note: This is a
32 simplified diagram concept and is not intended to show all wiring, grounding, bonding, overcurrent
33 protection, and so forth.] (Concept drawing by NECA)
34

35 **Section 5** 36

37 Figure 5.1.1 Typical danger/safety labels provided on electrical equipment by manufacturers.

38 Figure 5.1.2 Typical warning label that is field applied in accordance with NEC 110.16. See ANSI Z535
39 for information related to danger, warning, and caution markings and signage. (Concept drawing by
40 NECA)

41 Figure 5.2.1 Use appropriate personal protective equipment (PPE) for justified energized work. (Courtesy
42 of NJATC)
43

44 **Section 6** 45

46 Figure 6.3.1 Photo of a typical ground-mounted photovoltaic array (Courtesy of Central Florida
47 Electrical JATC)

48 Figure 6.6.1 Photo of a typical ground-mounted photovoltaic array (Courtesy of NEC Copyright)
49

1 Rob Colgan)
2 Figure 6.6.2 Typical pole-mounted photovoltaic solar tracking system (Courtesy of IBEW Local 26
3 Electrical JATC Training Center)
4 Figure 6.6.3 Photovoltaic system that tracks the sun (Courtesy of IBEW Local 26 Electrical JATC
5 Training Center)
6 Figure 6.8.1 Roof-mounted solar photovoltaic array attached to structural members in building (Roof
7 penetrations should be sealed by qualified contractor)
8 Figure 6.12.1 Typical photovoltaic solar panel used to connect with other modules when forming an
9 array.
10 Figure 6.12.2 Typical inverters for a small photovoltaic system (Courtesy of Central Florida Electrical
11 JATC)
12 Figure 6.20.1 Grounding is required for photovoltaic systems and metal parts of equipment
13 associated with a photovoltaic installation. (Courtesy of Central Florida Electrical JATC)
14 Figure 6.20.2 Use grounding terminals and means of connection suitable for the environment where they
15 are installed.
16 Figure 6.20.3 Bond DC system electrode(s) to AC system grounding electrode(s) [Note: Simplified
17 drawing provides concepts only and is not intended to serve as a complete schematic for every system]
18 (Concept drawing by NECA)

19 20 **Section 7**

21
22 Figure 7.1.1 Typical warning label identifying a bipolar photovoltaic array (system) (Concept drawing by
23 NECA)
24 Figure 7.1.2 Back-fed breakers must be securely fastened to panelboards. (Concept drawing by NECA)
25 Figure 7.1.3 Breakers marked “LINE” and “LOAD” are not permitted to be back-fed. (Concept drawing
26 by NECA)
27 Figure 7.3.1 Typical inverter nameplate information for small photovoltaic system
28 Figure 7.4.1 Disconnecting means typically not permitted to break the grounded (usually the neutral)
29 conductor. (Courtesy of NJATC)
30 Figure 7.4.2 Disconnection means to disconnect the inverter from the array (Courtesy of Central
31 Florida Electrical JATC)
32 Figure 7.5.1 Locate storage batteries in a dry location (secure from public access in cases where not
33 installed in an enclosure) and provide spill containment as required.
34 Figure 7.5.2 Do not exceed the manufacturers charge rates (secure from public access in cases where not
35 installed in an enclosure)
36 Figure 7.7.1 Wiring, junction boxes, conduit bodies, and equipment must be marked with the words
37 “Photovoltaic Power Source.” (Concept drawing by NECA)
38 Figure 7.7.2 Cautionary or warning marking is required to indicate that the line and load side of switches
39 and circuit breakers could be energized (Concept drawing by NECA)

40
41

1 (This annex is not part of the standard)

2

3 **Annex C: Reference Standards**

4

5

6