Essential Safety Practices for Designing and Installing PV Systems

DESIGNING AND INSTALLING a photovoltaic (PV) power system requires strict attention to guidelines, legal requirements, and directions. Safety practices are critical to reducing or eliminating installation errors, electrical hazards, or worse—injury or death on the job. Guidelines make sure that systems are measured and installed appropriately. The NEC is the go-to guide for legal requirements for installing PV systems. NEC regulations are updated every three years. Step-by-step directions simplify and secure installation.

This chapter describes safety practices and procedures that must be used to install PV systems. These practices protect the health and safety of the installation team and property owners. It touches on the critical processes for connecting and operating PV systems. It also provides tips for safely testing PV systems.

Topics & Concepts

This chapter covers the following topics and concepts:

- Working safely with PV systems
- Connecting and operating PV systems
- Marking and labeling requirements
- Access, pathways, and smoke ventilation requirements
- Location and protection of direct current (DC) conductors
- Non-habitable building requirements
- Ground-mounted PV arrays
- Safe design of PV systems—what the NEC code says
- Safety hints for testing a PV system

Goals

When you complete this chapter, you will be able to:

- Discuss the specific safety needs for parts of the PV system.
- List the marking and labeling requirements for installing PV systems.
- Discuss the types of non-habitable buildings.
- Explain access, pathway, and smoke ventilation requirements.
- Discuss safety tips and hints for testing PV systems.

Working Safely with PV Systems

Working safely with PV systems requires a clear understanding of electrical systems and safety requirements. It also requires following strict safety practices. Working with PV systems can be very dangerous and calls for careful and responsible action. Workers must approach every step with common sense based on safety training. Workers on a project site must be alert and follow safety requirements and regulations at all times because of the risk for property damage, personal injury, or even death.

Construction sites contain numerous and often continually changing risks, such as:

- Minor to serious cuts
- Tripping and falling
- Environmental and equipment-generated heat, smoke, or fire
- Chemical and electrical burns
- Shock and electrocution
- Falling objects

The cause of such incidents is usually human error, such as carelessness or failure to follow well-established safety procedures. Installing PV systems means knowing the hazards of every product, situation, and tool. Knowing and anticipating what can happen may save you or your team members from serious injury and/or death. An alert worker considers how his or her actions affect the installer, other workers, and customers. That knowledge is crucial.

NOTE

Wear gloves when handling anything that could be sharp or hot, or that might splinter.

Connecting and Operating PV Systems

Everyone working on PV systems should know and clearly understand the safety regulations of the **National Electrical Code (NEC)** and **Occupational Safety and Health**

Administration (OSHA). OSHA creates doctrines and regulations that require employers to provide a safe place of employment while reducing hazards. The purpose of the NEC is the practical safeguarding of persons and property from hazards arising from the use of electricity.

The NEC establishes the installation safety requirements for PV systems and other electrical equipment. Most local jurisdictions throughout the United States adopt the NEC as law. The NEC articles cover electrical systems safety and code compliance. Article 690 deals specifically with PV electrical energy systems. Many other sections of the code address PV-related issues.

The broad scope of OSHA regulations includes potential hazards likely to be found in PV installations. Specifically, 29 CFR Part 1926 Safety and Health Regulations for Construction applies to general construction practice, including several subparts applicable to the installation of PV systems:

- Electrical safety
- Fall protection
- Stairways and ladders
- Hand and power tools
- Personal protective equipment (PPE)
- Working space for electrical systems
- Photovoltaic modules
- Battery safety

Electrical Safety

About five workers are electrocuted every week in the US. Even at the height of employment in 2008, 360 US workers were electrocuted—nearly one per day. Electrical accidents are caused by a combination of three factors: hazardous equipment and/or installation, environmentally unsafe workplaces of employment, and dangerous work procedures. A growing number of drug abuse-related electrocution deaths also are taking place in workers under 25 years of age.

> Photovoltaic modules are energized while exposed to light. Installation, replacement, or servicing of array components while modules are irradiated can expose people to electric shock. (NEC 2011)
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There are four main types of electrical injuries:

- Direct injuries, such as burns, electric shock, or electrocution
- Secondary electrical injuries, such as falls due to electrical shock
- Concussions
- Eye damage

The seriousness of an electrical injury depends on the current flow path through the body, the amount current, and duration of the electrical current exposure. Low voltage does not mean low hazard! Shock-related injuries such as electrical burns are widespread. Touching electrical wiring or equipment that is not properly used or maintained is the main cause of electrical burns. They typically are to the hands, arms, or legs. They can be very serious and need immediate first aid.

NOTE

Currents above 10 mA can paralyze or freeze muscles.

NOTE

Rapid heartbeats can occur when electrical current is greater than a 75 mA flow through the body. The current flow can result in death in minutes unless a defibrillator is used. Small power drills use 30 times as many mA!

Electric shock is another injury that occurs during PV installations. Electric shock usually occurs with direct current. DC can continue to arc even as the conductors are separated. It allows the human conductor (an arm, leg, or any portion of the skin) to continue to experience the effects of electricity.

Use barriers and guards to stop electrical current. Two safety methods used to prevent electrical shocks and burns from live circuits are lockout and tagging.

- Lockout opens the circuit by locking down the alternating current (AC) or DC power source disconnect with a padlock.
- Tagging labels the deactivated controls, equipment, and circuits at all points where they can be energized.

TECH TIPS

Use three-wire flexible grounded extension cords on construction projects. They are designed for tough use in a work environment.

NOTE

Workers should treat every circuit as a hot circuit.

Protection from Falls

The primary cause of death in the construction industry is a fatal fall. Working on PV systems involves climbing ladders or scaffolds, or working on rooftops. Recognizing and mastering OSHA fall protection regulations is imperative for all PV installers.

OSHA requires fall protection for any situation where an employee can fall six feet or more. Fall protection is vital for work on roofs. It is necessary for walkways and ramps. Fall protection also is essential for work around holes and excavations.

Employers must provide training that empowers employees to recognize and minimize fall hazards. Training is required on

when and how to use fall protection systems and devices. Fall protection systems must be in place before work commences. There are several fall protection options, including personal fall arrest systems (PFAS), guardrails, and safety nets. Training is required on how to use PFAS, including the anchorages, lifelines, and body harnesses.

Personal Fall Arrest Systems (PFAS)

Properly using PFAS, such as anchorages, lifelines, and body harnesses requires education and training.

Guardrails

Open-sided floors and platforms require the use of guardrails to protect workers. The top rails must be between 39 and 45 inches tall. The guardrails also must have a mid rail. The lower rail, or toe board, should be at least 3 1/2 inches high.

Safety Nets

Work sites at least 25 feet above ground require safety nets. Safety nets catch falling workers and reduce fall-related injuries.

NOTE

Safety nets shall be provided when workplaces are more than 25 feet above the ground or water surface, or other surfaces where ladders, scaffolds, catch platforms, temporary floors, safety lines, or safety belts are impractical. (OSHA 1926.105(a))

Stairways and Ladders

On a job site, OSHA requires stairways and ladders at elevation breaks of 19 inches or more.

Stairs

Many job sites involve stairs. OSHA provides specific requirements in this area, such as:

- Install stairs at an angle of between 30 and 50 degrees.
- Handrails are required for stairways with four or more risers.
- Stairways with vertical rises every 12 feet are required to have landings that are at least 30 inches deep and 22 inches wide.
- All unprotected landings are required to have the customary 42-inch guardrail on all sides.
- Landings need to extend 20 inches if there is a door or gate to allow for the pivot of the door or gate.

NOTE

Handrails and the top rails of stair rail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890 n) applied within 2 inches (5 cm) of the top edge, in any downward or outward direction, at any point along the top edge. (OSHA 1926.1052(c)(5))

Ladders

- Use ladders only on dry, firm, and even surfaces.
- Do not paint wooden ladders.

- Space ladder treads evenly from 10 to 14 inches apart.
- When working around equipment that could cause electric shock, use only wooden or fiberglass ladders.
- Do not put more weight on a ladder than it's designed for—read the manufacturer's recommended loading, and act accordingly.
- Repair faulty ladders or label them as "Do Not Use."

NOTE

Fixed ladders should have one of the following: (1) a safety mechanism; (2) pulley or zip lifelines every 150 feet with rest areas; (3) various sections, each one no greater than 50 feet.

When a work site has 25 employees or more, use a double-cleated ladder with center rail. This is especially important when there is only one way to enter or exit a working area. Double-cleated ladders are also required where there is two-way traffic.

Hand and Power Tools

Hand and power tools can be hazardous. Injuries can occur from flying objects and metal splinters to harmful dusts. Workplace risks usually occur through mishandling and poor upkeep. Workers should follow these basic tool safety rules:

- Maintain the tool properly and regularly.
- Use the right tool for the job.
- Follow the manufacturer's instructions.
- Wear the proper personal protective equipment.

Equip power tools with the necessary safeguards. Each power tool has its own set of requirements for use. Those rules hinge primarily on the power source. When installing PV systems, workers will use electric power tools, air-filled tools, hydraulic tools, and tools that require liquids such as gasoline. Knowing the hazards associated with the power source will dramatically reduce the number of potential incidents.

Personal Protective Equipment

Personal protective equipment (PPE) protects workers from harm. Dangers, such as falling items, unsecure materials, and loud noises, can cause injury. Examples of PPE include:

- Safety glasses
- Face shields for eye and face safety
- Hardhats for head protection
- Steel-toed safety shoes for foot protection
- Armor for hands and arms, such as gloves
- Hearing protection devices, such as earplugs or earmuffs

Working Space for Electrical Systems

The NEC is very specific about working area and space requirements. Its requirements apply particularly when you are working with electrical equipment. The requirements for proper working space are essential for safety, maintenance, and usability. They preserve and protect safety in the electrical working space. They also keep the working space accessible.

Article 110.26 covers the requirements relative to working spaces. According to Article 110.26(a)(1-3):

- All electrical equipment requires at least three feet of clearance in front of it.
- Electrical equipment functioning at 600V necessitates 30 inches of working space in front of it.
- There needs to be at least six feet of headway clearance for the equipment.

Some PV installations may involve working in attic spaces. Working in an attic generally will require wearing PPE, such as breathing mask, eye protection,

(A) Working Space. Working space for equipment operating at 600 volts, nominal, or less to ground and likely to require examination, adjustment, servicing, or maintenance while energized shall comply with the dimensions of 110.26(A)(1), (A)(2), and (A)(3) or as required or permitted elsewhere in this Code.

(1) Depth of Working Space. The depth of the working space in the direction of live parts shall not be less than that specified in Table 110.26(A)(1) unless the requirements of 110.26(A)(1)(a), (A)(1)(b), or (A)(1)(c) are met. Distances shall be measured from the exposed live parts or from the enclosure or opening if the live parts are enclosed.

(2) Width of Working Space. The width of the working space in front of the electrical equipment shall be the width of the equipment or 762 mm (30 in.), whichever is greater. In all cases, the work space shall permit at least a 90 degree opening of equipment doors or hinged panels.

(3) Height of Working Space. The work space shall be clear and extend from the grade, floor, or platform to a height of 2.0 m (6 1/2 ft) or the height of the equipment, whichever is greater. Within the height requirements of this section, other equipment that is associated with the electrical installation and is located above or below the electrical equipment shall be permitted to extend not more than 150 mm (6 in.) beyond the front of the electrical equipment.
(NEC 2011, 110.26(a)(1–3))

and protective clothing. The PPE protect skin and face from insulation. Check out the level of safety hazard in the attic to ensure that it is a safe working space. If not, take the appropriate steps and action to protect the employee. Also, you should navigate the exits. An attic is not a usable working space if it can't support the weight of a person without risk of falling through the ceiling. An attic also needs plenty of lighting for employees to work safely and effectively. Make sure that workers do not stay in an attic for long periods, especially in hot weather. Remember that you and your workers must stay hydrated.

Photovoltaic (PV) Modules

Avoid electric shock when working with PV modules. (A **module** is the smallest unit in a PV array, containing many PV cells.) This is a warning to heed, especially when there are several PV modules connected together. High voltages of 400–600 DC are frequent in strings. When exposed to sunlight or intense artificial light, PV panels should always be treated as "hot." The electric current can arc between the open wire ends on modules and anything—or anyone—that will complete the circuit.

Potential short circuits may not blow any fuses. However, the circuits might produce a very intense DC arc between the wires. Temperature can reach as high as 10,000 degrees Celsius (18,000 degrees Fahrenheit). DC arcs are fire and burn hazards. They may cause ultraviolet exposure, burns, or damage to the eyes. Arcs may surprise installers by distracting or stunning them. This could cause them to miss a step or lose footing.

Batteries can be the most dangerous component in a PV system. When improperly handled or installed, bad things can and often do happen. Batteries can store thousands of amps and discharge them in seconds. A short in the battery, a cable, or damage to a terminal can cause arcs, shocks, fires, and explosions. In addition, batteries used in PV systems give off hydrogen and other corrosive gases. These gaseous combinations can create problems. Corrosion or explosions can occur as a by-product if the gases become trapped and ignited by a flame. Proper venting and charging will reduce hydrogen concentration before the mixture becomes explosive.

- Triple check the voltage meter's polarity when connecting a battery or battery groups to complete a circuit.
- Vent battery containers at the top to allow an airflow path for the hydrogen to escape.
- Place batteries in a proper containment space that can hold the entire battery and its fluids in the event of a spill or broken container.
- Keep the battery storage cabinet out of the sun, and provide moderate temperatures as recommended by the manufacturer.
- Do not place batteries directly on concrete.
- Keep batteries, cables, and terminals clean.

NEC BATTERY SAFETY

Insulation of Batteries of over 250 Volts. The provisions of 480.6 shall apply to storage batteries having the cells connected so as to operate at a nominal voltage exceeding 250 volts, and, in addition, the provisions of this section shall also apply to such batteries. Cells shall be installed in groups having a total nominal voltage of not over 250 volts. Insulation, which can be air, shall be provided between groups and shall have a minimum separation between live battery parts of opposite polarity of 50 mm (2 in.) for battery voltages not exceeding 600 volts.

480.8 Racks and Trays. Racks and trays shall comply with 480.8(A) and (B).

(A) Racks. Racks, as required in this article, are rigid frames designed to support cells or trays. They shall be substantial and be made of one of the following: (1) Metal, treated so as to be resistant to deteriorating action by the electrolyte and provided with nonconducting members directly supporting the cells or with continuous insulating material other than paint on conducting members; (2) Other construction such as fiberglass or other suitable nonconductive materials.

(B) Trays. Trays are frames, such as crates or shallow boxes usually of wood or other nonconductive material, constructed or treated so as to be resistant to deteriorating action by the electrolyte. 480.9 Battery Locations. Battery locations shall conform to 480.9(A), (B), and (C).

(A) Ventilation. Provisions shall be made for sufficient diffusion and ventilation of the gases from the battery to prevent the accumulation of an explosive mixture.

(B) Live Parts. Guarding of live parts shall comply with 110.27.

(C) Working Space. Working space about the battery systems shall comply with 110.26. Working clearance shall be measured from the edge of the battery rack.

480.10 Vents.

(A) Vented Cells. Each vented cell shall be equipped with a flame arrester that is designed to prevent destruction of the cell due to ignition of gases within the cell by an external spark or flame under normal operating conditions.

(B) Sealed Cells. Sealed battery or cells shall be equipped with a pressure-release vent to prevent excessive accumulation of gas pressure, or the battery or cell shall be designed to prevent scatter of cell parts in event of a cell explosion.

(NEC 2011, 480.7 – 480.10)

- Electrical equipment must not be placed above batteries.
- Use electrically insulated tools to reduce shock and shorting hazards.
- All tools used around batteries must be counted and removed after installation or maintenance to reduce any accidental electrical hazards.
- Treat batteries with extreme caution when installing or working on or around them.

NOTE

Keep baking soda close by when using lead-acid batteries. In the event of a leak or spill, baking soda neutralizes the battery acid fluid.

Use vinegar to diffuse nickel-cadmium battery alkaline electrolyte spills. The acetic acid in vinegar neutralizes the nickel-cadmium's strong base.

Pay special attention to the characteristics of the batteries. **Lead-acid batteries** should not have a depth of discharge (DOD) below 50 percent and preferably not below 20 percent; otherwise battery life and the number of battery charge and discharge cycles will be dramatically reduced. Nickel-iron batteries can perform well with a 50 percent DOD. For other types of batteries, consult the manufacturer or an experienced battery representative for appropriate DODs.

- Battery acids and alkaline electrolytes are corrosive to most materials and skin, so use PPE to protect your skin and eyes.
- Wear protective clothing, such as a leather or plastic apron and gloves.
- Provide plenty of room to workers for battery maintenance, including watering, torquing connections, and cleaning components.
- Use proper lifting techniques and equipment for batteries—they are often heavy.

Make sure the battery overcurrent device has an interrupting rating strong enough to stop the battery short-circuit current. An appropriate interrupting rating protects all of the PV components, as well as all PV workers. This is especially true in cases where the battery terminal has currents greater than 10,000 amps. A major flow could cause the battery to explode. It could cause serious injury to anyone around it.

Cold climates can cause battery acid to freeze. The proportion of battery acid freezing continues to increase as the batteries toil. If a battery freezes, *do not charge it*. Let batteries thaw slowly in the containment space, which can hold the fluid if the battery shell should crack.

Marking and Labeling Requirements

Marking or **labeling** is required on all interior and exterior PV components, such as disconnects, subpanels, SES, PV breakers, and other items as required by code. Marking provides warning and guidance for others. All appropriate PV equipment should be labeled as well. Labeling indicates the location of the disconnecting means that provide isolation from the source of electricity. Most PV installers use preprinted metal labels to mark PV equipment. Preprinted metal labels will not fade or fall off if attached properly, and many job hazard analysis (JHA) technicians and utilities now require metal labels because of their readability and longevity.

Marking

Many PV systems conductors and components must be clearly labeled and marked. **Marking** identifies the energized electrical line. Never slice or cut into energized electrical lines, and when cutting into any electrical line, check the

marking and or labeling to know what you are working with, and then make sure it is locked out. "Marking is required on all interior and exterior PV conduit, raceways, enclosures, cable assemblies, and junction boxes to alert the fire service to avoid cutting them." (NEC 2011, 690.31(e)(1))

Main Service Disconnect

"Each photovoltaic system disconnecting means shall be permanently marked to identify it as a photovoltaic system." (NEC 2011, 690.14(c)(2).) For residential applications, mark within the main service disconnect panel. If the main service disconnect is workable with the disconnect panel closed and locked, then mark the outside of the panel. When using main service disconnects commercially, label the disconnect so that it is clearly visible from the operation lever.

Marking Content and Format

Most PV installers use preprinted metal labels for marking PV equipment. The labels must have the following layout:

- Always label content as per the NEC.
- Write in all capital letters.
- Use a red background with white lettering.
- Letters must be at least 3/8 inch high.
- Use Arial font, non-bold.
- Use reflective, weather-resistant materials.

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

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

(NEC 2011, 690.51)

Marking for Direct Current Conduit, Raceways, Enclosures, Cable Assemblies, and Junction Boxes

"All interior and exterior DC conduit, raceways, enclosures, cable assemblies, and junction boxes are marked every 10 feet." (NEC 690.31(d)(2).) All DC combiner and junction boxes are marked as well. This alerts the fire service to avoid cutting them.

Inverters

An inverter converts sunlight into AC electricity. The device transforms DC electricity from the PV modules to AC electricity for use in the building's electrical system or the grid.

Labeling and marking of the inverter shall be in accordance with NEC 690.5(c). Warnings need to be listed for all operating conditions in which the normally grounded conductor may become ungrounded.

Labeling

The NEC requires labeling every appropriate component of PV systems. Workers should use drawings and photos to help identify all the equipment. Schematics help ensure that everything is labeled properly. This aids the PV workers during maintenance and system testing. That way they know where every component is located when they are addressing voltage, current, and AC and DC issues.

Workers must identify all source circuits with permanent markings such as wire tabs or other numbering methods. Some systems are quite complex. They should label all the points of connection as they relate to locations on the PV

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

WARNING

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

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

(NEC 2011, 690.5(c))

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

1. Exposed raceways, cable trays, and other wiring methods
2. Covers or enclosures of pull boxes and junction boxes
3. Conduit bodies in which any of the available conduit openings are unused
4. Marking and Labeling Methods and Locations. The labels or markings shall be visible after installation. Photovoltaic power circuit labels shall appear on every section of the wiring system that is separated by enclosures, walls, partitions, ceilings, or floors. Spacing between labels or markings, or between a label and a marking, shall not be more than 3 m (10 ft). Labels required by this section shall be suitable for the environment where they are installed.

(NEC 2011, 690.31 (3) – (4))

system drawings. This makes system checkout and maintenance easier. The NEC requires a long list of labels, including:

- Ground-fault protection device [NEC 690.5]
- System disconnects—Each PV disconnecting means in the system shall be permanently marked to identify it as a PV system disconnect. [NEC 690.14(c)(2)]
- Open energized terminals should say the following: "WARNING. ELECTRIC SHOCK HAZARD. DO NOT TOUCH TERMINALS. TERMINALS ON BOTH THE LINE AND LOAD SIDE MAY BE ENERGIZED IN THE OPEN POSITION." (NEC 690.17)

NOTE

Disconnects may not be located in bathrooms.

Local code offices, inspectors, and the local utility have the final say in all installations. Labeling every appropriate component will enable the PV inspector to verify proper conductor ampacity. They will also check equipment against drawings. They will be able to confirm overcurrent device ratings. Labeling also allows the user to compare system performance with the manufacturer's specifications.

Access, Pathways, and Smoke Ventilation Requirements

Roof access points are places where nothing can block the opening. They are located at load bearing positions within the building's structure. They are not to

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

(NEC 2011, 690.14(c)(2))

be obstructed by tree limbs, mechanical equipment, or other equipment or wires. Workers need to observe access and spacing requirements, including those that:

- Ensure access to the roof
- Grant clear paths to particular spaces on the roof
- Do not interfere with aeration for smoke ventilation
- Allow emergency exits

Local authorities may have different requirements than those above. Conditions for access, pathways, or ventilation may include the following:

- Proximity and type of nearby exposures
- Other access opportunities
- Access to roof from the ground
- Solar array ventilation
- Other aeration prospects
- Automatic ventilation device
- New technology or methods that make access safe and easy for fire departments

Residential Systems—Single-and Two-Unit Residential Dwellings

It is advisable to examine the local, state, and national requirements for residential access, pathways, and smoke ventilation. Many in the fire protection industry recommend that PV systems taking up more than 50 percent of the roof area be reviewed. This review will look at access, pathways, and smoke ventilation. The following information comes from the California Department of Forestry and Fire Protection's Solar Photovoltaic (PV) Installation Guideline.

Access

Homes with hip roof layouts should have modules with at least one clear access pathway that is three feet wide. Place this pathway at a bearing wall. Bearing walls are structurally strong enough for this.

Residences with a single ridge should have two access pathways three feet wide. The best location for these pathways is from the eave to the ridge. Each roof slope with modules should have a pathway.

Houses with hips and valleys should have PV modules one-and-one-half feet to a hip or a valley. The requirement is contingent on the PV module placement on both sides of a hip or valley.

Smoke Ventilation

Place PV modules three feet below roof ridges for the best smoke ventilation.

Commercial Buildings and Residential Housing—Three or More Units

Access

The roof requires a clear perimeter at least six feet wide around the edges of the roof.

Exception: Building axes 250 feet or less must have a clear perimeter at least four feet wide around the edges of the roof.

Pathways

Pathways should take into account the solar installation plan. Pathways adhere to the following guidelines:

- Place pathway over structural elements such as rafters.
- Provide pathway on both axes of the roof.
- Run pathways as close as possible to the centerlines while following the roof structure.
- Pathways should be routed to steer clear of skylights, roof structures, such as chimneys, and ventilation hatches.
- Install roof access openings with one four-foot-clear pathway to roof edge.

Smoke Ventilation

Here are several ventilation options between array sections:

- Pathways eight feet or wider
- Areas with roof skylights or ventilation hatches require at least four-foot pathways
- Large roof areas require four-foot or wider pathways bordering 4 x 8 feet every 20 feet on alternating sides of the pathways

Location and Protection of Direct Current (DC) Conductors

Wiring and conduit should be located as close as possible to an outside wall. This reduces tripping. It also maximizes aeration.

The conduit between sub-arrays and to the DC combiner box should be designed to take the shortest path possible. Run DC wiring in metallic conduit when it is located within a building. This limits the risk of cutting live circuits when installing the ventilation or any reconstruction on the building. Consider using metal conduit on the roof and wherever the conduit is in direct sunlight for reduced long-term maintenance in extreme climates. This provides longevity and wire protection.

The location of the DC conductor is important. It should also be protected from the environment.
Courtesy of PerfectPower

Non-habitable Building Requirements

PV arrays can be used on a variety of structures. **Non-habitable buildings**, such as parking structures, are great for PV power system installation. However, they must offer suitable solar exposure. Each building is already grounded. The electrical isolation needed for PV panels and their components is already provided.

Ground-Mounted PV Arrays

Ground-mounted outdoor PV array installations can be set up in a variety of ways. The most important factor in installing modules is the PV module

Where the conductors of more than one PV system (sub-array or inverter) occupy the same junction box or raceway with removable cover(s), the AC and DC conductors of each system shall be grouped separately by wire ties or similar means at least once, and then shall be grouped at intervals not to exceed six feet.
(NEC 2011, 690.4 (4))

orientation and panel slope. Since solar rays vary seasonally, the tilt angle of the PV array should be sloped at approximately the local latitude minus 9 or 10 degrees to get the greatest gain. Off-grid systems may be adjusted to provide the highest energy gain during the months or seasons where additional energy is required. In the Northern Hemisphere, solar panels are mounted on a north-south tilt. The high end is north.

Ground-mounted solar arrays should be built in areas clear of vegetation that could burn. Provide sufficient clearing around the PV array for at least 10 feet to eliminate shading. Check with local building authorities to see if other regulations apply.

Chicago Center for Green Technology (CCGT) ground mount, 32.4 kW system.
Courtesy of DOE/NREL

Safe Design of PV Systems—What the NEC Says

The National Electrical Code covers the legal requirements for every PV system installed in the United States. The NEC is the go-to guide for legal requirement for installing electrical systems. Regulations are updated every three years. As a result, regulations keep up with new technologies as technologies change. Article 690 is all about PV systems. It includes information on:

- Circuit requirements
- Disconnecting means
- Wiring methods
- Grounding
- Marking
- Batteries

The NEC requires the following when designing PV systems:

- System and current voltage
- Wiring and disconnect requirement
- Grounding
- PV system output

System and Current Voltage Code

When designing a PV system, consider the following:

- Use PV system open-circuit voltage rating.
- Voltages must be less than 600 volts. (NEC 2011, 690.8)

- Make sure PV source circuits, inverters, and battery conductors have **overcurrent protection** (fuses or circuit breakers). (NEC 2011, 690.9)
- Overcurrent protection should bear 125 percent of the short-circuit current from the source circuit. (NEC 2011, 690.9)

Wiring and Disconnect Requirements

Article 690.3 discusses NEC wiring methods:

- The ground conductor is white or gray. Equipment ground is green or bare.
- The first undergrounded conductor is typically red. It can also be any color other than green or white/gray.
- The second undergrounded conductor is black.
- Use sunlight-resistant cables for all exposed cables.

There are also specifications for disconnecting the power source:

- Clearly label junction boxes and switches. [NEC 690.17]
- Make sure junction boxes and switches are accessible. [NEC 690.17]
- Be able to disconnect and isolate all PV source circuits. [NEC 690.13]
- Disconnect all underground **converters** from the inverter. [NEC 690.15] (A converter is a unit that converts one DC voltage to another DC voltage.)
- Detach fuses from both ends. [NEC 690.16]

Grounding Code

Grounding means making a connection to the ground to dissipate electrical energy. It is very important in PV installations. Grounding often involves putting a metal rod deep into the soil. It prevents unwanted current from flowing into the wrong places. Unwanted currents can cause equipment damage, personal injury, or death. Proper grounding and overcurrent protection limit damage that ground faults cause. There are two parts of the PV system that need conductor protection—the equipment and the modules.

Junction boxes and disconnects allow you to isolate the arrays from the rest of the system.

Courtesy of PerfectPower

Electrodes permitted for grounding include metal underground water pipes, metal frame of a building or structure, concrete-encased electrode, a ground ring, rod and pipe electrodes, and plate electrodes. Do not use metal underground gas piping systems or aluminum.

> A single-conductor, sunlight-resistant, outdoor-rated cable used as a grounded conductor in photovoltaic power systems, as permitted by 690.31, shall be identified at the time of installation by distinctive white marking at all terminations.
> (NEC 2011, 200.6 (6))
>
>

Equipment Grounding

Equipment grounding conductors should be a bare wire or a green wire. [NEC 690.41] They need to handle the highest current that could flow through the circuit. [NEC 690.41–690.44]

PV Module Grounding

Article 690.5 discusses grounding and fault protection:

- Use a single ground point.
- Ground one conductor (> 50 volts V)).
- Ground the neutral wire of a three-wire system.

Safety Hints for Testing a PV System

Before testing any PV system, know the answers to the following questions:

- What are the system voltages?
- What are the system currents?
- How many circuits are there?
- What are the overcurrent devices?
- Where are the overcurrent devices?
- Where is the system disconnected?
- Where is the safety equipment located?

After those questions are answered, then it is time to go to the PV system site. When at the PV system site, always take these precautionary measures:

1. Take off any jewelry.
2. Walk around the system and document any dangerous circumstances—write them down and take pictures.
3. Locate the inverter and battery.

4. Check system grounding.
5. Inspect all the system disconnect switches.
6. Check all the fuses.
7. Sever the source circuit, tag, and lockout if working on the PV system.
8. Calculate the open-circuit voltage for each string.
9. Measure the voltage from each connector to the ground.
10. Gauge the voltage from line to line.

Once the circuits are tested, the PV system testing can begin. Remember: *Do not test the PV system alone*, and always take these steps:

1. Keep hands dry.
2. Put on insulating gloves.
3. Use only one hand if possible.
4. Have someone at the disconnect switch.
5. Keep work area clear.
6. Measure wire voltage before disconnecting it.
7. Tape the end of any disconnected wire.
8. Reconnect source circuit wires before disconnecting another.

Chapter 2 Summary

This chapter focuses on safety practices when installing, connecting, and operating PV power systems. The tips and recommendations encourage working safely with PV systems. Specific safety components aid the steps of installing PV systems. Marking and labeling requirements help identify live electrical circuits and locate different parts of the PV system. Safety hints ensure that PV system testing and operating are smooth.

Key Concepts and Terms

Converter
Labeling
Lead-acid battery
Marking
Module
National Electrical Code (NEC)
Non-habitable building
Occupational Safety and Health Administration (OSHA)
Overcurrent protection
Personal protective equipment (PPE)
Volt (V)

Chapter 2 Assessment

Essential Safety Practices for Designing and Installing PV Systems

1. A stairway or ladder is required for every 19-inch elevation break on a job site, as required by OSHA.
   - ❑ **A.** True
   - ❑ **B.** False
2. What mA electrical current can paralyze muscles and cause falls on a jobsite?
   - ❑ **A.** 10
   - ❑ **B.** 30
   - ❑ **C.** 50
   - ❑ **D.** 75
3. What are lockout and tagging used for?
   - ❑ **A.** Removing hazards prior to energizing equipment
   - ❑ **B.** Preventing people from energizing electrical circuits while they are being serviced

- ❑ **C.** Disabling a PV system from being interconnected to the utility grid until inspections have been passed
- ❑ **D.** Identifying and isolating defective components in an electrical system until service can be performed

4. What is the purpose of ground-fault protection devices?
- ❑ **A.** They interrupt the circuit below the fuses or breaker-disconnect amperage, before electric shock can drive the heart into ventricular fibrillation.
- ❑ **B.** They reduce the probability of electrical shock to service personnel.
- ❑ **C.** They limit losses of the PV-output energy to ground.
- ❑ **D.** They reduce ruin of structural supports from rapid electrolysis.

5. What should not be done if the electrolyte freezes?
- ❑ **A.** Discharge the battery.
- ❑ **B.** Charge the battery.
- ❑ **C.** Heat with a hair dryer.
- ❑ **D.** Remove the battery.

6. What color are equipment-grounding conductors?
- ❑ **A.** White
- ❑ **B.** Black
- ❑ **C.** Green
- ❑ **D.** Orange

7. OSHA requires fall protection where an employee or worker can fall how many feet?
- ❑ **A.** 4
- ❑ **B.** 6
- ❑ **C.** 8
- ❑ **D.** 10

8. Which of the following devices does the NEC require to be a part of PV systems mounted on residential dwellings?
- ❑ **A.** Utility interconnection
- ❑ **B.** Stand-off mount for the PV modules
- ❑ **C.** Accessible source-circuit combiner box
- ❑ **D.** Ground-fault device

9. The purpose of an inverter is to convert:
- ❑ **A.** AC at one voltage to DC at the same voltage.
- ❑ **B.** DC voltage to AC voltage.
- ❑ **C.** AC at one voltage to AC at the same or another voltage.
- ❑ **D.** DC at one voltage to DC at another voltage.

10. What is the best method to avoid electrical shock while troubleshooting a PV system?

- ❑ **A.** Wear protective gear, turn off switches, and measure voltages and currents.
- ❑ **B.** Inspect all questionable terminals, wear rubber gloves, and turn off all switches.
- ❑ **C.** Keep one hand behind your back, with all switches turned off, and touch only grounded surfaces.
- ❑ **D.** Wear shoes with soft rubber soles, turn off all switches, and don't touch metal surfaces.