PV Systems Safety

An Online Continuing Education Course for Engineers

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PV Systems Safety

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This course provides helpful and easily-accessible instructions on how to work safely with PV systems. The course includes a description of specific hazards, their frequent causes, and ways to prevent and avoid them.

This course has three different sections:

- The PV System Characteristics and Hazards section provides the background of PV system characteristics and relevant hazards involved with PV systems. Recommended safe-guards are provided.
- The Safe PV Systems section presents a discussion of relevant safety standards and codes, and regulations that need to be followed and applied when designing, installing, testing and commissioning a PV system.
- The "For Your Health" section contains a discussion of possible injuries and elaborates on basic First Aid concepts.

Safety is a permanent responsibility of every technician or engineer. Practicing safety requires:

1. Good work habits and a clean and tidy work area
2. Adequate tools and equipment and their use
3. Awareness of hazards and how to prevent them
4. Training in CPR (cardiopulmonary resuscitation) and First Aid
5. Periodic reviews and assessment of safety processes

This course provides safety instructions for people who work with photovoltaic (PV) installations. Photovoltaic systems generate direct current (DC) power from sunshine. This energy may be transferred to DC loads or kept in electrochemical batteries for use when there is no sunshine. Also, direct current can be inverted to alternating current (AC) power for AC loads or for export to an electric transmission or distribution network. This versatility of PV energy is one of the main reasons it is being utilized in an increasing number of applications.

A PV array consists of individually framed PV modules that are electrically linked to generate the voltage and current needed by the electric load. When exposed to sunshine, the most frequently available PV module generates about 22 V DC when open circuited and about 15 V when working at its peak power output. A 1' x 4' module with 4-inch square PV cells functioning at this voltage will generate about

3 A, in full sunshine. This is sufficient current and voltage to induce injury under worst case circumstances. If an array consists of more than two modules connected in series, the shock hazard grows. When working and operating any PV system, the safeguards described below should be heeded.

1. The best safety method is an alert mind, a doubting nature, and a slow hand.
2. Never work on a PV installation alone.
3. Know the PV and associated electrical system before you start to perform work.
4. Discuss the test goals and methods with your partner. Observe and understand PV system electrical diagrams and connections.
5. Keep your test equipment in top operating condition. Inspect your test equipment and tools before you go to the PV system site.
6. Wear appropriate clothing. Wear an approved electrical safety hat. Wear eye protection, particularly if working on batteries. Remove jewelry. Wear dry leather gloves to reduce the probability of getting electrically shocked.
7. Measure first. Measure and record the conductivity from exposed metal frames and junction boxes to ground. Measure voltage from all conductors (on the PV system output circuit) to ground. Measure and record the operating voltage and current. Use only one hand whenever feasible.
8. Question everything. Expect the unforeseen and surprises. Do not presume that switches always function, that the actual installation matches with the electrical schemes, that current is not going through the grounding conductors, etc.

PV system characteristics and hazards

PV installations are made to satisfy a particular load and are rarely consistent in schematic and element usage. Some PV systems that are connected to electricity grid use hundreds of modules linked in series and parallel to generate large quantities of energy. Operating voltages may surpass 600 V DC and currents at the subfield level may be hundreds of amperes. Many stand-alone PV installations have fewer modules but use batteries to keep power for later use. One of the common

12 V batteries can generate over 6000 A if shorted--serious burns and injuries can happen. The point is, each installation presents hazards to engineers, technicians and maintenance staff. Helping you distinguish these hazards and avert injury is the main goal of this course.

PV system characteristics

The PV effect can be made with several different materials. However, there is a limited number that are technically feasible. Few elements with commercial potential are shown in Table 1. Since over 99.9% of PV power installations in service today use crystalline silicon material, we will focus our attention to these cells. Unless specially mentioned otherwise, reference to a PV cell system will mean a crystalline silicon PV cell system.

Table 1. Commercially used PV materials

Material	Typical cell voltage at open-circuit	Typical cell current at short-circuit
Crystalline and Polycrystalline Silicon (x-Si)	~0.6 V	~ 35 mA/cm2
Gallium Arsenide	~ 1 V	~ 27 mA/cm2
Amorphous Si (a-Si)	~0.9 V	~15 mA/cm2
Tandem a-Si (Two-cell)	~1.8 V	~10 mA/cm2
Copper-Indium Diselenide (CIS)	-0.4 V	~35 mA/cm2
Cadmium Sulfide, Cadmium Telluride	-0.7 V	~25 mA/cm2

The voltage on a PV cell system quickly grows when illuminated and reaches its peak value even at low solar conditions. For this reason, any PV installation should be treated electrically "hot" during the daytime. Each PV cell, regardless of its surface, generates around 0.6 V DC when open-circuited and exposed to sunshine. The current output of a cell directly changes with its surface and the solar irradiance. A 4-inch square cell generates around 3 A, in full sunshine.

A PV module system is a laminated, environmentally-sealed pack of PV cells, typically linked in series to generate a usable voltage. The more typical PV modules consist of 35-40 cells in series and produce an open-circuit voltage of around 22 V D.C.

When a number of PV modules are linked in series to produce the voltage needed to service the load, the scheme is called a source circuit (also called a string). A PV array contains parallel-connected source circuits that produce the current needed to meet the power requirements of the load. For bigger systems, several source circuits may be grouped and routed through big DC disconnect breakers. Such a grouping is called a sub-array or subfield. The PV system consists of not only the source circuits or sub-arrays, but also the related power conditioning, protection and safety elements, and support structures.

The current-voltage feature (I-V) curve of a PV module, source circuit, or array is particular to that device but all I-V curves have approximately the same shape. An I-V curve can be found by modifying the impedance linked to the device output. At each point on the curve, the current-voltage product is the power of the equipment at that point. For each curve, there is only one point at which the power is the highest. This is the largest surface rectangle that can be drawn under the curve. This point is called the maximum power point, Pmax, and is the favored operating point for majority of applications. Other points of interest are the short-circuit current, Isc, and the open-circuit voltage, Voc. If the equipment is required to function in the second or fourth quadrant (negative voltage or current), it must dissipate power. This will induce heating and early fault. Bypass diodes are utilized in most arrays to limit the negative voltage across a cell.

The current of the PV cell grows linearly with solar irradiance and/or the surface of the cell. The power output of silicon PV equipment reduces with growing temperature. The current of the equipment grows somewhat with temperature, but the voltage reduces at a more rapid rate. The result is a reduction in power of 0.4-0.6 % per °C.

System types

PV systems are organized in few different ways. Some common categorizations are:

1. Stand-Alone system: A PV system that is not interconnected to the electricity transmission network. Most stand-alone PV systems utilize batteries to keep the energy generated during daylight hours for use at night or on cloudy days.

2. Grid-Connected system: A PV system connected to the electric transmission or distribution electricity network. The energy not used by the loads is exported to the electricity network; the load can get the energy from the electricity network when the PV system is not producing enough to meet demand.

3. Flat-Plate system: A PV system consists of modules that are flat in geometry and use natural (unfocused) solar irradiance. They utilize both direct beam and diffuse (or scattered) solar irradiance to generate electrical power, and some energy is produced even on cloudy days. The sum of direct and diffuse solar irradiance is called total global irradiance.

4. Concentrator system: A PV system consists of modules that contain focusing optics as part of their installation. They utilize only the direct beam solar irradiance. Since only the direct beam irradiance can be concentered by lenses or mirrors, a focusing system will not produce energy on cloudy days. The high intensities generated by these modules also generate acute heating that must be dissipated by active or passive cooling systems.

5. Fixed-Tilt system: Any PV array with modules at a constant tilt angle and orientation. The array may be installed on a rooftop, on a pole, or on the ground. These systems utilize flat-plate modules only, since concentrator modules must track the sun to catch the direct beam irradiance.

6. Tracking system: A PV system with modules installed on a tracking unit that follows the sun. Single-axis trackers follow the sun daily from east to west, and two-axis trackers include elevation control to adapt for seasonal north-south sun movement. Tracked systems are more costly than fixed-tilt installations, but also generate more electric power per unit surface because they follow the sun and "see" the maximum irradiance at all times. Tracking installations may employ either flat-plate or concentrator modules.

7. Hybrid system: Any installation with more than one power source.

Balance of systems

The balance-of-systems (BOS) is determined as everything except the PV modules and the load. The BOS consists of:

1. The land, fencing, facilities, etc.
2. Module support installations
3. External wiring and connection boxes
4. Power conditioning elements-- inverters, controllers, transformers, etc.
5. Safety and protective elements-diodes, lightning protection, circuit breakers, ground rods and cables, etc.
6. Batteries
7. Electricity network interface and connection devices
8. Weather equipment (pyranometers, thermometers, anemometers, etc.)
9. Data acquisition devices for monitoring and evaluating the PV system operation

System hazards and related recommendations

You can get harmed operating on any PV installation. Cuts, burns, falls, and sprains hurt just as much and induce as much lost time as the electrical shock and burn hazards typically thought of. Even though, main safety recommendations are just simple common sense, technicians, engineers and operational people still get injured in industrial accidents. Luckily, just a few have been hurt operating PV installations—no deaths have been reported. The objective is to decrease the number of injuries to zero. This needs good work habits, awareness and knowledge of potential hazards and a program where safety recommendations are usually reviewed. The responsibility is yours.

Non-Electrical Accidents

There is a wrong belief among many that you can't get injured working on a small PV installation. Anyone who has witnessed a car battery explosion could argue this statement. Safety should be first in the mind of anyone operating PV installations. Some common accidents that may be found are elaborated below.

Exposure

PV installations are mounted where the sun is the brightest and no shade exists. When you work on a PV installation you should wear a hat, keep the limbs covered, and/or use enough lotion with a sunscreen factor of 15 or higher. In the summertime, consume a lot of liquid-never alcoholic-and take a break and get into the shade for a few minutes each hour. During wintertime, dress warmly and wear gloves whenever possible.

Insects and snakes

Spiders, wasps, and other insects often inhabit junction boxes in PV installations. Some wasps make nests in the array framing. Rattlesnakes use the shade made by the array and fire ants are typically located under arrays or near battery boxes. Be ready for the unexpected when you open junction boxes. Look cautiously before you crawl under the array. It may sound funny, but fire ants or black widow spiders (let alone rattlesnakes) can induce painful injury.

Burns and cuts

Majority PV installations consist of metal framing, junction boxes, bolts, nuts, guy wires, anchor bolts, etc. Many of these elements are sharp and can induce injury if you are not cautious. Wear gloves when working with metal, especially if you are drilling or sawing. Slivers from metal made by drilling bit usually remain around a hole and these can cause serious cuts to a bare hand. Wear a dielectric hard hat if you are working under an array or on an installation with hardware higher than your head.

Falls, sprains, and strains

Many PV installations are mounted in remote locations in rough terrain. Walking to and around the remote site, especially carrying materials or test devices, can end up in falls and/or sprains. Wear comfortable safety shoes, preferably with soft soles. Steel toe reinforced safety shoes should not be worn around PV installations because they decrease the resistance of a potential current path. Be cautious when lifting heavy equipment and elements, especially battery packs. Lift with the legs and not the back to prevent back strains. If climbing is needed, make sure the ladder is securely placed on the ground and keep in mind a PV module can act as a wind sail and knock you off a ladder on windy days.

Thermal burns

Exposed metal outdo ... manipulate and operate, but is unlikely to induce b ... PV installations pose an additional hazard from ... ate up to 400 suns on the PV cell. This additional the ... ng systems with temperatures far surpa...

Instant contact can indu ... a heat transfer fluid that can scald flesh (it may al ... PV installations in the summertime. Inspect the ... oling elements.

Acid burns

Most stand-alone PV insta ... attery packs are the lead-acid type and the hyd ... f the acid gets in touch with an exposed part of th ... ou are working around lead-acid battery packs you ... ctive eye wear, and a neoprene coated apron.