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# PV Systems Safety

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# PV SYSTEMS SAFETY

This course was made as a reference with helpful and easily-accessible instructions on how to work safely with PV systems. Some recommendations are based on the common sense and they will help readers to keep safe. Course includes description of specific hazards, their frequent causes, and ways to prevent and avoid them.

This course has three different sections:

1. 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.

2. 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.

3. 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 needs:

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 jewellery. 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 a number of 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, a number of 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, $P_{max}$, and is the favoured operating point for majority of applications. Other points of interest are the short-circuit current, $I_{sc}$, and the open-circuit voltage, $V_{oc}$. If the equipment is required to function in the second or fourth quadrant (negative voltage or current), it will have to 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.