Working Safely with Photovoltaic Systems

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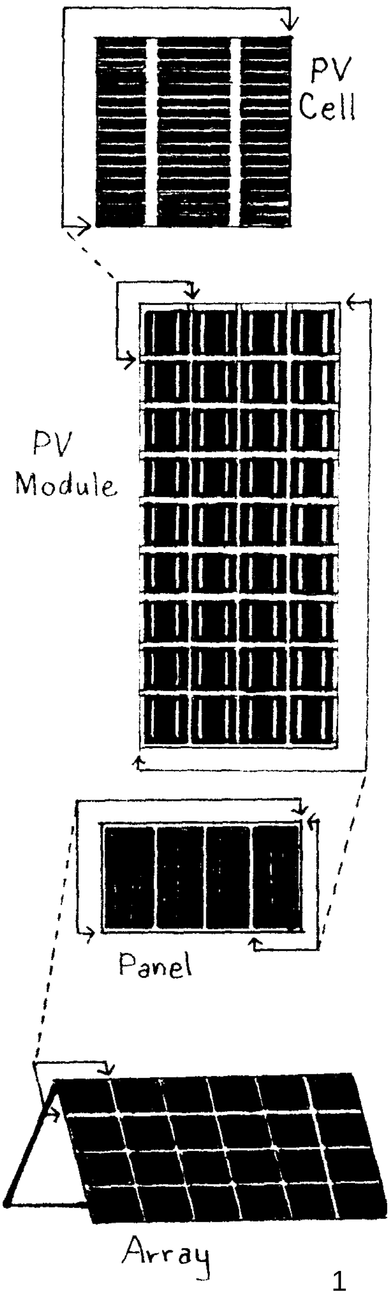
1.0 Introduction

Safety is a full-time and the responsibility of every employee. Practicing safety requires:

- Good work habits and a clean work area
- Proper equipment and its use
- Awareness of hazards and how to avoid them
- Training in CPR (cardiopulmonary resuscitation) and First Aid
- Periodic reviews of safety procedures

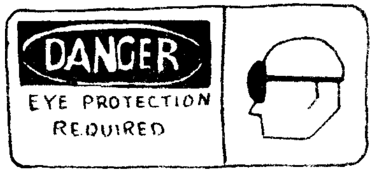


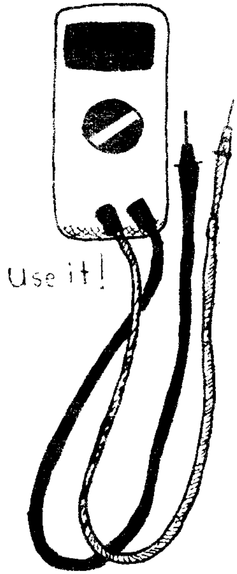
This booklet contains safety recommendations for people who work with photovoltaic (PV) systems. Photovoltaic systems produce direct current (dc) power from sunlight. This power may be directed to dc loads or stored in electro-chemical batteries for use when the sun is not shinning. Also, it can be inverted to alternating current (ac) power for ac loads or for transfer to an electric utility grid. This versatility of PV power is one reason it is being used in an increasing number of applications.

A PV array is made up from individually framed PV modules connected electrically to produce the voltage and current required by the load. When exposed to sunlight, the most commonly available PV module produces about 22 volts dc when open circuited and about 15 volts when operating at its peak power output. A 1’ x 4’ module with 4-inch square cells operating at this voltage will produce about 3 amperes in full sun. This is enough current and voltage to cause injury under worst case conditions. If an array contains more than two modules in series, the shock hazard increases. When working with any PV system, the precautions listed below should be heeded.

- The best safety system is an alert mind, a skeptical nature, and a slow hand.
- Never work on a PV system alone!!
- Know the system before you start to work on it. Discuss the test objectives and techniques with your partner. Study electrical diagrams of the system.

- Keep your test equipment in top operating condition. Check your test equipment before you go to the system site.
- Wear appropriate clothing. Wear an approved electrical safety hat. Wear eye protection, particularly if working on batteries. Remove any jewelry. Wear dry leather gloves to reduce the probability of getting shocked.
- Measure first -- always measure! Measure the conductivity from exposed metal frames and junction boxes to ground. Measure voltage from all conductors (on the PV output circuit) to ground. Measure the operating voltage and current. Work with one hand whenever possible.
- Be skeptical. Expect the unexpected. Do not assume that switches always work, that the actual configuration agrees with the electrical diagrams, that current is not flowing in grounding circuit, etc.





2.0 About This Booklet

This booklet was written for use as a reference and a handbook with helpful and easily-accessible information on how to work safely with photovoltaic systems. It contains common-sense recommendations that will help keep you safe. It contains information on specific hazards, their common causes, and ways to avoid them. References for further reading and more detailed information are provided.

This booklet has three main parts:

- **PV System Characteristics and Hazards** contains an overview of PV system characteristics and a list of hazards involved in working with PV systems. Recommended safe-guards are given.
- **Safe PV Systems** contains a discussion of applicable safety codes, and regulations to follow when designing, installing, and testing a PV system.

- **The For Your Health** section includes **a** discussion of possible injuries and describes basic First Aid techniques.

This booklet has two columns per page. The right column on each page contains notes, location guides, references, or warnings. Drawings of Wise Watt and Jo Ordinary are used to illustrate or emphasize a point. The left column contains the text with **bold print** or underline used for important items.

3.0 PV System Characteristics and Hazards

Photovoltaic systems are designed to meet a specific load and are seldom consistent in configuration and component usage. Some grid-connected PV arrays use hundreds of modules connected in series and parallel to produce large amounts of power. Operating voltages may exceed 600 volts dc and currents at the subfield level may be hundreds of amperes! Many stand-alone systems have fewer modules but use batteries to store energy for later use. One of these typical **12-volt** batteries can produce over 6000 amperes if shorted--severe burns can occur. The point is, each system presents hazards to operating and maintenance personnel. Helping you recognize these hazards and avoid injury is the sole purpose of this booklet.

Remember ...... alert mind and slow hand.

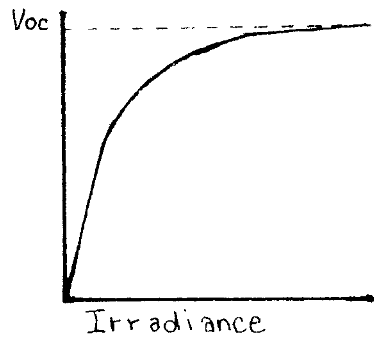
3.1 PV System Characteristics

The photovoltaic effect can be produced with dozens of materials. However, there are a limited number that are technically feasible. The few with some commercial potential are given in Table 1. Since over 99.9 percent of PV power systems installed today use crystalline silicon material, we will limit our attention to these cells. Unless specifically stated otherwise, reference to a PV cell will mean a **crystalline silicon PV cell.**

Table 1
Photovoltaic Materials with Commercial Potential

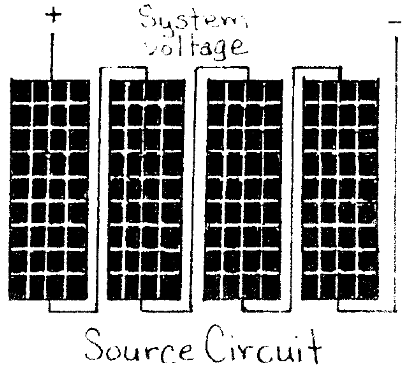
Material	Typical Cell Voltage at Open-Circuit	Typical Cell Current at Short-Circuit
Crystalline and Polycrystalline Silicon (x-Si)	~0.6 Volts	~35 mA/cm^2
Gallium Arsenide	~1.0 Volts	~27 mA/cm^2
Amorphous Si (a-Si)	~0.9 Volts	~15 mA/cm^2
Tandem a-Si (Two-Cell)	~1.8 Volts	~10 mA/cm^2
Copper-Indium-Diselenide (CIS)	-0.4 volts	~35 mA/cm^2
Cadmium Sulfide, Cadmium Telluride	-0.7 volts	~25 mA/cm^2

The voltage on a PV cell increases rapidly when illuminated and approaches its maximum value even at low solar conditions. For this reason, any PV assembly should be considered electrically “hot” during the daytime. Each PV cell, regardless of its area, produces approximately 0.6 volts dc when open-circuited and exposed to sunlight. The current output of a cell varies directly with its area and the solar irradiance. A 4-inch square cell produces about 3 amperes in full sun.



A **PV module** is a laminated, environmentally-sealed package of PV cells, usually connected in series to produce a usable voltage. The more common PV modules contain 35-40 cells in series and generate an open-circuit voltage of about 22 volts dc.

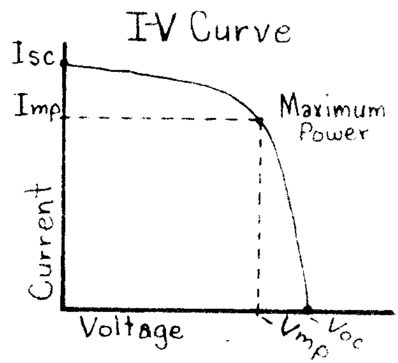
When a number of PV modules are connected in series to generate the voltage required to operate the load, the configuration is called a source circuit (also called **a string).**



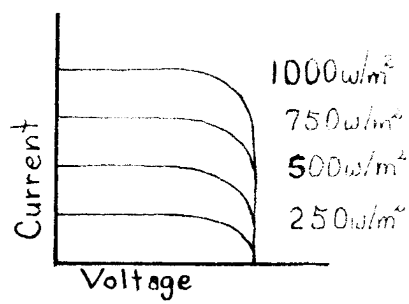
A **PV array** consists of parallel-connected source circuits that generate the current required to meet the power demands of the load. For larger systems, a number of source circuits may be grouped together and routed through large dc disconnect switches. Such a grouping is called a **subarray** or **subfield.**

The **PV system** includes not only the source circuits or subarrays, but also the associated power conditioning, protection and safety equipment, and support structures.

Further reading on photovoltaic technology and the design and installation of PV systems can be found in general texts. **{1, 2, 3}**

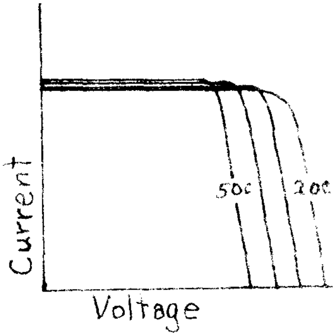


The current-voltage characteristic **(I-V) curve** of a PV cell, module, source circuit, or array is specific to that particular device but all I-V curves have roughly the same shape. An I-V curve can be obtained by changing the impedance connected to the device output. At each point on the curve, the current-voltage product equals the power of the device at that point. For each curve, there is a single point at which the power is the greatest. This is the largest area rectangle that can be drawn under the curve. This point is called the **maximum power point, Pmax,** and is the preferred operating point for most applications. Other points of interest are the **short-circuit current, Isc,** and the **open-circuit voltage, Voc.** If the device is forced to operate in the second or fourth quadrant (negative voltage or current), it will have to dissipate power. This will cause heating and early failure. **Bypass diodes** are used in most arrays to limit the negative voltage across a cell.



The current of the PV cell increases linearly with solar irradiance and/or the area of the cell. For a given device, the I-V curves for constant temperature and changing solar irradiance look like those shown at the right.

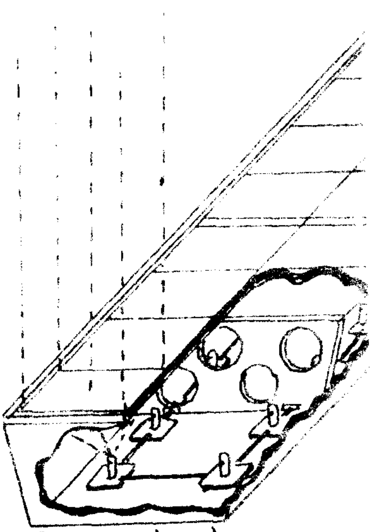
The power output of a silicon PV device decreases with increasing temperature. The current of the device increases slightly with temperature, but the voltage decreases at a more rapid rate. The result is a decrease in power of 0.4-0.6 percent per degree C.



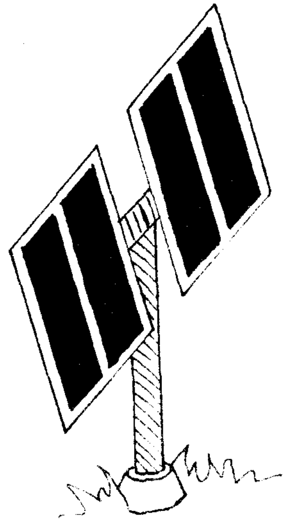
3.1.1 Types of Systems

PV systems are grouped in several ways. Some common classifications are:

- Stand-Alone System: A PV system that is not connected to the utility grid. Most stand-alone systems use batteries to store the energy produced during daylight hours for use at night or on cloudy days.
- Grid-Connected System: A PV system tied to the electric utility's power distribution grid. The power not used by the loads is transferred to the grid (which, in the United States, the electric utility is required to accept); the load can receive the power from the grid when the PV system is not generating enough to satisfy demand.
- Flat-Plate System: A PV system comprised of modules that are flat in geometry and use natural (unconcentrated) solar irradiance. They use both **direct beam** and **diffuse** (or scattered) solar irradiance to produce electricity, and some power is generated even on cloudy days. The sum of direct and diffuse solar irradiance is called **total global** irradiance.
- Concentrator System: A PV system comprised of modules that have concentrating optics as part of their structure. They use only the direct beam solar irradiance. Since only the direct beam irradiance can be focused by lenses or mirrors, a concentrating system will not generate power on cloudy days. The high intensities produced by these modules also produce intense heating that must be dissipated by active or passive cooling mechanisms.


Concentrator

- Fixed-Tilt System: Any PV array with modules at a fixed tilt angle and orientation. The array may be mounted on a rooftop, on a pole, or on the ground. These systems use flat-plate modules only, since concentrator modules must track the sun to capture the direct beam irradiance.
- Tracking System: A PV system with modules mounted 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 correct for seasonal north-south sun movement. Tracked systems are more expensive than fixed-tilt systems, but also produce more electric energy per unit area because they follow the sun and "see" the maximum available irradiance at all times. Tracking systems may employ either flat-plate or concentrator modules.
- Hybrid System: Any system with more than one power source.



3.1.2 Balance of Systems

The **balance-of-systems (BOS)** is defined as everything except the PV modules and the load. The BOS includes:

- The land, fencing, buildings, etc.
- Module support structures
- External wiring and connection boxes
- Power conditioning equipment-- inverters, controllers, transformers, etc.
- Safety and protective equipment--diodes, switches, lightning protection, circuit breakers, ground rods and cables, etc.
- Energy storage batteries
- Utility grid interface and connection devices
- Weather instruments (pyranometers, thermometers, anemometers, etc.)
- Data acquisition equipment for monitoring and evaluating the PV system performance

3.2 System Hazards and Recommendations

You can get injured working on any PV system. Cuts, bumps, falls, and sprains hurt just as much and cause as much lost time as the electrical shock and burn hazards generally thought of. Although, most safety suggestions are **just plain common sense,** people still get hurt in industrial accidents. Fortunately, few have been hurt working on PV systems--no deaths have been reported. The goal is to reduce the number of injuries to zero. This requires good work habits, an awareness of potential hazards and a program where safety rules are frequently reviewed. The responsibility is yours.

Strains, cuts, or falls are painful and cause lost time..

3.2.1 Non-Electrical Hazards

There is an incorrect perception among many that you can't get hurt working on a small PV system. Anyone who has seen a car battery explode could argue this point. Safety should be foremost in the mind of anyone working on PV systems. Some common hazards that may be encountered are discussed below.

Exposure

PV systems are installed where the sun is brightest and no shade exists. When you work on a PV system you should wear a hat, keep the limbs covered, and/or use plenty of lotion with a sunscreen rating of 15 or higher. In the summertime, drink plenty of liquid--never alcoholic--and take a break and get into the shade for a few minutes each hour. In the wintertime, dress warmly, wear gloves whenever possible, and if you are working on a pumping system, don't stick your tongue on the pump handle.

Use common sense

Dress for the weather

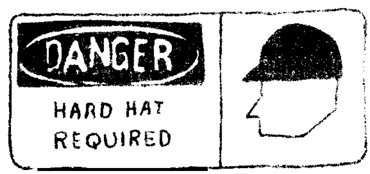
Insects, Snakes, and Other Vermin

Spiders, wasps, and other insects often move in and inhabit junction boxes in PV systems. Some wasps build nests in the array framing. Rattlesnakes use the shade provided by the array and fire ants are commonly found under arrays or near battery storage boxes. Always be prepared for the unexpected when you open junction boxes. Look carefully before you crawl under the array. It may sound funny, but fire ants or black widow spiders (let alone rattlesnakes) can cause painful injury.

. . . insects love to move in . . .

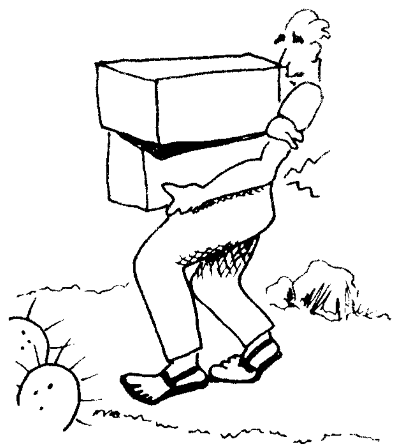
Cuts and Bumps

Most PV systems contain metal framing, junction boxes, bolts, nuts, guy wires, anchor bolts, etc. Many of these common items have sharp edges and can cause injury if you are not careful. Wear gloves when handling metal, particularly if you are drilling or sawing. Metal slivers from a drill bit often remain around a hole and these can cause severe cuts to a bare hand. Wear a dielectric hard hat any time you are working under an array or on a system with hardware higher than your head.



Falls, Sprains, and Strains

Many PV systems are installed in remote areas in rough terrain. Walking to and around the site, particularly carrying materials or test equipment, can result in falls and/or sprains. Wear comfortable shoes, preferably with soft soles. Steel toe reinforced shoes not be worn around PV systems because they lower the resistance of a potential current path. Be careful when lifting and toting heavy equipment, particularly batteries. Lift with the legs and not the back to avoid back strains. If climbing is required, be sure the ladder is firmly anchored and remember a PV module can act as a windsail and knock you off a ladder on windy days.



Lift with the legs . . . .

Burns--Thermal

Metal left exposed in the sun can reach temperatures of 80°C. This is too hot to handle, but is unlikely to cause bums if extended contact is not made. Concentrating PV systems pose an added hazard from burns. Some concentrating PV systems focus up to 400 suns on the PV cell. This added thermal energy is dissipated using active or passive cooling mechanisms with temperatures far exceeding 100°C.

Momentary contact can cause serious bums. Active cooling systems contain a heat transfer fluid that can scald flesh (it may also be caustic). Wear gloves anytime you have to work on PV systems in the summertime. Survey the system and make sure you do not bump into cooling elements.

Burns--Acid

Most stand-alone PV systems contain batteries. A large percentage of the batteries are the lead-acid type and the hydrochloric acid is a hazard. Chemical burns will occur if the acid makes contact with an unprotected part of the body--your eyes are particularly vulnerable. Anytime you are working around lead-acid batteries you should wear non-absorbent gloves, protective eye wear, and a neoprene coated apron. See Section 3.2.3 for more hazards associated with batteries.

3.2.2 Electrical Hazards

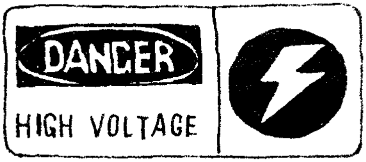
Common electrical accidents result in shocks and/or burns, muscle contractions, and traumatic injuries associated with falls after the shock. These injuries can occur anytime electric current flows through the human body. The amount of current that will flow is determined by the difference in potential (voltage) and the resistance in the current path. At low frequencies (60 Hz or less) the human body acts like a resistor but the value of resistance varies with conditions. It is difficult to estimate when current will flow or the severity of the injury that might occur because the resistivity of human skin varies from just under a thousand ohms to several hundred thousand ohms depending primarily on skin moisture.

If a current greater than 0.02 amperes (only 20 milliamperes) flows through your body, you are in serious jeopardy because you may not be able to let go of the current carrying wire. This small amount of current can be forced through sweaty hands with a voltage as low as 20 volts, and the higher the voltage the higher the probability that current will flow. High voltage shock (>400 V), may burn away the protective layer of outer skin at the entry and exit points. When this occurs the body resistance is lowered and lethal currents may cause instant death. Dalziel {4} and Lee {5} studied the effects of ac electrical shock on the human body. Dalziel also reported on the reaction of his subjects when they were exposed to a dc electrical shock. The data in Table 2 are based on their reports and you can see that low currents can cause severe injury or death.

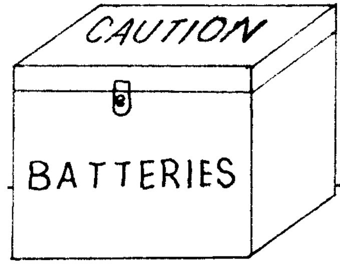
Table 2
Electric Shock Hazards

Reaction	Current AC	Current DC
Perception - Tingle, Warmth	1 ma	6 ma
Shock - Retain muscle control; reflex may cause injury	2 ma	9 ma
Severe Shock - Lose muscle control, cannot let-go; burns; asphyxia	20 ma	90 ma
Ventricular Fibrillation - Probable death	100 ma	500 ma
Heart Frozen - Body temperature rise; death will occur in minutes	>1 A	>1 A

Electrical shock is painful and a potentially minor injury is often aggravated by the reflex reaction of jumping back away from the source of the shock. **Anytime a PV array contains more than two PV modules, a shock hazard should be presumed to exist.**



The best way to avoid shock is to measure--always measure--the voltage from any wire to any other wires, and to ground. Use a clamp-on ammeter to measure the current flowing in the wires. Never disconnect a wire before you have checked the voltage and current. Do not presume everything is in perfect order. Do not trust switches to operate perfectly and do not "believe" schematics. A digital voltmeter is a wonderful instrument and using it often could save your life.



3.2.3 Battery Hazards

Any system with batteries is a potential hazard. Three areas of concern are:

- **Electrical Burn:** Shorting the terminals of a typical battery that might be found in a PV system can cause currents of over 6000 amperes to flow for a few seconds. Severe burns and death can occur even though the voltage is low.
- **Acid Burns:** Any battery acid can cause bums if it comes in contact with exposed skin. Contact with the eye may cause blindness.
- **Gas Explosion or Fire:** Most batteries used in PV systems release hydrogen gas as a result of the charging process. This flammable gas is **a** hazard and all flames and equipment that could create a spark--such as a controller with relays--should be kept away from the batteries. The battery should be located in a well-ventilated area.

Anytime you work with batteries . . . .

Any time you work with batteries you should wear protective clothing, gloves, and goggles to cover the eyes. A neoprene coated apron is recommended if you are going to measure specific gravity or open the battery to add water to the electrolyte. Wear rubber boots.

Live electrical equipment.

3.2.4 AC Power Hazards

If alternating current (ac) power is to be supplied, a power conditioning unit is required to convert the dc power from the PV system to ac power. This equipment will have high voltage at both input and output when it is operating. The output is nominally 120 V at or 240 V at and enough current will be present to kill. All of the precautions for ac circuits that are given in the National Electric Code should be followed. (See the next section.)

4.0 Safe PV Systems

Almost all PV systems that are installed in the United States are covered by regulations in the **National Electric Code** (NEC). {6} The intent of the NEC is to ensure safe electrical systems are designed and installed. Some PV system designers ignore the NEC because they don't think it applies to their system. Sometimes they consider the "Code" as an impediment and a few have spent more time trying to circumvent applicable regulations than it would have taken to meet them. We need to recognize the Code for what it is--a set of regulations that have contributed to making the electrical systems in the United States one of the safest in the world. Although addressing Code issues can be frustrating at times, most inspectors are willing to listen and work with you if you are making a good faith attempt to meet the Code requirements and install and maintain a safe PV system.

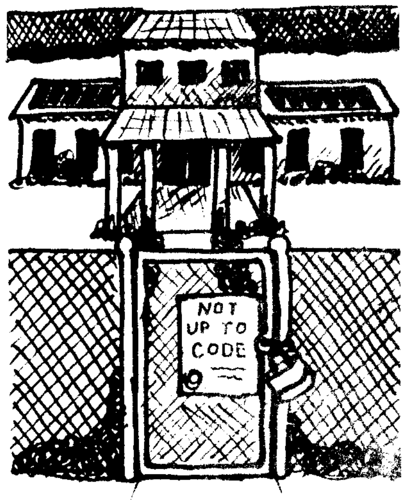
This section will summarize some important issues covered by the NEC and present some safety procedures that should be followed when testing existing systems--some of which may not meet all requirements of the Code.

. . . to ensure safe electrical systems . . .

4.1 Applicable Safety Codes

The National Fire Protection Association has sponsored the National Electric Code since 1911. The NEC is a how-to guide that changes as technology evolves and component sophistication increases. The Code is updated every three years and in 1984, Article 690 was included to provide regulations pertaining to solar photovoltaic systems. The

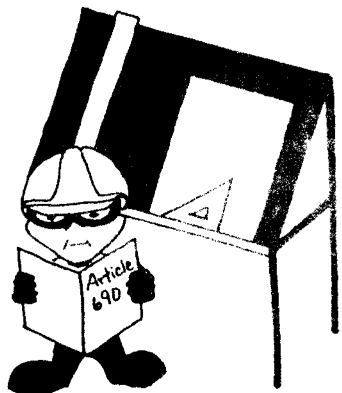
NEC is not a PV system design guide and does not attempt to make things easy for the designer, installer, operator or maintenance person. However, following the Code is not optional-- it is the law in most location. You can negotiate with the local inspector, but you cannot bypass the recommendations given.



There are other codes and standards that have been developed for PV systems and components that touch on safety issues. **Underwriters Laboratory (UL)** has developed construction standards and test procedures for PV modules and selected other components that might be installed in **a** PV system. {7} However, few components from PV manufacturers have been submitted for UL certification. The **IEEE Standards 928 and 929** gives recommendations for designing terrestrial PV systems and connecting them to the utility respectively. {8,9}

We will consider mostly the NEC, specifically Article 690 which addresses PV systems. Some of the other sections of the NEC that may apply are:

- Article 240 - Overcurrent Protection
- Article 250 - Grounding
- Article 300 - Wiring Methods
- Article 339 - Underground Feeders
- Article 480 - Storage Batteries
- Article 705 - Interconnected Power Sources
- Article 720 - Low Voltage Systems

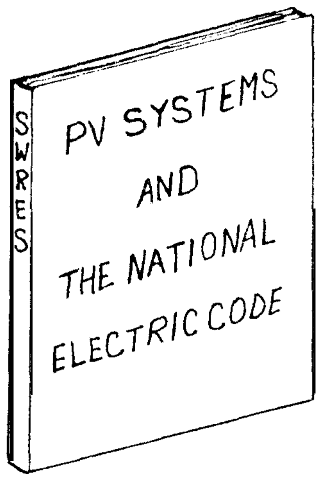


Before designing and installing a PV system.....

Before designing and installing a PV system you should read Article 690. It has eight sections, A through H, with information on the topics shown below.

A General
  690-1 Scope
  690-2 Definitions
  690-3 Other Articles
  690-4 Installation
  690-5 Ground Fault Detection & Interruption

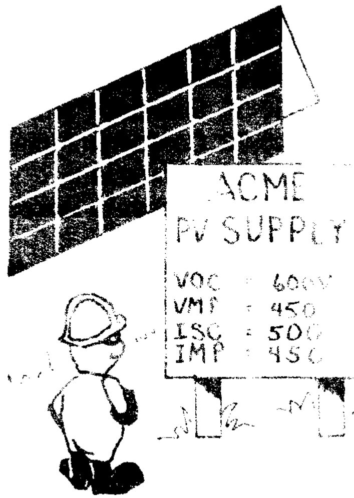
B Circuit Requirements
690-7 Maximum Voltage
690-8 Circuits Over 150 Volts to Ground
690-9 Overcurrent Protection
C Disconnecting Means
690-13 All Conductors
690-14 Additional Provisions
690-15 Disconnection of Photovoltaic Equipment
690-16 Fuses
690-17 Switch or Circuit Breaker
690-18 Disablement of an Array
D Wiring Methods
690-31 Methods Permitted
690-32 Component Interconnections
690-33 Connectors
690-34 Access to Boxes
E Grounding
690-41 System Grounding
690-42 Point of System Grounding Connection
690-43 Size of Equipment Grounding Conductor
690-44 Common Grounding Electrode
F Marking
690-51 Modules
690-52 Photovoltaic Power Source
G Connection to Other Sources
690-61 Loss of System Voltage
690-62 Ampacity of Neutral Conductor
690-63 Unbalanced Interconnections
690-64 Point of Connection
H Storage Batteries
690-71 Installation
690-72 State of Charge
690-73 Grounding



A good reference with recommended PV system installation practices that comply with the NEC is produced and distributed by the Southwest Technology Development Institute. {10} Development of this handbook was under the direction of Sandia National Laboratories with funding from the Department of Energy. Most of what is presented here is discussed in more detail in this reference.

4.2 Designing and Installing a PV System- What the NEC Says

This section will highlight the primary requirements of the NEC that apply to the design and installation of PV systems. This list is a simplification of the Code requirements and not intended to replace or supplement the NEC. Hopefully, it will serve to increase awareness of the NEC by identifying the broad issues in the Code that the designer should consider. This section is based on the latest version of the NEC (1990) with articles referenced by numbers in brackets, e.g. [690-1].



4.2.1 System Current and Voltage

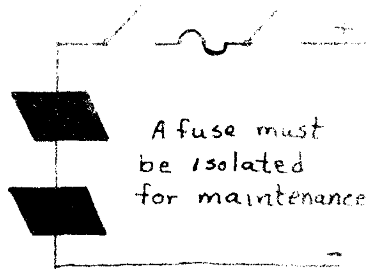
When designing a PV system, consider the following:

- Use open-circuit voltage as the rated voltage in any PV source circuit. [690-7a]
- Voltages should be less than 600 Volts. [690-7c]
- Conductors and overcurrent devices shall be able to carry at least 125 percent of the short-circuit current of the source circuit. (690-8)
- PV source circuit, inverter, and battery conductors shall have overcurrent protection. [690-9a]
- A sign indicating the PV system operating voltage and current, the open-circuit voltage, and the short-circuit current shall be placed near the system disconnect point. [690-52]

4.2.2 Wiring and Disconnect Requirements

The Code requires certain conventions for color of conductors and specifies requirements for disconnecting the power source. Specifically:

- The grounded conductor is to be white. [200-6] Convention is for the first ungrounded conductor of a PV system to be red, and the second ungrounded conductor black (negative in a center tapped PV system).
- Single-conductor cable is allowed for module connections only. Sunlight resistant cable should be used if the cable is exposed. (690-31 b]
- Modules should be wired so they can be removed without interrupting the grounded conductor of another source circuit. [690-4c]
- Any wiring junction boxes should be accessible. [690-34]
- Connectors should be polarized and guarded to prevent shock. [690-33]
- Means to disconnect and isolate all PV source circuits will be provided. [690-13]
- All ungrounded conductors should be able to be disconnected from the inverter. [690-15]
- If fuses are used, you must be able to disconnect the power from both ends. [690-16]
- Switches should be accessible and clearly labeled. [690-17]

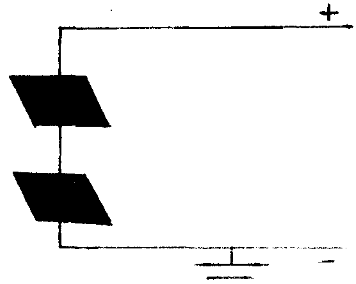


4.2.3 Grounding

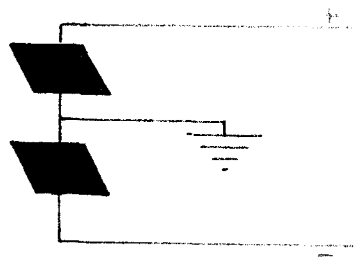
The purpose of grounding any electrical system is to prevent unwanted currents from flowing (especially through people) and possibly causing equipment damage, personal injury, or death. Lightning, natural and man-made ground faults, and line surges can cause high voltages to exist in an otherwise low-voltage system. Proper grounding, along with overcurrent protection, limits the possible damage that a

Don't become part of the grounding circuit.

ground fault can cause. Consider the following and recognize the difference between the equipment grounding conductor and the grounded system conductor:

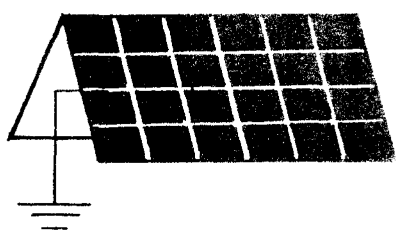


- One conductor of a PV system (>50 volts) must be grounded, and the neutral wire of a center tapped three wire system must also be grounded. [690-41] If these provisions are met, this is considered sufficient for the battery ground (if batteries are included in the system). [690-73] A ground is achieved by making a solid low resistance connection to a permanent earth ground. This is often done by driving a metallic rod into the earth, preferably in a moist location. [250-83]
- A single ground point should be made. [690-42] This provision will prevent the possibility of potentially dangerous fault current flowing between separate grounds. In some PV systems where the PV array is located far from the load, a separate ground can be used at each location. This will provide better protection for the PV array from lightning surges. If multiple ground points are used, they should be bonded together with a grounding conductor.



- All exposed metal parts shall be grounded (equipment ground). [690-44]
- The equipment grounding conductor should be bare wire or green wire. [210-5b]
- The equipment grounding conductor must be large enough to handle the highest current that could flow in the circuit. [690-43]

4.2.4 The PV System Output



Before the PV array is connected to a toad, battery, or inverter, there are certain requirements stated in the NEC. Additional battery requirements are given in NEC Article 480.

- If an inverter is used to interconnect the PV system to a utility, it must disconnect automatically if the utility power goes off. [690-61] If the inverter is operating in a stand-alone hybrid system, it may continue to supply power to the load.

- The output of a single-phase inverter should not be connected to a three-phase service. [690-63a]
- The ac output from a PV system inverter must be grounded in accordance with requirements for ac systems. [250-5]
- A circuit breaker or fuse/switch mechanism must be included so that the PV system output can be disconnected. [690-64]
- The interconnection shall be made so that all ground fault interrupters remain active. [690-4]
- If batteries are used in a system, they must be guarded to prevent unauthorized access if the voltage is greater than 50 volts dc. Otherwise, the voltage must remain below 50 volts dc. [690-b]
- Charge controllers must be used with batteries. **[690-72]**

4.3 Testing a PV System--Safety Hints

Sometimes it is necessary to troubleshoot **a** PV system that is not working correctly. Safety should be the main concern, both in planning before you go to the site and during the actual testing. Some recommendations are given. **Remember: Do not test a PV system alone!**

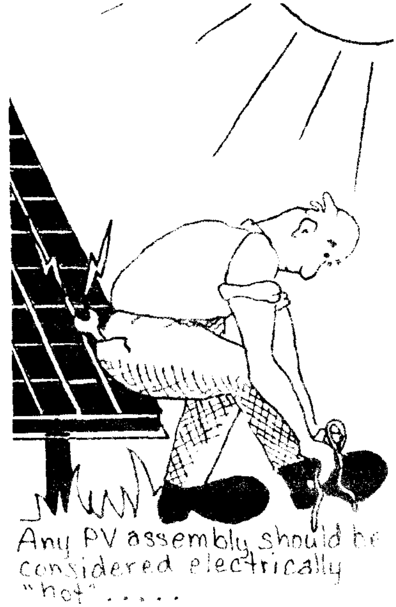
Before testing any PV system, you should become familiar with the electrical configuration. How many modules make up a source circuit? What are the system voltages? Currents? How many circuits are there? Do overcurrent devices exist? Where? How can the system be disconnected? What safety equipment is available.

Remember, Do not test a PV system alone... know the configuration.

When you get to the PV system site:

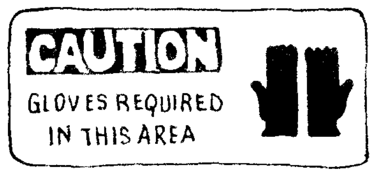
- Remove jewelry.
- Walk around the PV system and record any apparent hazards in the system logbook or a notebook. Take photographs of the system and any hazards.

- Locate the safety equipment, fire extinguisher, etc. and check their condition. Where is the nearest telephone?
- Check the actual system configuration against the electrical schematics.
- Locate and inspect all subsystems such as the batteries, inverter, and the load.
- Determine if, how, and where the system is grounded. Check to see if the ac and dc grounds are common.
- Locate and inspect all disconnect switches. Check any fuses. Determine if the switches are designed to interrupt both positive and negative conductors.
- Disconnect the source circuits and measure all open-circuit voltage to verify the proper operation of the disconnect switch.
- Measure the voltage from each conductor to ground, and from line to line.



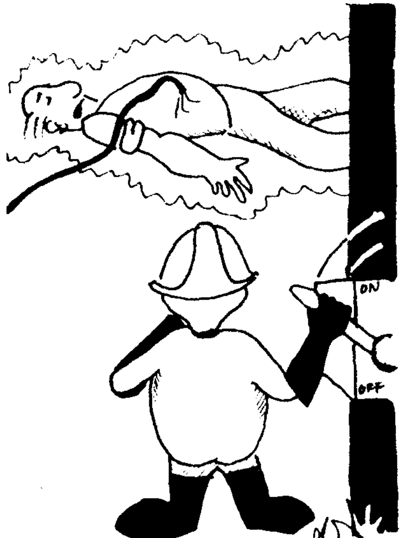
Only when you are sure that you understand the circuit should you proceed with testing.

- Keep the work area clear of obstacles, particularly the area behind you.
- Never disconnect a wire before measuring voltages.
- Keep your hands dry and/or wear gloves.
- Work with only one hand if possible.
- Have your buddy stationed near the disconnect switches.
- Once a wire is disconnected don't leave the end exposed--tape it or use a wire nut for temporary covering.
- Reconnect the wires from one source circuit before disconnecting a second source circuit.



5.0 For Your Health

This section presents a review of the first aid procedures that anyone working on PV systems should be familiar with. They are based on the book "American Red Cross: Standard First Aide." {11} It is recommended that each person also complete a CPR course or equivalent training offered by the American Heart Association or the American Red Cross. This booklet contains a summary of first aid suggestions, but is not intended to replace formal training in first aid or CPR.



...disconnect the power..

If you witness an accident or are the first person to arrive at the scene:

- **Survey the scene for potential hazards.**
  Try to determine if a shock hazard still exists. Is a live conductor still lying on or near the victim's body? Is the victim still holding a live conductor? Are there other hazards such as fire or spilled caustic material that would put you in jeopardy? You will be safer in assisting a victim if you are with someone else, but don't delay your help to watt for a buddy. Also, be aware that some otherwise trustworthy people cannot be trusted in an emergency situation--everyone reacts differently. You are on your own to protect yourself and save the victim--make it happen!
- **Check the victim for breathing and pulse.**
  Determine victim's status.
- **Call for help and give victim status.**
  During an emergency, do anything you can to quickly attract attention to the scene. Call an ambulance, get someone else to do it, or even pull a fire alarm, but get qualified emergency personnel to the scene as quickly as possible. Then attend to the victim using accepted CPR techniques.

— everyone reacts differ- ently....

Roth electrical and non-electrical injuries can occur when working around/with PV systems. First aid techniques for each will be reviewed.

5.1 Non-Electrical Injuries

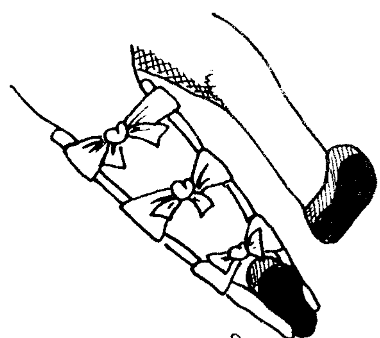
These injuries include cuts, sprains, broken bones, exposure, and insect or snake bites. In most cases they are not life threatening, but if care is not given immediately, the victim may go into shock and could die. Respond quickly.

Cuts

Stop the bleeding by using the following methods in this order: direct pressure, elevation, pressure points, and a pressure bandage. If possible, apply direct pressure with a sterile dressing (gauze pad) between the wound and your hand. Use a clean cloth if a sterile dressing is not available. If bleeding does not stop, elevate the wound area if possible. If the wound is still bleeding, apply pressure on a nearby **pressure point.** For example, if the lower arm is cut, apply pressure with fingers on the middle inside of the upper arm where a pulse is felt. Lastly, use a **pressure bandage** by adding more sterile dressings if necessary and wrap with a roller bandage. Use overlapping turns to cover dressing completely and secure by tying off the bandage over the wound.

Sprains, Strains, Dislocations, and Fractures

It is sometimes hard to tell the difference between these injuries so treat them all as you would a fracture. Help the victim move into the shade and/or comfortable position with as little movement to the injured area as possible. The injury (usually an arm or leg) needs to be splinted to lessen the pain and prevent further injury. Splints can be made from rolled up newspaper, magazines, pieces of wood, blankets, or pillows. The splint can be tied up with bandages or cloth (a shirt torn into strips will do). The following principles apply. Splint only if you can do it without causing more pain. Splint an injury in the position you find it. Immobilize the limb and joints above and below the injury. Check the blood circulation by pinching nail beds of the fingers or toes. Red color should



return in two seconds--if not loosen splint. If the injury is a closed fracture (no bone extruding) apply a cold pack to it. Do not apply a cold pack to an open fracture.

Exposure-Cold

Persons exposed to extended periods of cold may suffer from hypothermia. Symptoms that may occur are shivering, feeling dizzy, confusion, or numbness. Take the victim to a warm place, remove wet clothing, and warm the body slowly. Call an ambulance. Give nothing to eat or drink unless the victim is fully conscious. If fully conscious give him a warm drink a little at a time. Check the temperature of the liquid. Don't add a scalded tongue to their injuries.

Remove ... person from the heat ... half glassful of water

Exposure-Heat

This is a common hazard for PV system maintenance personnel because of the location of the systems. If you or your partner has cramps, heavy sweating, cool and pale skin, dilated pupils, headaches, nausea, or dizziness you may be nearing heat exhaustion. Get the victim to the shade and give him one-half glassful of water (if he can tolerate it) every 15 minutes. If heavy sweating occurs have the victim lie down and raise his feet, loosen clothing, and put wet towels or sheets over him. If the victim has red dry skin, he may have heat stroke, which is life-threatening. Immerse in cool water, if possible, or wrap the body with wet sheets and/or fan the victim. Don't give him anything to drink. Call an ambulance.

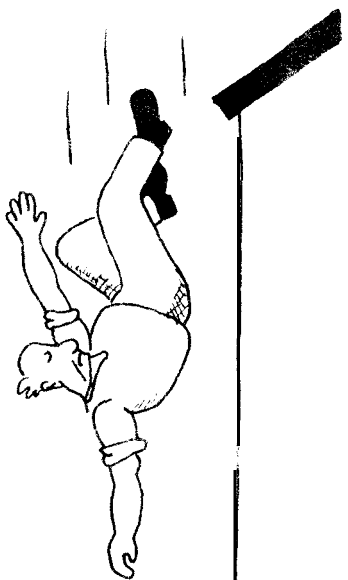
...remove it (do not squeeze it)...

Insect/Snake Bites

A small number of people may have an allergic reaction to an insect bite or sting. In this case, it could be life-threatening. Signs of an allergic reaction are pain, swelling of the throat, redness or discoloration, itching, hives, decreased consciousness, and difficulty in breathing. If these symptoms occur call an ambulance immediately. If a stinger from an insect is embedded into the flesh remove it (do not squeeze it) with tweezers or scrape it away with a credit card. Then wash the area and put on a cold pack with a cloth between the skin and the ice. Try to arrange the victim so the bitten area is below the heart. Few people die from snake bites. However, if someone is bitten by a snake, they should receive medical help quickly. Call an ambulance. Keep the victim still and the bitten area below the heart to slow absorption of the snake venom. A splint can be used if the bite is on an arm or leg. Try to remember what the snake looked like. Do not cut a snake bite and try to suck the venom out.

5.2 Electrical Injuries

The number one priority in assisting injured people should always be your (the rescuer's) safety. This is especially important in situations involving elect&al hazards. **Avoid becoming a second victim.** Electrical injuries consist mainly of shocks, burns, muscle contractions, and traumatic injuries associated with falls after electric shocks. Electric shock is a general term, indicating any situation where electric current flows through the body. The intensity of a shock can vary from a barely perceptible tingle, to a strong zap, to instant death. A stabbing pain or intense tingling and burning is usually associated with electric shock. The points of entry and exit are often badly burned.



..falls after electric shocks...

Frequently a shock involves involuntary muscle contraction. If the strong muscles of the back and legs contract, this can lead to falls and broken bones. The large muscles of the chest, throat, and diaphragm can contract, and cause respiratory arrest.

When electric current passes through the heart, it can cause a spasmodic contraction and relaxation of the ventricles, called ventricular fibrillation. This is one of the major causes of death associated with shocks. Once a person’s heart has begun fibrillating, it is difficult to stop. Sometimes another electric shock, administered by a paramedic using a defibrillator, can restore the heart to its normal beating cycle. **Victim fibrillation need qualified (paramedic) help in minutes if they are to live.**

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