FUNDAMENTALS OF

Photovoltaics

FOR THE FIRE SERVICE

Fundamentals of Photovoltaics for the Fire Service

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Training Consultant

With Funding Provided by,

California Solar Energy Industries Association

Sacramento Municipal Utility District (SMUD)

ACKNOWLEDGEMENTS

This training program became necessary when the emergency response community started to recognize and ask questions regarding the presence and prevalence of Photovoltaic technology. The Sacramento Municipal Utility District (SMUD) in collaboration with the California Solar Energy Industries Association (CAL SEIA) responded with the funding of this training program. SMUD and CAL SEIA recognized the need to train emergency responders to operate safely when working around solar electric systems.

I am personally grateful for the opportunity to develop this important program for both the fire and solar electric industries. I would like to specifically thank my good friend Sue Kateley of the California Energy Commission for her dedication and support for this project. Sue has worked with me for over five years in trying to find a funding solution for this program. I would also like to recognize Jon Bertolino of SMUD for providing the funding and the program guidance along with Les Nelson, Executive Director of CAL SEIA, for providing the industry contacts and keeping this program on track.

Many of the ideas and direction for this training program came after I attended the Photovolatics Design and Installation class taught by Jay Peltz and Kris Sutton, instructors for Solar Energy International. A fun and fact filled week at solar camp in Occidental, California jump started the development of this training program. I'm very grateful to my classmate Marc Fontana who provided many of the photographs from solar camp now a part of this training program. By coincidence, I visited the Occidental Fire Department to borrow a salvage cover so that I could block out the sunlight and render the solar panels we were installing inoperable. I met Ron Lunardi, Fire Chief of the Occidental Community Services District. Chief Lunardi not only has a vast amount of fire service experience but he is also an electrical contractor with a keen interest in this program.

I am particularly grateful to Johnny Weiss, President of Solar Energy International. Of all the reference material used to research the subject of Photovoltaics, S.E.I's the "Photovoltaics Design and Installation Manual" was the most comprehensive of all!

I also called on a number of friends and associates to review and provide recommendations to this training program. Lee Parker of the Modesto Fire Department provided technical review of this program. Lee is a Master Instructor in the California Fire Training and Education System. I trust Lee's firefighting experience and his knowledge of fire ground operations that are shared universally with the fire service community. Bob Gill, Fire Chief of Central Calaveras Fire & Rescue is also an accomplished instructor in the field of Hazardous Materials. I've relied on Bob's Hazmat background in other training programs and knew he was a good choice to review this program as well.

Reviewers from Southern California include associates Russ Tingley, Dirk Drossel, and Scott Corrin. Russ Tingley, Fire Chief of the Hermosa Beach Fire Department, lends the Southern California firefighting perspective and experience to the text. Dirk Drossel, fire inspector with the Burbank Fire Department, has had plan review experience which includes several photovoltaic applications, while Scott Corrin, Campus Fire Marshal for U.C. Riverside, brought his code and regulation experience, along with his own interest of photovoltaic systems into the review. Complimenting Scott's code background is Howard Cooke, Fire Inspector for the Sacramento Fire Department. Howard brings practical code application to the project in his work inspecting SMUD's solar-related projects.

At the same time this text was under development, I had the opportunity to meet Michael Callan, a 32 year veteran of the Wallingford, Connecticut Fire Department. Michael's body of work includes training in hazardous materials as well as gas and electric utility emergencies. Along with the number of conversations we've had, his text "Responding to Utility Emergencies" also became a reliable source book for this program.

The completion of this project was accomplished using the services of my student assistant, Justin Bibler, whose goal to become an English professor was put to the test in proof reading this document. Another friend, Tammara Askea, Owner of Scentimental Packets and Design, brought her unique skills to formatting and publishing the compact disk.

I am also very thankful for the support of my former Chief, Ronny J. Coleman, California State Fire Marshal (retired), in writing the Foreword to this text. As any author knows, your name maybe on the cover, but it's the names and reputations of a wide range of people whose knowledge and experience make a project like this viable. I am grateful and thankful to each and every one!

All the Best,

Rodney Slaughter

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FOREWORD

Ronny J. Coleman

A frequently quoted phenomenon of coping with change is for people to refer to "the leading edge." This conjures up the image of being in front of something and has a somewhat positive spin to it. Others who have experienced the unintended consequences of change have often called it the "bleeding edge" of change. This is because change often creates consequences that have negative impacts.

Among my historical collection of interesting newspaper columns, I have an issue of Argus, published in San Francisco in the late 1880's. In that article a battalion chief of the San Francisco Fire Department wrote a passionate letter to the editor strongly advising the city fathers to prohibit the installation of electricity in buildings. The article identified the many risks and hazards associated with electricity. It stated that if the city allowed the continued installation of electricity it would cause fires and quite possibly result in the death of firefighters. That battalion chief was right. But, electricity was installed and is now a fact of life that has resulted in a quality of life that exceeds that firefighter's concern.

The reality for many in the fire service is that technology will continue to evolve. When that technology evolves, the fire service can either be on the leading edge or suffer the bleeding edge. The difference may often be determined by how well trained and educated the fire service is on the specifics of a technology as it emerges into the main stream of society.

Rodney Slaughter's effort to produce leading edge information has been an important part of making the fire fighting a safer occupation through awareness. This is not his first effort and it will certainly not be his last. What is more important is that those who can benefit the most from this knowledge need to be incorporating this information into both the training and education systems for the fire service. Having read Rodney's work on electric powered vehicles, alternative fueled vehicles, and other technological advances, I pay a lot of attention to what I see when I am in the field. This particular course is no exception.

For example, I recently conducted an inspection of a wildland community in which a significant number of homes were solar powered. Checking into an airport to rent a car recently, I was asked if I preferred an electrical powered vehicle. The technology that I see serving society will continue to evolve outside of the influence of the fire service.

To update and paraphrase Benjamin Franklin, "an ounce of awareness is worth a ton of state compensation benefits." The information contained in this program may just be the difference between a firefighter handling an event successfully or them becoming a job injury statistic. The former is preferred over the latter.

ABOUT THE AUTHOR

Rodney Slaughter is the author and instructional designer for this project. Rodney has 32 years of fire service experience; beginning his fire service career in 1974, as a military and civilian fire fighter for the United States Air Force, with assignments in Florida, Hawaii, and California. Since 1988, Rodney has been employed as a Deputy with the California State Fire Marshal's Office working in training, code enforcement, grant coordination and codes and regulations.

Rodney has a keen interest in environmental issues as they relate to the fire service. This interest is reflected in the number of training programs he has developed for the fire service community, which includes: tire fire prevention and suppression, emergency response to electric and hybrid electric vehicles, compressed and liquefied natural gas vehicles, and urban-wildland interface fire prevention and mitigation. Rodney has traveled the country teaching fire departments the fine art of successful grant writing. Rodney is a nationally recognized instructor and a frequent speaker/trainer at fire-related classes and conferences around the country. Rodney studied Fire Science at Honolulu Community College, and has a Bachelor of Arts in Anthropology from California State University of Sacramento.

INTRODUCTION/OVERVIEW

While terrorism, weapons of mass destruction, and natural disasters dominate the mindset of emergency responders; subtle changes in our society, and the technologies that we use, have been left largely unnoticed. Increased cost in hydrocarbon fuels and the electrical energy associated with it, have forced many Americans to look for alternative energy options. These options range from solar, wind and micro-hydro electric energy production at the building site.

Unsuspecting firefighters responding to a structural fire could be unpleasantly surprised to discover that once the main electrical power to the building has been disconnected, a secondary source of power may still be present and charged with lethal voltages of electricity.

With a variety of alternative electrical generation systems available, none is becoming more prevalent than solar electric. Firefighters can be sure that they, at some point in the future, will have at least one emergency involving a building with a solar electric system.

What are the chances?

In 2005 worldwide production of electricity from the sun was at 1,565 megawatts (MW). This is expected to increase by 10% in 2006. By 2010, 2.5 gigawatts (GW) are projected.

Of the 1,565 megawatts produced in 2005 worldwide; Germany produced 53% or 837 MW, Japan produced 14% or 292 MW and the United States comes in at a distant third place with 3% or 104 MW. The State of California is America's leader and generates the majority of solar electricity in the country.

According to the California Energy Commission (CEC), the state has more than 17,300 grid-connected commercial and residential Photovoltaic (PV) system installations representing 136 megawatts of power as of April 2006. The trend will continue with the CEC rebate program, federal tax incentives and the increased cost of energy.

The California Governor's goal, to have 1 million solar roofs generating an additional 3,000 MW of electricity by 2017, will also fuel this growing trend. Note that 3,000 MW will double the 1,565 MW in worldwide production of solar energy for 2005! California is and will continue to be the country's largest producer of solar electricity. That means California firefighters in both rural and urban areas will be equally affected by solar electricity now and well into the future.

A multi-family housing development in Livermore, California is outfitted with photovoltaic modules. (Photo Credit: Marc Fontana).

Are Solar Electric Systems Safe?

With so much solar power already available, one has to ask the question: Are solar electric systems safe? The answer is an emphatic yes! Under normal operating conditions these systems provide a safe, secure and environmentally friendly source of energy. The solar electric industry itself has maintained an incredible safety record with no documented cases of life lost from an electrical shock.

In emergency conditions involving solar electric components however, fire fighting personnel need to be aware of the potential dangers and hazards. The obvious danger is electric shock. In addition, if the panels become involved in a fire or explosion, an inhalation hazard from the chemicals used to manufacture the solar panels could also pose a potential health risk.

In an exhaustive search for recorded fire fighter injuries, a solar industry news source, Photon International, found a single case in Switzerland in November 2002 where a firefighter received an electrical shock while working a structural fire at a retirement home. Fortunately, the fire fighter sustained no serious injuries. This single incident spotlights the need for a preemptive awareness level class for emergency responders.

The 2003 San Diego Firestorm threatened the Scripps Ranch community. (Photo Credit Bob Epplet Office of Emergency Services)

During the 2003 San Diego, California firestorm, where thousands of homes burned, including homes with solar electric systems, there were no reported injuries involving solar electricity (Phototon International, May 2005). Recognizing the need to keep emergency responders safe, SMUD and CAL SEIA funded this program to ensure continued firefighter safety while working around solar electric, or more appropriately, photovoltaic (PV) systems.

The bottom line is that while solar electric systems are safe under normal operating conditions, "no energy technology is risk free when all aspects of its utilization are taken into account. Every technology has some attendant direct and indirect health and safety concerns (Etnier and Watson, September 1981)." Our focus for this program is on firefighter safety.

The Purpose of this Program…

is to guide you through the basics of photovoltaic design and application. You will learn about the associated components of the photovoltaic systems and how they are integrated into the building. With this shared background you will be able to respond to any emergency involving solar electric systems safely.

The Goal of this Program…

is to provide the fire service with an awareness of photovoltaic systems, so that they can make informed decisions during an emergency.

The Objectives…

To achieve this goal, every student of this training program will be able to:

Recall the principles of solar electricity production.

Identify the components of a photovoltaic system.

Identify applications of photovoltaic systems.

Apply codes and regulations to photovoltaic installations.

Recall electrical safety principles when working around solar and all electrical systems.

Establish standard operating guidelines for your department when responding to a building emergency where employs solar electric systems are installed.

Program Design

This training program was published in its entirety on a compact disk to provide an inexpensive distribution of standardized training materials and get this information into as many hands, and minds, as possible. The compact disk contains information for individual self study or for use as part of a formal training program in an instructor-lead classroom setting.

The compact disk contains all the training materials needed to teach this class as a stand alone training program or one that can easily be incorporated into larger training programs involving building technologies. These training materials include a student manual, instructor guide, and Powerpoint slide show.

The student manual provides an overview of the Photovoltaic technology along with standard operating guidelines for emergency responders. Text boxes with "Important Notes" spotlight information useful to emergency responders. A glossary of terms is included in the student manual for both solar industry personnel unfamiliar with firefighting terms and for firefighters unfamiliar with electrical and utility terms. A complete list of reference is provided to not only give credit to source information, but also to identify resources for those who would like to do a little more research of their own on the topic. A list of web-related resources is also provided for the same purpose.

The instructor guide is intended to assist the instructor in presenting this material in a classroom setting. Behavioral objectives, length of time to deliver each section, references, and recommended materials are all on the first page of each lesson plan. Recommended student activities are also included in select lesson plans.

The Powerpoint slide show provides bullet points and graphics for the each of the lesson plans. Instructors are encouraged to customize and incorporate photographs of solar systems and applications in your area.

The class is designed primarily for firefighting personnel, but installers and people new to the industry will find the safety considerations a valuable resource as well. Above all, the express purpose of this program is personnel safety!

PHOTOVOLTAIC CELLS AND COMPONENTS

> *"Give me the splendid silent sun with all its beams full-dazzling."*
>
> —Walt Whitman, 1865

The solar cell and the photovoltaic effect begin at the source—the Sun, of course! Every single day enough solar energy falls on the earth to supply all the world's energy needs for four to five years (Got Sun Go Solar)! The Sun's full intensity and brightness is 1,000 watts per meter squared (referred to as insolation). This intensity can be diminished according to the micro climate and site specific conditions (shade). But even on overcast days caused by smog or clouds, solar electricity can still be generated by the solar panels, although at significantly reduced efficiencies.

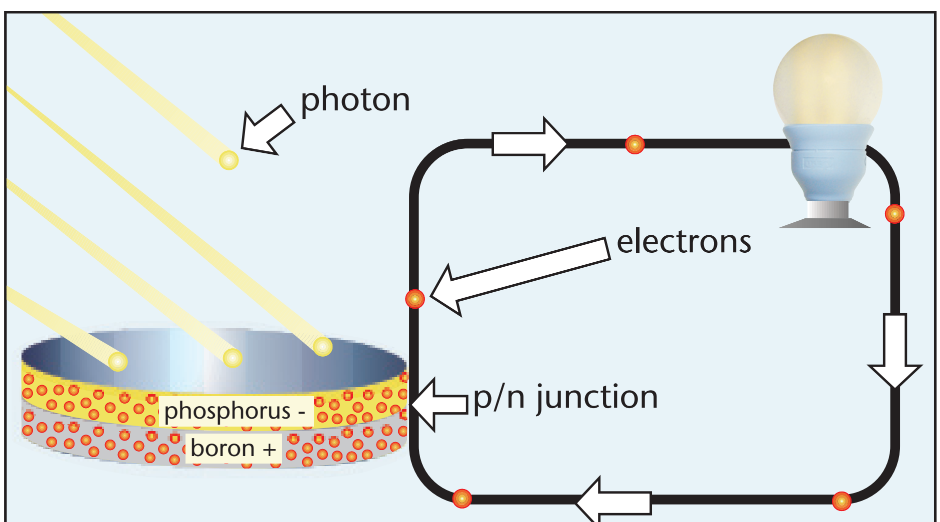
In the Northern Hemisphere, peak sun per day is about 5 hours, between 10 am and 3 pm (peak energy production). Not surprisingly, most photovoltaic systems are orientated towards the south to maximize the amount of light falling on the photovoltaic panels. But we are getting ahead of ourselves—what are photovoltaic panels and how do they work?

Anatomy of a Solar Cell

The solar cell is the smallest unit and the backbone of the Photovoltaic (PV) system. There are two types of manufactured PV's: silicon cell or amorphous silicon. In either case, there is a very thin layer of silicon; 1/100th of an inch thick. By the way, silicon is not only one of the most abundant elements on the planet, but the silicon used in PV systems is similar in purity and quality to that used in the semiconductor industry.

Silicon is a semiconductor. Some manufacturers layer slices of silicon with atoms of boron or phosphorus in a process known as doping. Boron is used for the positive layer of the cell in that it has an electron deficiency. Boron has room, or a hole, in the outer shell of the atom to add an electron (Solar Energy International, 2004).

Phosphorus, on the other hand, has an extra electron and is used for the negative layer of the solar cell.



The Photovoltaic Effect

Photons generated from the sun energize and knock loose the extra electron in the negative layer which crosses the positive-negative (P-N) junction to fill the hole on the positive Boron side. The energy released in the process produces .5 volt of direct current (DC) and flows through the metal contacts built onto the cell. These energized electrons combine with electrons from the other solar cells in the system, flow through the circuitry of the wiring system, run the appliances, and then flow back into the negative layer only to be re-energized once again.

The composition of the silicon crystalline structure varies from manufacturer to manufacturer. The purest silicon structure employs the growth of a single crystal (monocrystalline) cut in to thin wafers. Multiple crystals cast together and sliced into thin wafers form polycrystalline structures.

Other manufacturers don't make "cells" at all, instead using a chemical process which deposits silicon on a substrate material. These panels don't have the circles because the entire surface of the substrate is the "cell." Silicon deposited on glass or stainless steel as a thin film is referred to as amorphous (Solar Energy International, 2004).

To improve PV efficiency and to reduce production cost, the industry is using and experimenting with other materials such as cadmium telluride and gallium arsenide. The industry is also developing synthetic alternatives to the silicon wafers.

Monocrystalline

Monocrystalline is the oldest and most expensive production technique. Complete modules have output capacities of 14 to 15%. Boules (large cylinders) of pure single-crystal silicon are grown in an oven, and then sliced into semi-circular wafers before being doped and assembled (Solar Living, 12th Ed). Monocrystalline achieves the highest efficiency in electric energy production and its production cost is higher than other silicon types.

Polycrystalline

In this production technique, pure molten silicon is cast into molds, then sliced into wafers, doped and assembled. Polycrystalline is lower in conversion efficiency compared to Monocrystalline, averaging about 12 to 14% output capacity. Polycrystalline is shaped as a square, taking in as much of the available area of the PV module as possible.

New single family housing projects like this in Livermore, California have upgrade options that include photovoltaic systems. This polycrystalline PV system is rated at 3.6 kW and is "grid connected". (Photo Credit: David Springer, Davis Energy Group).

Amorphous

Amorphous silicon is made by vaporizing silicon and depositing it on a glass or flexible surface. Some amorphous PV panels are flexible and are able to be rolled and used for remote electricity generation. In this case, strips of amorphous PV can be wired together to form an array. One advantage of thin film (amorphous) PV products are that they can be laid between the seams of metal roofs and held into place with an adhesive backing. Other amorphous panels are made on a rigid substrate so that they can be installed in the same manner as the other types of PV panels. The

flexibility of this technology allows it to be used in a wider range of applications. The production technique costs less than other production techniques, but the output capacity, is reduced to 5 to 7%. A square foot of amorphous silicon averages about 5 watts, compared to monocrystalline or polycrystalline which average about 10 watts per square foot (Solar Living 12th Ed).

A semitransparent amorphous silicon product used as a gas station canopy in Fairfield, California. (Photo Credit: BP Solar)

Photovoltaic Modules

Solar cells are covered with an antireflective material, placed on a backing material and encapsulated together within a glass and aluminum frame. When several cells are connected together in series and parallel the voltage and amperage is accumulated to achieve the desired electrical output. Photovoltaic cells connected together in this manner form a PV module. Weather-proof electrical connections are mounted on the back of the module for quick connections to other modules that comprise the PV array. Modules can come in a variety of sizes and rated output. The standard size module is 24-volts, consisting of 72 solar cells. An average size crystalline module weighs between 30 and 35 pounds.

Important Note: A wide range of toxic and hazardous chemicals are used in the PV manufacturing process. When a module is exposed to fire or an explosion, trace chemicals can be released into the atmosphere. The inhalation of PV modules fumes and smoke "could affect human health. (Etnier and Watson)" With the concentration of PV modules in commercial applications (larger PV arrays), the risk would be higher for surrounding populations than for PV systems on residential fires. In the case of a large commercial photovoltaic array involved in a fire or explosion, surrounding populations should be warned to shelter in place until the emergency is over.

An installer adds a PV module into the array. (Photo Credit: Rodney Slaughter)

Photovoltaic panels have no moving parts and require very little maintenance. A building owner may need to occasionally hose and/or squeegee dust, dirt and bird droppings off the panels to keep them operating at peak efficiency. The panels themselves are completely weather proof, so there is little danger to the building occupants who perform this maintenance function.

Photovoltaic Array

Two or more modules connected together form a photovoltaic array. The modules are wired together in a series to accumulate voltage, and the strings are wired together in parallel to increase amperage. Residential system outputs of 600 volts are not uncommon. The average household in California uses about 6,500 kilowatt-hours per year, and a PV system in the three-to four-kilowatt range would be adequate to meet most homeowner's electricity needs. A 30 module array would operate at over 4,000 watts and weigh approximately 900 to 1,050 pounds. This weight would be spread equally over a 420 square foot area of the roof, resulting in a roof weight load of approximately 2.5 pounds per square foot.

Important Note: The PV array can be home to a wide range of insects, including ants, spiders and wasps. Each of these has been known to inhabit the array framing, electrical junction boxes and other enclosures. Be prepared for the unexpected should you reach under the array or open a junction box (Solar Energy International).

Photovoltaic Tiles and Shingles

You will see some residential PV systems that have been constructed as roof tiles or roof shingles. These PV tiles or shingles are integrated into the home's roof covering and become part of the structure. This type of PV systems is a form of "building-integrated" design. PV roof tiles duplicate the depth of cement or clay tile roofs, and PV shingles do the same for composition shingles. It takes more installation time, wiring and bundling individual tiles or shingles together to install these types of systems. This PV roofing system is aesthetically pleasing but can cost considerably more than the mounting process for modules and arrays.

Centex Homes has built model homes in San Ramon, California. The homes were unveiled in the summer of 2004. The photograph shows PV tiles being installed on a tiled roof. (Photo Credit: Davis Energy)

For building owners living in high fire hazard severity zones, roofing systems must meet Title 24 of the California Building Code for Class A roofing materials. Building integrated PV systems (PV tiles or shingles) would also have to meet this regulation.

Some manufacturers of PV roofing tiles have had their products tested and have met the standard for Class A roofing. Manufacturers of PV shingles have achieved their Class A rating by using a fire resistant underlayment beneath the section of the roof covered by PV shingles. PV modules that are mounted on racks above the roof covering would not have to meet the roofing requirement—but the roofing material underneath would.

Battery Systems

Lead acid batteries are used to store solar-generated electricity. Batteries are used most frequently in off-grid PV systems, although batteries are also used in grid-connected applications where the user wishes to have electricity availability when local blackouts occur. Without batteries, a PV system cannot provide electricity when the electrical grid is not energized.

A battery is an electrochemical cell in which an electrical potential (voltage) is generated at the battery terminals by a difference in potential between the positive and negative electrodes. When an electrical load (appliance) is connected to the battery terminals an electrical circuit is completed.

A battery cells consists of five major components; electrodes, separators, terminals, electrolyte and a case or enclosure. Several batteries are wired together achieve the desired voltage and amperage to run select household appliances when the sun is not shinning.

There are two terminals per battery, one negative and one positive. The positive electrode of a lead acid battery consists of a lead grid covered with lead oxide (PbO_2). The negative electrode is essentially lead (Pb) with an inert expander that causes the surface to be porous. These electrodes are interspersed and electrically insulated from one another with an inert separator. The electrolyte is sulfuric acid (H_2SO_2) which most often is in a liquid form but can be immobilized in a glass mat or suspended in a gel.

Pinnacles National Monument in California installed a 9.6-kilowatt photovoltaic system. The system provides power for three employee residences, a ranger station, visitor center, campground, comfort station, well pump, and two wastewater effluent pumps. It eliminates the fuel bill for a diesel generator that produced 143 tons of carbon dioxide each year. (Photo Credit: National Park Service)

Important Note: As a rule, batteries do not burn; or rather, they burn with great difficulty. If batteries are exposed to fire, however, the fumes and gases generated are extremely corrosive. Spilled electrolyte can react and produce toxic fumes and release flammable and explosive gases when it comes into contact with other metals. Due to the potential of explosive gases, prevent all open flames and avoid creating sparks. In emergencies involving batteries, always wear full protective clothing and self-contained breathing apparatus (SCBA) on positive pressure. Extinguish lead-acid battery fires with CO_2, foam or dry chemical fire extinguishers.

A bank of batteries similar to the one shown here would be used to back-up the PV system in off grid applications. (Photo Credit: Alan Wing)

The electrical potential between the positive and negative electrodes is about 2 volts direct current (DC). The voltage varies with temperature, the state of charge, and whether the cell is being charged or discharged. During discharge, the voltage decreases as the state of charge decreases. As the battery approaches a state of full discharge, the exchange of electrons from the positive and negative electrodes continues until both are covered with lead sulfate and are at equal electrical potential; referred to as a discharged cell.

> **Important Note:** Never cut into the batteries under any circumstances! Even though the voltage generating system may be disconnected from the battery bank, the batteries themselves still have potential for electrical shock. If the battery is punctured by a conductive object, assume that the object has electrical potential.

During the charging process, the reactions occur in the opposite direction to reform both electrodes back to lead and lead oxide respectively. As the reformation proceeds, the electrical potential of the cell is returned to its original value of approximately 2 volts.

Outside the battery current flows from the positive terminal, through the appliance and returns to the negative terminal. If the electrical load is replaced by an external power source that reverses the flow of the current through the battery, the battery can be charged. This process is used to reform the electrodes to their original chemical state, or full charge.

During charging, the battery can enter a state of over charge in which the electrodes will off-gas oxygen from the positive electrode and hydrogen from the negative electrode. In conventional, free flowing electrolyte batteries, the gasses bubble through the electrolyte to the surface and out of the battery, resulting in a drop in the batteries electrolyte level (Slaughter/Rawson). The escaping gases are highly flammable. For this reason, sparks and open flames are not allowed in the area of the batteries.

Controllers

To keep battery charge levels in check, a charge controller is used in the PV system. The addition of a battery charge controller prevents over-charging and reduces the danger of off-gassing. Many of the commercial controllers on the market also protect the battery from over-discharges as well. A PV charge control senses battery voltage. When the batteries are fully charged, the control will stop or decrease the amount of current flowing from the PV array into the battery. When the batteries are being discharged to a low level, many of the controllers will shut off the current flowing from the battery to the DC loads. Charge controllers come in a variety of sizes, from a few amps to as much as 60 amps.

The battery controller shown here was used in an off-grid PV system. (Photo Credit: Alan Wing)

Inverters

The PV array, batteries and charge controllers all function on direct current. This is great for the off-grid building owner who is also using direct current appliances. However, these DC appliances are more expensive, limited in variety, and harder to find than their alternating current counterparts. So, for the building owner to take advantage of a wider range of appliances, or to connect to the grid, the PV direct current has to be converted to alternating current. This is accomplished with a PV inverter.

The inverter changes the direct current to alternating current at 60 hz. Inverters are classified according to the waveform they produce. There are three types of inverters; square wave, modified square wave and sine wave. Sine wave inverters are used in many applications because they produce a high quality waveform used to operate sensitive electrical equipment. Utility connected inverters are required for grid-tied PV systems. Utility grid inverters are typically of the sine wave type in order to correspond to the frequency of the utility supplied power and are designed to shut down the solar generated electricity when there is no grid power. When converting DC to AC a significant amount of heat is generated. Inverters are designed with a heat sink assembly to dissipate the heat away from the system.

Inverters come in a wide range of styles, classifications, and optional features. The one shown here is manufactured by PV Power and includes a digital read out. (Photo Credit: Rodney Slaughter)

Mounting Systems

There are a variety of ways that PV modules and arrays can be mounted. Typically a roof with a southern exposure allows a quick and effective installation. Although there are systems that can be mounted directly on the roof, in many cases, specialized roof racks lift the array from the roof deck allowing for air

to circulate under the modules. Many PV systems are designed to withstand 80 mile per hour winds.

Fixed pole mounted PV system foreground with roof mounted PV modules and solar thermal modules on the roof in the background. (Photo Credit: Alan Wing)

A solar water heating panel is installed below the PV array. (Photo Credit: Les Nelson, CAL SEIA)

PV systems can also be mounted on the ground using customized racks, or they can be mounted on poles. Sophisticated tracking systems that allow the entire array to move with the direction of the sun are a feature of pole mounted systems.

Other Solar Technologies

Can you distinguish PV panels or modules from other solar technologies like solar thermal systems or skylights? Solar thermal panels (solar water heating collectors), are used to heat water for the swimming pool or for domestic hot water. Unlike PV panels, which convert up to 15 % of the suns energy into electricity, solar thermal panels convert 95% of the sun's energy into heat. Another type of solar thermal panels is used exclusively for heating swimming pools. These panels typically consist of a polymer material, and usually lay flat on the roof. Solar pool heating panels usually have no glass cover plate or other metal enclosure.

Solar thermal panels run copper tubing inside an aluminum box with a flat or convex glass cover. Solar thermal panels are not inherently dangerous to emergency responders-- unless fire fighters trip over them while working on the roof! There is no wiring associated with solar thermal panels- only plumbing and hot water. It is important to be aware that both technologies can be in use on the same roof at the same time.

Skylights are a function of passive solar design—allowing natural light to enter the interior of the building. When they are available, fire fighters can use skylights to ventilate the building of superheated gasses and smoke expeditiously. Skylights from the interior of the structure, with a sheet rocked ceiling, will be sheet rocked up to the underside of the skylight. This is advantageous to fire fighters in that the chimney created by the sheet rock underneath the skylight also provides some protection from superheated gas and smoke getting into the attic area. Another advantage is that a broken skylight is cheaper to fix than a hole chopped in the roof assembly.

Skylights come in a variety of shapes and sizes and are fairly distinctive with clear, translucent or tinted plastic or glass. To keep rain from getting inside the skylight, they are integrated into the roof with metal flashing around the base. A skylight with integrated photovoltaic will have a distinctive amorphous rectangular pattern in the glass. Once again it is conceivable that skylights may be on the same roof as PV panels and solar thermal panels.

Laminated to the skylight glass are photovoltaic cells that produce electricity as well as serve as an element in the shading and day lighting design at the Thoreau Center for Sustainability, Presidio National Park, San Francisco, California. (Photo Credit: Lawrence Berkeley Lab)

Photovoltaic Identification

PV panels are distinctive, making them relatively easy to recognize when you know what to look for. In the case of monocrystalline, the PV panel looks like there are a group of semi-circular squares that are laid out in a rectangular panel. Polycrystalline panels have square cells laid out in a rectangular panel. In either case these modules are usually laid on a racking system elevating them a couple of inches above the roof. Amorphous panels have a pattern of rectangles integrated across the entire panel. The color of all these solar cells ranges from black to blue.

It is not recommended that fire fighting personnel attempt to remove or cut into the PV modules. Attempts to do so could potentially release all the energy inherent in the system simultaneously. Similarly, there is no need to cut into or remove a solar thermal module (water heating collector) during a structural emergency.

Skylights with integrated PV circuits should not be broken for ventilation purposes. All other skylights can be used for ventilation purposes if it meets the strategic and tactical objective of the emergency. When the PV array covers the south facing roof, and the need to ventilate occurs, choose a spot on the east, west or north facing slope of the roof and cut a ventilation hole at the highest point over the fire.

SUMMARY

The greatest danger for emergency responders is the lack of PV knowledge needed to safely operate around this emerging technology. This section provided you with an introduction to the photovoltaic system. Identification of the PV array and all the related components is critical in an emergency response; understanding how the PV system is integrated into the building's electrical distribution system is important to safe fireground operations.

Photovoltaic technology is an incredible scientific and engineering feat. But as wonderful as this technology is, there are still some limitations. Many people believe that purchasing a photovoltaic system will allow them to say good-bye to their electric company and their utility bills forever! As you will see that is simply not the case. In many cases the utility industry becomes a partner in the PV system by providing many people with the back-up electricity they need when the sun is not shinning!

"Is it fact, or have I dreamt it—that, by means of electricity, the world of matter has become a great nerve, vibrating thousands of miles in a breathless point in time."

—Nathaniel Hawthorne, The House of the Seven Gables, 1851

FUNDAMENTALS OF PHOTOVOLTAICS FOR THE FIRE SERVICE

PHOTOVOLTAIC PERFORMANCE

Photovoltaic technology does not convert 100% of the Sun's energy into electricity. The highest efficiency PV technology available today is used on satellites, and for applications such as the Space Station, where cost is less of a consideration. These types of PV cells are able to convert as much as 30 % of sunlight into electricity. The highest efficiency PV products used in conventional building applications today convert from 10 to 20 % of sunlight into electricity.

Environmental factors like overcast days caused by clouds and smog can lower system efficiency. Site factors such as chimneys, trees and nearby buildings can shade the panels during part of the day and greatly reduce the output for the entire array. And, like people themselves, PV systems operate best within a comfortable range of temperatures.

PV output will be greatly reduced when the temperature of the individual cells goes above 90 degrees Fahrenheit. For this reason panels are usually installed on a racking system that lifts the panels off the roof to allow air to circulate around the modules, thereby keeping the PV array cooler. Extreme cold temperatures can have the opposite effect. Increased output of 30 to 40% has been recorded in cold temperatures with clear days, and sunlight reflecting off snow banks.

To achieve peak performance, sunlight should strike the PV panel at a 90 degree angle. Of course, the sun changes position during the day,

PV Historical Brief

1839 French scientist Edmond Becquerel discovers the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution—electricity-generation increased when exposed to light.

1873 Willoughby Smith discovered the photoconductivity of selenium.

1876 In 1876 William Grylls Adams and Richard Evans Day discover that selenium produces electricity when exposed to light.

1905 Albert Einstein published his paper on the photoelectric effect (along with a paper on his theory of relativity) and wins the Nobel Prize for his theories in 1921.

1918 Polish scientist Jan Czochralski developed a way to grow single-crystal silicon.

1954 The photovoltaic technology is born in the United States when Daryl Chapin,

Calvin Fuller, and Gerald Pearson develop the silicon photovoltaic (PV) cell at Bell Labs.

1958 The Vanguard I space satellite used a small (less than one watt) array to power its radios.

1962 Bell Telephone Laboratories launches the first telecommunications satellite, the Telstar (initial power 14 watts).

1964 NASA launches the first Nimbus spacecraft—a satellite powered by a 470-watt photovoltaic array.

1982 The first, photovoltaic megawatt-scale power station goes on-line in Hisperia, California. It has a 1-megawatt capacity system.

1982 Worldwide photovoltaic production exceeds 9.3 megawatts.

1983 ARCO Solar dedicates a 6-megawatt photovoltaic substation in central California. The 120-acre, unmanned facility supplies the PG&E's utility grid with enough power for 2,000-2,500 homes.

1984 The Sacramento Municipal Utility District commissions its first 1-megawatt photovoltaic electricity generating facility.

1999 Cumulative worldwide installed photovoltaic capacity reaches 1000 megawatts.

and between seasons. For this reason a PV designer conducts a site inspection to determine availability of sunshine throughout the year, including a number of site specific characteristics such as average daily insolation, site latitude, magnetic declination (true south), tilt angle and site specific information such as local weather and climate, all the while keeping an eye out for shading obstacles. Regardless of these considerations, however, all the PV systems in the Northern hemisphere will be orientated towards true south.

> **Important Note:** While there are many factors that affect PV performance over a period of time, emergency response personnel should remember that even in the worst daylight conditions the PV array is still generating electricity—maybe not at its peak performance, but if you get shocked by cutting into the system, the performance issue is a moot point.

When designing a PV system, engineers and installers typically underestimate the PV module output by 15 to 25% from the manufacturers tested output. This calculation allows for a buffer in the specifications to ensure that the installed system will meet the building owner's energy needs.

Another factor in design efficiency is the output of the system and the fact that the mono and polycrystalline cell degrades about .25 to .5% every year. This low degradation percentage, gives PV manufacturers the confidence to guarantee that their solar panels will be operational for at least 25 years. The reality is that these systems may actually outlive many of their original owners.

A Fire Department salvage cover was used in a failed attempt to block sunlight from reaching the newly installed PV array.

A fire department salvage cover was employed in California only to discover that while it significantly reduced the Sun's intensity and the electrical energy that it generates—it did not completely block out the Sun and the system still generated enough volts and amps to shock a potential victim. (Photo Credit: Marc Fontana)

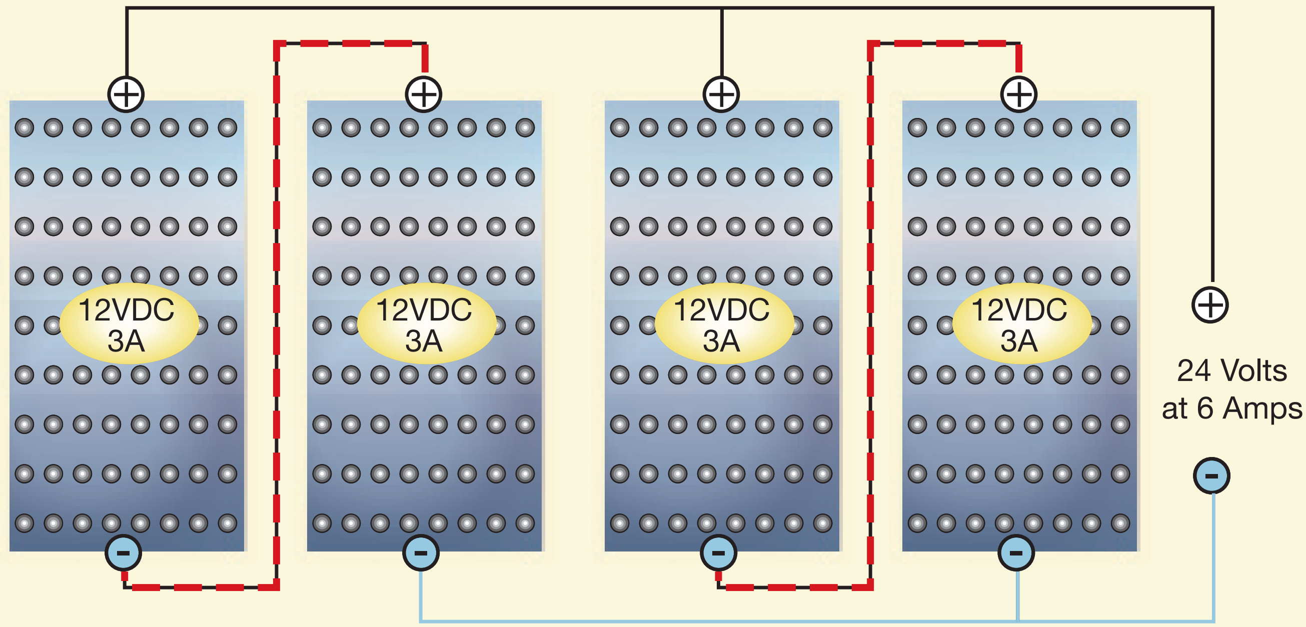
> **Important Note:** When the sun is shining there is no way to turn off the PV system. German fire fighters tried using foam to obliterate the sunlight on the array. The foam is translucent and cannot completely block all the Sun's intensity. More importantly, the foam kept sliding off the surface of the PV array.

Photovoltaic Concepts

The point of photovoltaic technology is to generate electricity. More significantly, electricity generated from a clean and reliable source—the Sun! While you work with and around electricity every day, you may need a refresher on what electricity is and the terminology associated with it.

Electricity is the flow of electrons through a conductor. PV designers are driven by the electrical concepts associated with this flow of electrons—voltage (volts), amperage (amps) and wattage (watts).

Voltage is the measure of electrical potential between two points. The unit of force, or pressure, it takes to



PV MODULES IN SERIES AND PARALLEL

motivate electrons to move through a circuit is measured in volts. The rate at which the electrons flow through the circuit is measured in amps. Wattage is simply a measure of the amount of electrical power provided by the circuit. A watt is the rate an appliance uses electrical energy, or rather the amount of work done when one amp at one volt flows through one ohm of resistance. One watt is equivalent to 1/746 horsepower. A watt is the product of voltage (volts) multiplied by (amps).

When you put all these terms and concepts together you end up with Ohm's Law. Ohm's Law is a mathematical equation to help you calculate all of these terms when you know at least two of the values. The formula looks like this:

Volts x Amps = Watts

So, consider your circular saw that draws 7.5 amps of power when plugged into a 120 volt wall outlet, it will consume, 7.5a X 120v = 900 watts of power. You can flip this equation around to find other values.

Watts ÷ Amps = Volts and Watts ÷Volts = Amps

For PV designers and installers this formula is important when calculating the energy demand of the building they are trying to power with a PV system. Since consumers need to know to know how much energy they use, the watt-hour is an important measurement and one that PV designers can work with. To calculate watt hours all you need to know is the rated wattage for the appliance and how the long the appliance stays on. Add together all the appliances in the building and you get an idea of how many potential watt-hours maybe needed by the system.

Imagine if you calculated all the watt-hours in the room you are sitting in right now? How many watt-hours do you suppose is being used? If you count the lights, the stereo or television, the electric heater or the air conditioner, the figure could be staggering—in the thousands of watts, and over a period of one hour, thousands of watts per hour (one thousand watts consumed over the period of one hour is one kilowatt hour, or kWh). Once you get into these numbers you will see that the kWh consumed in the normal course of living are substantial. Your own monthly utility bill will show the amount of energy you and your family consume in terms of kilowatt hours.

Why is this information so important to PV designers and installers? PV systems need to be sized to meet consumer energy use. But the catch is that a PV system is still relatively expensive and the average American consumer uses a lot of electrical energy. The bigger the system, the higher the out-of-pocket expense to the building owner: to the tune of tens of thousands of dollars. Not only that, but a PV system cannot deliver a constant amount of energy every day in every season.

The trick here is energy conservation. Reputable designers and installers will analyze the consumer's energy usage and expectations from the system. They will make recommendations on how to conserve energy before they talk about sizing and installing the PV system.

SUMMARY

The physics of electricity never change, regardless of how the electricity is generated. There are a number of factors that affect overall system performance. Geographical location, site specifics, including roof slope and declination (degrees east or west of true south), system size, the electrical demands of the system, and the PV components themselves are all factors related to performance. Recognizing these factors is another key to personnel safety when working around PV systems.

PHOTOVOLTAIC APPLICATIONS

"The world we live in is but thickened light."

—Ralph Waldo Emerson, The Scholar,1883

Understanding how solar cells generate electricity is one thing. Understanding what to do with all that electricity is another. In most cases, a PV system will generate more electricity during the sunniest part of the day than can be used at that time. Photovoltaic designers and installers have several options in regards to system design in order to address this issue. The first is to store excess electricity in a bank of batteries so that the electricity can be used when the sun is not shining. This design is typical of an off-grid system. The second option is to credit all excess electricity generated back to the utility company. This is typical of a grid-connected system.

A third option is to store electricity in the battery bank and then credit excess electricity back to the utility grid. This battery back-up system ensures that the building owner will have enough electricity stored in case of a utility grid power outage. While battery back-up systems do exist, they are not common. It's far more cost effective (and probably easier for most building owners to maintain) to back-up an off-grid, or grid-tied system for that matter, with a generator.

The design choice, the building site, and the building owner's expectations will all be considered to determine the type of equipment that will be installed at a given site. The obvious advantage of a solar energy system is that it produces clean and reliable energy that can be used in a wide range of applications. In fact the application of solar electric is so prevalent in your life that you probably don't even think about it.

Day Use

You are familiar with day use solar technology where solar cells or modules are wired directly to solar generated appliances like a calculator, toys, fan, blower or pump. These are simple and inexpensive solar electric applications. These appliances operate when the solar cell is exposed to the sun or a bright light.

Integrated Photovoltaic with Battery Back-Up

Other applications that you may be familiar with might include integrated photovoltaic with battery back-up where the solar energy is stored in rechargeable batteries so that the appliance can be used when the sun isn't shining. These appliances include watches, radios, flashlights, telecommunication equipment, railroad lights and low voltage landscape lighting systems. Again these are fairly simple, inexpensive and specific applications of the photovoltaic technology (think about the cost of running electrical wires to all of the thousands of solar-powered call boxes along California's freeways). Even if you don't use PV directly you are doing so indirectly. Communication systems and satellites with integrated PV systems provide power that improves the efficiency of our everyday lives even though you may not be aware of it.

In December of 1998 Astronauts Jerry L. Ross (left) and James H. Newman work together on the final of three space walks of the STS-88 mission. (Photo Credit: NASA)

Direct Current (DC) Systems

Recreational vehicles, boats or buildings in rural areas where there is no access to the power grid (off grid applications), can employ photovoltaic systems with storage batteries and direct current appliances. With batteries employed in the system, the operator can store the solar-electric energy generated during the day for use in the evenings or on cloudy days. Components used in a direct current system include; a photovoltaic module or array, charge controller, batteries, and direct current appliances.

> **Important Note** The "Hot Stick" fire departments carry on their engines only detects alternating current (AC). Using a hot stick on the PV side of the system will not detect direct current (DC), thereby misleading fire fighting personnel into believing that electricity is no longer present! There are commercially available clamp-on AC/DC meters that would be the preferred method for detecting voltages in the wring system.

Direct Current to Alternating Current Systems (DC to AC)

Another technique, for people in rural areas to power their homes is to convert the direct current (DC) generated from the PV system to alternating current (AC). While still independent from the utility power grid, the homeowner can take advantage of a wider range of affordable electrical appliances. These systems would include similar components found in the DC system, such as: solar modules or array, charge controller, and batteries, plus the addition of an inverter, to convert DC to AC.

Like modern day sails, the solar panels on the roof of this Lake Oroville houseboat provides power. (Photo Credit: Alan Wing)

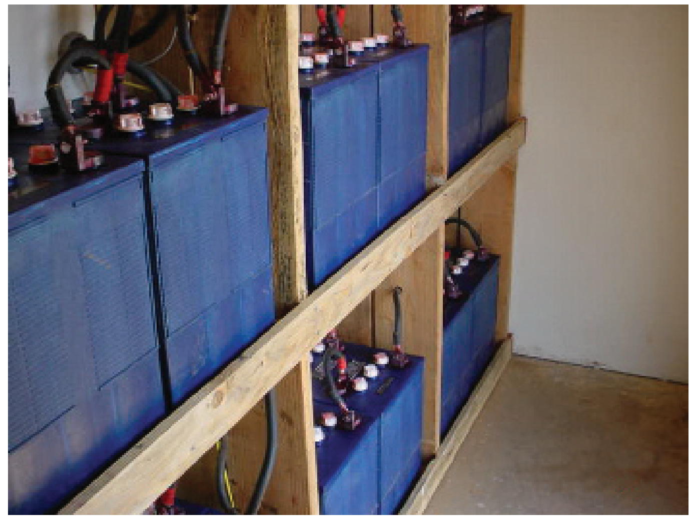
The US Fish and Wildlife Service needed a cleaner, quieter power source for this island 30 miles west of San Francisco. This reliable 9.1 kW photovoltaic system runs the facility that serves as a home for USFWS biologists who study the islands 6000 sea lions and thousands of birds. (Photo Credit: Farallon National Wildlife Refuge)

PV works best when the sun is shining. In California, fog and rainy days can last for several weeks longer than most battery systems can store energy. Some PV systems are additionally backed-up with generators (commonly) or other alternative devices such as micro-hydroelectric or wind powered generating systems.

Battery backed-up PV systems are designed to provide electricity for a specific period of time without sunshine. People with off-grid systems are usually very energy conscious, choosing to live without some of the conveniences that grid-tied homeowners are accustomed to. They are willing to spend time monitoring the fluid levels and charge/recharge capacity of their battery systems. For the peace of mind that comes from living off grid they appear to be happy to monitor their own systems.

This rural home in northern California uses both an off-grid PV system along with a solar thermal system. (Photo Credit: Alan Wing)

The controller monitors the electricity entering and exiting the back-up battery system. (Photo Credit Alan Wing)



The bank of back-up batteries stores PV generated electricity. (Photo Credit Alan Wing)

The inverters used in this system convert PV generated direct current to alternating current. (Photo Credit: Alan Wing)

Important Note: Volunteer firefighters in rural areas need to understand the photovoltaic technology and identify the locations of these systems. Not only should you be aware of the electrical shock hazards posed by the photovoltaic array, but you have the additional responsibility to mitigate banks of batteries and their associated hazards during a structural fire.

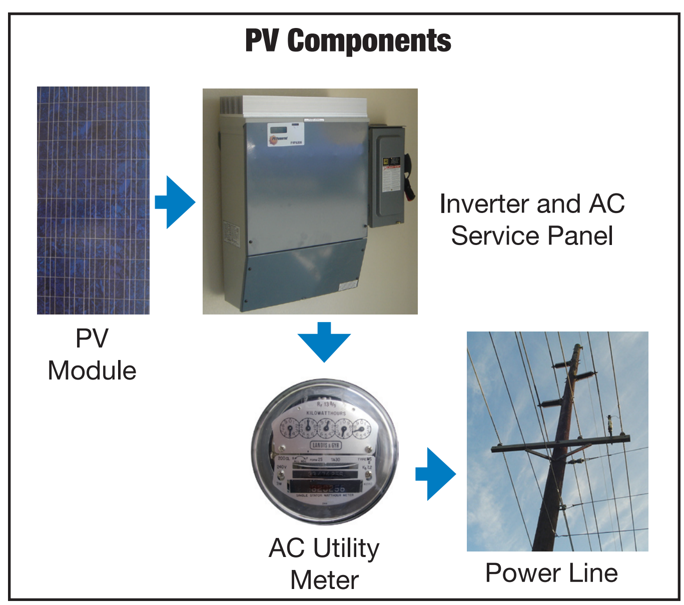
Grid-Tied Systems

Another option, and one of the most prevalent for homeowners and businesses, is the grid-tied system. This system allows the building owner to generate and use solar power during the day and deliver excess power directly to the utility grid: effectively reversing the meter. When the system is not generating enough electricity for the home or business, electricity is imported from the electric grid. Net metering is achieved when the utility billing practices, or "tarrifs," allow for a "netting out" of these electrical flows and corresponding costs at the end of a month or year; "net metering." In this type of system the utility grid provides the back-up and eliminates the need for batteries in the system. System components would include a PV array and a grid-tied inverter.

> **Important Note:** It may not be possible to see a PV system on a flat roofed building from street level. It is incumbent on the building owner/operators to label solar electric systems at the main electrical panel. The fire department must preplan for structural emergencies on specific commercial and industrial buildings in their jurisdiction.

The roof top of the USPS processing and distribution center in Marina Del Rey, California shows the use of a 127 kw mono-crystalline PV system. (Photo Credit Power Light Corporation)

The inverter for this system is significantly larger than those you would expect to find on a residential system. (Photo Credit: U.S. Postal Service)



This PV system at the Cal Expo in Sacramento, California, was installed in September 2000. The 540-kilowatt PV system produces enough energy to power about 180 homes. The solar arrays serve as a shaded oasis for 1,000 cars in a desert of scorching blacktop. (Photo Credit: Kyocera Solar)

Grid-tied systems automatically shut-down when there is no utility grid power present. Loss of power from the utility will essentially knock out all electricity in the building including the ability to use the electricity generated from the PV system. However, the electrical lines from the PV panels to the inverter are still energized! Electric power from the inverter to the rest of the building's wiring system and to the grid becomes isolated during a power outage. This system protects utility company personnel from electrical shock while working on the lines during power outages —ensuring that the solar electricity is not being back-fed into the system.

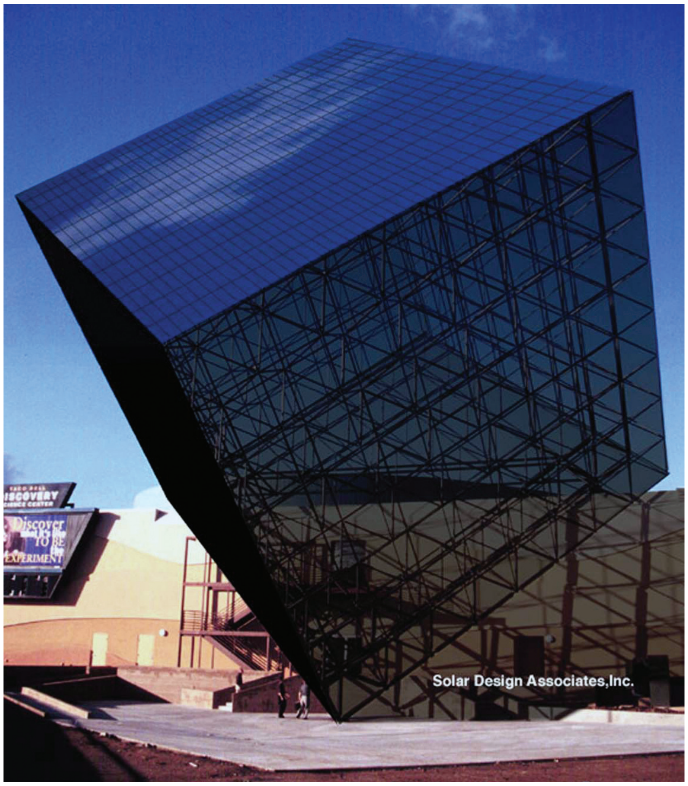
> **Important Note:** When you lock out the main electrical power to the building you are disabling the power from the grid, simulating a power outage, which isolates the power from the PV array at the inverter. Remember, electricity is still present from the PV panels to the inverter.

As an extra measure of safety, fire fighting personnel can also use the manual disconnect on the inverter to ensure that the PV system is in fact isolated from the rest of the building. In many cases, PV systems can be identified with warning stickers and labels at the main electrical panel next to the inverter.

Building Integrated Design

The architectural design and building technology trend is to incorporate PV systems into the building's exterior finish. These systems appear as PV roofing systems, windows, skylights or patio covers. These systems are more expensive, and therefore not as prevalent as roof or ground mounted systems. But they do pose new design opportunities for building designers and owners.

> **Important Note:** Solar electric panels look a lot like solar thermal panels. Solar thermal panels are used to heat water for pools and domestic hot water.. Solar electric and solar thermal panels look like skylights. Using skylights to ventilate a building should only be an option if you know that it is truly just a skylight!



Thin-film Millienna photovoltaic modules (494 total) from BP Solar were used on the Solar Cube. The cube stands 135 feet tall on top of the Discovery Science Center in Santa Ana, CA and can be seen for many miles from the neighboring Interstate Highway 5. Solar Design Associates designed, engineered, and constructed the 20-kilowatt grid-connected array. (Photo Credit: Solar Design Associates)

PV glazing for windows and skylights can be installed in the curtain wall of a high rise or designed into a skylight or atrium. This technology uses a film attached to electric leads and sandwiched between panes of glass. The PV panel functions to not only generate electricity but also filters the harsh sunlight coming through the window. This type of PV system is less effective in generating electricity than the solar panels on the roof, so a number of south facing windows are covered to generate the required amount of energy for the building.

> **Important Note:** It is not recommended that you break the glass protecting any type of solar cell, whether it is a panel, window or skylight. Breaking through the glazing can potentially unleash all of the inherent energy in the system instantaneously, posing a significant shock hazard to the fire fighter.

A design trend in Europe is to find clever ways of incorporating PV systems into the architecture or landscape of the building site. As PV becomes more prevalent in American planning, you can expect to see PV incorporated into fountains, sculpture, sheltering structures and lighting systems in landscaping projects. Building design may incorporate PV sun shades or appear as shutters around multiple windows—or even be installed in the window itself! Blending this technology into traditional building and landscape design is one of the many challenges designers are involved in and presents new challenges for emergency responders in identifying PV technology when sizing-up an emergency.

Pre-fire planning residential and commercial buildings will help you identify where building integrated designs are located. Roofs on residential building integrated PV systems are still fairly easy to identify by the shiny surface when compared to the rest of the roofing material that surrounds it.

> **Important Note:** Emergency responders can no longer assume that once the main electrical disconnect has been shut off that it will automatically ensure that all power to the building has been disconnected. The wiring and connections from the photovoltaic panel to the inverter are still energized and caution should be taken not to cut into these conduits.

SUMMARY

The future of photovoltaic technology will continue to be integrated into our daily lives. The future trend will be to integrate PV seamlessly and unobtrusively into buildings and building sites. This trend will make PV system identification a little more challenging for emergency responders.

Our dependence on non-renewable energy sources has to shift to renewable resources like PV for the survival of the California way of life! Compared to other energy options like nuclear, hydrocarbon and large scale hydroelectric, photovoltaic technology is a safer, cleaner, and environmentally friendly alternative.

> “Progress imposes not only new possibilities for the future but new restrictions.”
>
> —Norbert Weiner, The Human Use of Human Beings, 1954

CODES AND STANDARDS

At the heart of the building codes are the life safety considerations for the building occupants and emergency responders. Granted, photovoltaic systems are safer to use and operate than many other energy technologies. Nevertheless, life safety considerations, standardization and interoperability with other electrical systems drive the building codes and regulations to where they are today. The intent of this section is to highlight a few of the important safety requirements inherent in the California Building, Electrical, and Fire Codes and the National Standards as they relate to photovoltaics.

Wiring Identification

Knowing that charged electrical lines are inherent in the building even after the main power supply has been locked out/tagged out raises the questions: Where do PV circuits exist within the building envelope and how do you identify them? Is there a mechanism to disconnect the system?

You can mentally trace the path of PV circuits from the PV array through the building to the controller, batteries and/or on to the inverter next to the main electrical panel. When a direct current photovoltaic conductor is run outside a building membrane, it will be contained in metallic raceways or enclosures from the point of penetration of the surface of the building to the first readily accessible disconnecting means.

This installer is running PV conductors into metallic junction box and conduit. (Photo Credit: Marc Fontana)

As an extra measure of protection, the NEC specifies that conductors of different output systems (utility grid, generator, hydro electric, or wind) will be contained in separate raceways, cable trays, cable, outlet box, junction box, or similar fittings. Never cut into these conduits or raceways.

System Disconnects

Both the Uniform Fire Code (11.1.7.1) and the NEC (690.13 & 690.15) address the ability to disconnect an electrical system. The Uniform Fire Code specifically adds that the disconnecting means is accessible to the fire department. NEC requirements provide the details for disconnecting all conductors in the system. Some of these requirements include:

- Means shall be provided to disconnect all current-carrying conductors of a photovoltaic power source from all other conductors in a building or other structure.
- The photovoltaic disconnecting means shall be installed at a readily accessible location either on the outside of a building or structure or inside nearest the point of entrance of the system conductors.
- The photovoltaic system disconnecting means shall not be installed in bathrooms.
- Each photovoltaic system disconnecting means shall be permanently marked to identify it as a photovoltaic system disconnect.
- The photovoltaic system disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure, in a group of separate enclosures, or in or on a switchboard.
- The photovoltaic system disconnecting means shall be grouped with other disconnecting means.
- A photovoltaic disconnecting means shall not be required at the photovoltaic module or array location.
- Means shall be provided to disconnect equipment, such as inverters, batteries, charge controllers, and the like, from all ungrounded conductors of all sources. If the equipment is energized from more than one source, the disconnecting means shall be grouped and identified.
- Battery installations, where there are more than twenty-four 2-volt cells connected in series (48 volts, nominal), shall have a disconnecting means, accessible only to qualified persons, that disconnects the grounded circuit conductor(s) in the battery electrical system for maintenance.
- A single disconnecting means shall be permitted for the combined ac output of one or more inverters or ac modules in an interactive system.
- The disconnecting means for ungrounded conductors shall consist of a manually operable switch(es) or circuit breaker(s) complying with all of the following requirements:
  - Located where readily accessible
  - Externally operable without exposing the operator to contact with live parts
  - Plainly indicating whether in the open or closed position
  - Having an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment
- Where all terminals of the disconnecting means may be energized in the open position, a warning sign shall be mounted on or adjacent to the disconnecting means. The sign shall be clearly legible and have the following words or equivalent:

WARNING
ELECTRIC SHOCK HAZARD.
DO NOT TOUCH TERMINALS. TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

There are a number of redundant system disconnects built into a PV system. Disconnects can be located next to the main electrical panel, the inverter, the controller, and the battery bank. As mentioned earlier, an inverter in a grid-tied or interactive solar photovoltaic system will automatically de-energize its output from the PV system and the AC distribution network of the building upon the loss of voltage in the system. The system will remain in this state until the electrical production and distribution network voltage has been restored.

The inverter (red box) center is flanked by (gray) junction boxes each with a knife switch that can isolate power from the PV array and the main circuit panel. (Photo Credit: Marc Fontana)

Importantly, a normally interactive solar photovoltaic system can be permitted to operate as a stand-alone system to supply loads that have been disconnected from electrical production and distribution network sources. You would find this arrangement in grid-tied systems with a battery back-up or generator back-up system.

Wiring (Conductors)

The type and size of wiring used in photovoltaic systems is determined by several factors, including whether the current is direct or alternating. Low voltage DC systems often have larger wiring sizes as compared to AC systems. The circuit conductors and overcurrent devices are sized to carry not less than 125 percent of the maximum calculated currents. Also, wiring exposed to the weather must be rated and labeled for outdoor use. Importantly, to reduce fire hazards, roof mounted PV systems, conductors, and components are all required to be grounded.

Ground Fault Protection

The ground-fault protection device or system detects a ground fault, interrupting the flow of fault current, and providing an indication of the fault. Specific requirements are listed in the NEC for providing ground fault protection for PV systems and components. These include:

- Labels and markings applied near the ground-fault indicator at a visible location, stating that, if a ground fault is indicated, the normally grounded conductors may be energized and ungrounded.
- In one- and two-family dwellings, live parts in photovoltaic source circuits and photovoltaic output circuits over 150 volts to ground shall not be accessible to other than qualified persons while energized.
- The DC circuit grounding connection shall be made at any single point on the photovoltaic output circuit.
- Locating the grounding connection point as close as practicable to the photovoltaic source better protects the system from voltage surges due to lightning.
- Exposed non–current-carrying metal parts of module frames, equipment, and conductor enclosures shall be grounded regardless of voltage.

Installer is connecting a ground wire to each module in the PV array. (Photo Credit: Rodney Slaughter)

PV Modules

In a photovoltaic module, the maximum system voltage is calculated and corrected for the lowest expected ambient temperature. This voltage is used to determine the voltage rating of cables, disconnects, overcurrent devices, and other equipment.

In one- and two-family dwellings, photovoltaic source circuits and photovoltaic output circuits that do not include lampholders, fixtures, or receptacles and are permitted to have a maximum photovoltaic system voltage of up to 600 volts. Other installations with a maximum photovoltaic system voltage over 600 volts shall comply with Article 490.

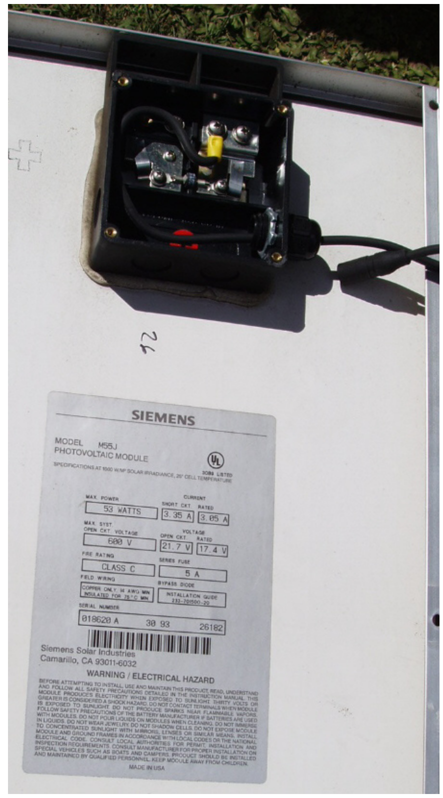
A label for the direct-current photovoltaic power source will be provided by the installer at an accessible location at the disconnecting means for the power source providing information on:

(1) Operating current

(2) Operating voltage

(3) Maximum system voltage

(4) Short-circuit current



On the back of a PV module you will find the module's junction box along with a label showing the modules rated capacity and Underwriters Laboratory label. (Photo Credit: Marc Fontana).

Batteries

Storage batteries in a photovoltaic system should be installed in accordance with the provisions of Article 480. The interconnected battery cells are considered grounded when the photovoltaic power source is installed in accordance with the NEC.

Storage batteries for dwellings will have the cells connected to operate at less than 50 volts nominal. Lead-acid storage batteries for dwellings shall have no more than twenty-four 2-volt cells connected in series (48-volts nominal).

In that, the batteries in photovoltaic systems are subject to extensive charge–discharge cycles, they typically require frequent maintenance such as checking electrolyte and cleaning the connections. For this reason live parts of battery systems for dwellings should be guarded to prevent accidental contact by persons or objects, regardless of voltage or battery type.

Batteries shown here in a well ventilated garage on wooden storage racks connected together in series and parallel. (Photo Credit: Alan Wing)

Flooded, vented, lead-acid batteries with more than twenty-four 2-volt cells connected in series (48 volts, nominal) shall not use conductive cases or shall not be installed in conductive cases. Conductive racks used to support the nonconductive cases shall be permitted where no rack material is located within 150 mm (6 in.) of the tops of the nonconductive cases. This requirement shall not apply to any type of valve-regulated lead-acid (VRLA) battery or any other types of sealed batteries that may require steel cases for proper operation.

As mentioned earlier, equipment is provided to control the charging process of the battery. All adjusting means for control of the charging process should only be accessible only to qualified persons. The reason for this is that certain battery types such as valve-regulated lead acid or nickel cadmium can experience thermal failure when overcharged.

Additional requirements for batteries can also be found in Chapter 52, NFPA 1, Uniform Fire Code (2006). Stationary lead-acid battery systems having an electrolyte capacity of more than 100 gal (378.5 L) in sprinklered buildings or 50 gal (189.3 L) in unsprinklered buildings used for facility standby power, emergency power, or uninterrupted power supplies will also contain these safety features:

- Valve-regulated lead–acid (VRLA) battery systems should have a listed device or other approved method to preclude, detect, and control thermal runaway.
- Battery systems are permitted in the same room as the equipment that they support. These systems should be housed in a noncombustible, locked cabinet or other enclosure to prevent access by unauthorized personnel unless located in a separate equipment room accessible only to authorized personnel.
- In other than assembly, educational, detention and correction facilities, health care, ambulatory health care, day care centers, residential board and care, and residential occupancies, battery systems should be located in a room separated from other portions of the building by a minimum of a 1-hour fire barrier.
- In assembly, educational, detention and correction facilities, health care, ambulatory health care, day care centers, residential board and care, and residential occupancies, battery systems should be located in a room separated from other portions of the building by a minimum of a 2-hour fire barrier.
- An approved method and materials for the control of a spill of electrolyte shall be provided. An approved method to neutralize spilled electrolyte should be provided capable of neutralizing a spill from the largest lead–acid battery to a pH between 7.0 and 9.0.
- Ventilation shall be provided for rooms and cabinets in accordance with the mechanical code and one of the following:

    1. The ventilation system shall be designed to limit the maximum concentration of hydrogen to 1.0 percent of the total volume of the room during the worst-case event of simultaneous "boost"

charging of all the batteries, in accordance with nationally recognized standards.

2. Continuous ventilation shall be provided at a rate of not less than 1 ft3/min/ft2 (5.1 L/sec/m2) of floor area of the room or cabinet.

- The battery environment shall be controlled or analyzed to maintain temperature in a safe operating range for the specific battery technology used.
- Doors or accesses into rooms, buildings, or areas containing stationary lead–acid battery systems should be provided with approved signs. The signs will state that the room contains lead–acid battery systems, that the battery room contains energized electrical circuits, and that the battery electrolyte solutions are corrosive liquids.
- Battery cabinets shall be provided with exterior labels that identify the manufacturer and model number of the system and electrical rating (voltage and current) of the contained battery system. Within the cabinet, signs shall be provided to indicate the relevant electrical, chemical, and fire hazard.
- In seismically active areas, battery systems shall be seismically braced in accordance with the building code.
- An approved automatic smoke detection system shall be installed in such areas and supervised by an approved central, proprietary, or remote station service or a local alarm that will give an audible signal at a constantly attended location.

Fire and life safety plan review will ensure that firefighters have adequate access to the roof. It is important that fire inspectors and plan reviewers get involved in the building permit and inspection process and to pass available information of PV installations on to the operational section of their departments. Fire fighters need to take this information and develop preplans for the commercial and residential structures in their jurisdictions.

Preplans should note electrical lock out and identify the location of PV components such as inverters, batteries, controllers, panels, and system disconnects. Once a structure with a PV system becomes involved in a structural emergency or fire, your department will have all the available information at their fingertips.

SUMMARY

Firefighters have successfully dealt with lead acid batteries and battery systems for decades. Personal protective equipment, knowledge of battery systems, and the ability to isolate the battery system, as provided by the codes, also provide the extra measure of personal safety.

The Building, Electrical, and Fire Codes ensure the safety for occupants and emergency responders. Automatic disconnect, along with manual service disconnects throughout the PV system allow emergency responders to contain the electricity at the source. Putting all this information together in a standard operating procedure is the final step in your ability to operate around these systems safely.

"We are here to make a choice between the quick and the dead"

—Bernard Baruch, United Nations Atomic Energy Commission, 1946

EMERGENCY RESPONSE

The days of rushing in to a structure without first making an assessment and size-up of the emergency have long past. In the Introduction to this manual we suggested that fire fighters need to be aware of photovoltaic technologies and the potential dangers and hazards. The potential dangers, in the form of an electrical shock and the potential hazards in the form of hazardous chemicals released during a fire or an explosion are the two primary safety concerns. Other safety concerns involve trip hazards and load weight on the roof. This section will review these dangers and hazards as well as make recommendations on how you can personally protect yourself.

Firefighter Inhalation Hazards

The manufacturing of silicon cells is very similar to the process used in the semi-conductor industry. A wide range of hazardous chemicals are used in this manufacturing process. By the time the solar module is ready for installation, only a few of these chemicals exist in the finished product, in minute quantities, and they are sealed in the module frame and coverings. During a fire or explosion the frame can quickly degrade exposing these chemicals to direct flame and then become dissipated in the smoke plume.

When you compare the list of known chemicals to the Department of Transportations "2004 Emergency Guide Book" and the "Fire Fighter's Handbook of Hazardous Materials" you realize how serious some of these chemicals are to human health:

Boron

Of all the chemicals used in photovoltaic manufacture, Boron is the least problematic for emergency responders and the public alike. Boron is one of the simplest of atoms with an atomic number of 5 on the periodic table. There are only four elements simpler than boron. Boron hydrolyzes in water to form a slightly alkaline solution, which is why Boron is good for cleaning (Borax Soap). Boron burns green and is used in pyrotechnics for color. Boron poses no health effects to humans or the environment.

Cadmium Telluride

The same, however, cannot be said for Cadmium Telluride. A known carcinogen, the primary route of exposure is inhalation. Dust and fumes from cadmium or its compounds may cause irritation of the nose and throat. If high concentrations are inhaled (especially from a freshly formed plume) a delayed reaction of coughing, chest pain, sweating, chills, shortness of breath and weakness may develop. In severe cases of exposure the result can be pulmonary edema and death.

Acute exposure to tellurium may cause an odor of garlic on breath and perspiration, dry mouth, metallic taste, sleepiness, loss of appetite and nausea. Chronic overexposure may cause lung injury (emphysema) and kidney dysfunction (proteinuria). Inhalation of cadmium telluride will aggravate diseases of the lungs and kidneys.

With that said, the Photovoltaic system contains trace amounts of

these elements per cell. The potential exposure hazard to a small residential array will be minimal. Larger arrays, like those found in large commercial applications, fully engulfed in a roof fire could be a potential exposure hazard to emergency responders and the population down wind of the smoke plume. Citizens with respiratory ailments, children, and the elderly should be sheltered in place until the emergency has been abated.

Gallium Arsenide

The health effects of Gallium Arsenide have not been thoroughly studied. It is however, considered highly toxic and carcinogenic. Gallium rivals silicon as a semiconductor in that it too has some remarkable electronic properties. However, silicon is much more abundant, and therefore less expensive, and it has greater physical strength than gallium. Gallium Arsenide, when combined with germanium and indium gallium phosphide, are the basis of a triple junction solar cell which holds the record efficiency of over 32%. This is the same solar technology that is powering the robots Sprit and Opportunity which are exploring the surface of Mars and is being used in experimental solar cars here on Earth.

Phosphorus

The fumes from phosphorus compounds are considered highly toxic. NIOSH recommended exposure limit to phosphorus is 5 mg/m3. A lethal dose of phosphorus is 50 milligrams. Phosphorus is extremely important to the agricultural industry as a primary ingredient in the production of fertilizer. Pure white phosphorus is extremely volatile and spontaneously ignites when exposed to the air. The type of phosphorus used as a dopant in the manufacture of photovoltaic cells is not in its pure form, but any form of phosphorus will react to extreme heat. Respiratory protection is required for people working around phosphorus.

Recommended Practice

The inhalation hazards from the chemicals inherent in PV modules engulfed in a fire or explosion can be mitigated as long as firefighters wear their SCBA's and personal protective equipment during a structural firefighting operation. It is the decision of the Incident Commander whether or not the emergency constitutes sheltering in place the population downwind of the emergency. Fire or explosion emergencies involving large number of PV arrays, as in a commercial application, may necessitate having people downwind of the emergency shelter in place.

Personal protective equipment (PPE) including; turnout pants and coat, helmet, gloves, boots, and SCBA will protect you from the hazards associated with structural firefighting emergencies including those involving PV systems. (Photo Credit: Rodney Slaughter)

Firefighter Electrical Safety!

The primary danger for firefighters working around an electrical system, and specifically PV systems, is electrical shock. The problem most firefighters have with electricity is that they cannot see it coming. Unlike a fire, which produces flames and heat, and burns in a relatively predictable manner, electricity, when it is not given its due respect, can strike unsuspecting victims—sometimes fatally!

A review of NIOSH after incident reports reveals that many people who work as electricians or in the utility industry are killed every year in electrical accidents. More surprisingly, the NIOSH report also reveals the number of firefighters who are also killed and injured annually in electrical incidents.

Electric Shock and Burn Hazards

You often hear, in reference to electrical safety, that "it's not the volts that kill you but the amps." While this is partially true-- why do you see so many warning signs that read: Warning: High Voltage?

Electricity can cause a variety of effects, ranging from a slight tingling sensation, to involuntary muscle reaction, burns, and death. The physiological effects produced by electricity flowing through the body include:

- Perception - 1 mA
- At the lowest levels of current in the body, we experience perception where currents as low as a few millionths of an ampere can be perceived as a tingling sensation by most people. Perceptible currents are harmful under certain circumstances.
- Startle Reaction – 5 mA
- Startle reaction, a slight shock; not painful but disturbing, results in involuntary muscular reaction. An average person can let go. The reaction to current may cause injury from uncontrolled body movement (like falling from a roof or a ladder). Underwriter Laboratory (UL) uses 5 milliamperes for a 60-Hz current as the let-go limit.
- Muscle Tetanization – 6 to 30 mA
- Muscle tetanization, a result of a painful shock, is defined as the 'continuous tonic spasm of a muscle, the steady contraction of a muscle without distinct twitching." Tetanization results in several effects of concern including: inability to let go of a gripped conductive part while the current flows from the part into the hand, the inability to move the body while the current flows from the conductive part into the body, possible respiratory arrest if the current flows through the torso and interferes with breathing. Tetanization effects last only as long as the current flows. With the exception of respiratory arrest, when the current stops the effects stops as well.
- Respiratory Arrest – 50 to 150 mA
- Extreme pain, respiratory arrest and severe muscular contractions occur between .5 to 1.5 amps.
- Ventricular Fibrillation – 1000 to 4300 mA (conversion: 1 to 4.3 amps)
- At 1 to 4.3 amps, ventricular fibrillation; the rapid, uncoordinated contraction of some portion of the heart muscle which causes irregular heartbeats and ineffectual pumping of the blood, is likely to occur. Ventricular fibrillation victims usually die after a few minutes from the lack of blood circulation. Unlike tetanization effects, ventricular fibrillation can be triggered by electric current passing through the heart. Once started ventricular fibrillation is not spontaneously reversible in humans. Nerve damage and death is most likely.
- Cardiac Arrest – 10,000 mA
- Lethal currents of 10 amps will cause cardiac arrest, severe burns and probable death. Look at the circuit breakers on your own home and see that most of the

breakers are rated at 15 to 20 amps. Each one of these circuits has enough voltage and amperage to seriously injure and potentially kill you.

Resistance to Electricity

When you become part of an electrical circuit there are a number of variables that play an important role in human resistance to electricity, these include:

- Amount of current flowing through the body.
- Pathway of the current through the body (hand-to-hand or hand-to-foot).
- Length of time the body is in the current.
- Other factors that may affect the severity of the shock are:
- Body size and shape (muscle mass and body, the larger the person the more resistive).
- Area of contact (with conductive parts).
- Pressure of contact (of skin to the contacts).
- Moisture of contacts (sweaty skin will be more conductive than dry skin).
- Clothing (is yours conductive or insulated; jewelry by the way, is very conductive).
- Type of skin (callused hands opposed to back of hand).

Electrical shock is but one consideration when working around electrical circuits--burns are another. Burns that can occur in electrical accidents include electrical, arc and thermal. With electrical burns, tissue damage occurs because the body is unable to dissipate the heat from the current flow. These types of burns are typically slow to heal.

Temperatures generated by an electric arc can melt nearby material, vaporize metal in close vicinity, burn flesh and ignite clothing at distances of up to 10 feet. Arc-flash results from high currents arcing through the air and vaporizing material like copper and aluminum. These high currents are initiated by contact between two energized points. Arc temperatures can reach 15,000 to 35,000 degrees. Comparatively, the temperature on the surface of the Sun is around 10,800 degrees.

A firefighter should never pull the electrical meter as a means of shutting-down power to a building. The potential for electrical arcing, described above, creates a risk that ranges from serious injury to death. Instead firefighters should lock out the main disconnect next to the meter and lock out/tag-out the meter box to insure that someone does not inadvertently re-energize the system (Callan).

> **Important Note:** Firefighters should not disconnect power by removing the electric meter from the meter box. Experience has shown that electrical arcing can occur and cause injury or death to the firefighter.

Roof Hazards

Imagine entering a burning building with 80 pounds of protective equipment and your air supply strapped to your back with nothing between you and the raging inferno except for the water in the hose that you drug in with you. That is an adrenalin rush, second only to the firefighter who must step across the roof with the structure burning below them, tasked with providing ventilation for the firefighters inside.

Roof ventilation just got a little trickier when you have a PV array covering a portion of the roof. Typically the firefighter would find a point on the roof just above the fire to effect ventilation. Now you must consider several things: the weight of the PV array on a weakening roof structure and the fact that you may not be able to access the roof over the fire. In this case, the point of ventilation should be at the highest point of the roof and as close to the fire as possible.

Roof vents pose a significant trip hazard to fire fighters conducting roof ventilation operations. (Photo Credit: Rodney Slaughter)

Important Note: While you already know to avoid trip hazards posed by vent stacks, skylights and other obstacles on the roof, you now need to also consider walking and working around the photovoltaic array and in as many cases solar water heating and swimming pool heating collectors.

A PV system installed during new construction or retro-fitted onto an existing building adds weight to the roof assembly. Light-weight constructed buildings are engineered for every consideration except for the event of a fire.

In light-weight construction, trusses are widely used to span wide areas without the need for vertical supports, reducing both material and construction costs. Under ordinary conditions, trusses work well. However, trusses often fail suddenly and totally during fires. Both wood and metal trusses are made of interdependent members which all fail if one member fails. Adjacent trusses, in their weakened state, are then unable to carry the additional load and these also fail in quick succession. The metal gusset plates that hold wood truss components together may fail quickly as fire consumes the wood in which the gusset teeth are shallowly embedded. It is impossible for crews operating at a fire to predict the time or extent of a collapse since they cannot see how many trusses are affected, which components, and to what extent.

Under fire conditions, because of the extra weight of PV systems, even on roofs engineered for the extra weight, the roof could be potentially prone to faster collapse. This is a distinct danger and area of caution for firefighters on the roof and firefighters and occupants under the roof. Many firefighters have been killed in collapses attributed to trusses, particularly wooden ones, since the 1970s. Incident commanders and/or safety officers typically consider the presence of trusses in their fireground risk analysis.

Important Note: The question you ultimately have to ask yourself: Does it really matter when you are lying on the ground seriously injured or dead whether or not it was the shock or the fall that put you there?

Battery Emergencies

As a rule, batteries do not burn; or rather, they burn with great difficulty. If batteries are exposed to fire, however, the fumes and gases generated are extremely corrosive. Spilled electrolyte can react and produce toxic fumes and release flammable and explosive gases when it comes into contact with other metals. Due to the potential of explosive gases, prevent all open flames and avoid creating sparks. In emergency involving batteries, always wear full protective clothing and self-contained breathing apparatus (SCBA) on positive pressure. Extinguish lead-acid battery fires with CO2, foam or dry chemical fire extinguishers. Do not use water.

Never cut into the batteries under any circumstances! Even though the voltage generating system may be disconnected from the battery bank, the batteries themselves still have potential for electrical shock. If the battery is punctured by a conductive object, assume that the object has electrical potential.

Personal Protective Equipment and Tools

Firefighters who are exposed to the hazards of structural firefighting should be provided with and use the protective ensemble that meets the applicable requirements of NFPA 1971, "Standard on Protective Ensemble for Structural Firefighting (2000) and the requirements of NFPA 1500, Chapter 7 Personal Protective Equipment (2002). This would include turnout pants, coat, boots, gloves, hood and helmet. Respiratory protection should also meet the NFPA 1500. This level of protection will provide the level of safety to all the hazards, electrical and chemical, described in this text. Jewelry such as watches, rings, and necklaces are all a good conductor of electricity and as such should not be worn around electrical components. When working in close proximity to electrical circuits, use insulated hand tools.

To check for electricity flowing between two contacts an AC/DC meter should be employed. Typically, hot sticks on many engines can only detect alternating current. When operating any electrical testing equipment follow the manufacturers recommended use, maintenance, and testing of the equipment.

Emergency Response Involving Photovoltaic Systems

Several things need to occur during the size-up of a structural emergency that takes into consideration PV technology. Arriving firefighters need to scan the roof to see if there are any solar related modules. The firefighter tasked with locking out and tagging out the electrical system at the electrical service meter should relay information back to the incident commander of any warning labels or extra junction boxes marked for the PV system. The incident commander should pass the information on to the rest of the emergency response team. Where there are accessible system disconnects at the inverter, battery controller, and battery bank these too should be locked out and tagged out as an extra measure of electrical safety.

Realize that in day time firefighting operations the solar panels are still generating electricity. Care should be taken not to cut into or walk across the PV modules or array. Breaking through the protective glass could potentially release all of the energy inherent in the entire PV system. If a flat roof is completely covered with a PV array, consider cross ventilation of the building. You cannot effectively block the sunlight with foam or salvage covers during a day time operation.

During night time operations you do not have to worry about the PV system generating electricity. Use of spotlights during an evening operation is not bright enough to generate electricity from the PV system. However, the brightness of a lightening storm could send a surge of power though the system. Lightening is the only other light source that approximates the sun's intensity at 1,000 watts per meter squared.

If conduits and wires are cut into during an evening firefighting operation, they could become energized by the PV panels in the daytime exposing personnel to potential shock or reigniting a fire via an electrical short. Care should be taken not to cut into wiring, conduits, or raceways.

What To Do in a PV Emergency

- Always wear protective clothing and SCBA
- Avoid wearing jewelry.
- Use hand tools with insulated handles.
- Locate battery storage area (if applicable)
- Be aware that biting and stinging insects could inhabit the module frame and junction boxes.
- Lock out/Tag out main electrical panel. This single act will isolate the PV system from the rest of the building wiring system.
- Lock out/tag out system disconnects at the module, controller, batteries, and/or the inverter. This will provide an extra margin of safety.

- Ventilate the roof at the highest point of the roof over the fire without cutting through the PV array.
- Extinguish lead-acid battery fires with CO2, foam or dry chemical fire extinguishers.
- Should a short in the wiring system start a fire in the PV array use Class C extinguishing agents-CO2 or dry chemical.
- Should the array become engulfed in a roof fire, use water in a fog pattern on the PV array.

What Not To Do in PV Emergency!

To ensure that you are not a victim of electrical shock from a PV system there are several things that you should not do:

- Do not step on, break or smash a PV module.
- Do not try to ventilate a roof through a PV array.
- Do not contact electrolyte from lead acid batteries.
- Do not cut conduit or wiring. Cutting PV wiring during a night time operation is not hazardous but is not recommended—sunlight the next day could activate the PV array causing loose wiring to short out and rekindle a structural fire or seriously injury someone.
- Do not cut into system components like the charge controller, batteries or inverter.
- Do not pull the electric meter from the main electrical panel under any circumstance.

As a rule, fire fighters should treat the photovoltaic system the same way you would treat electric battery systems. Always wear protective clothing and self contained breathing apparatus. Care should be taken when operating around PV systems; you should not cut in to the panels or wiring system and you should lock out/tag out associated disconnects.

Summary

Photovoltaic technology is around you every day and it is here to stay! Your fundamental understanding of photovoltaic systems will improve your confidence in working with and around solar technology safely. The photovoltaic industry, utility companies, manufacturers, suppliers, regulators, designers and installers are all counting on the fire service industry to be able to operate safely and effectively around photovoltaic systems. The PV industry has a good safety record and they are working with local emergency response agencies to ensure that the safety record stays intact!

Glossary of Terms

A

AC — see alternating current.

Activation Voltage(s) — The voltage(s) at which a charge controller will take action to protect the batteries.

Adjustable Set Point — A feature allowing the user to adjust the voltage levels at which a charge controller will become active.

Alternating Current (AC) — A type of electrical current, the direction of which is reversed at regular intervals or cycles. In the United States, the standard is 120 reversals or 60 cycles per second. Electricity transmission networks use AC because voltage can be controlled with relative ease.

Acceptor — A dopant material, such as boron, which has fewer outer shell electrons than required in an otherwise balanced crystal structure, providing a hole, which can accept a free electron.

Ambient Temperature — The temperature of the surrounding area.

Amorphous Semiconductor — A non-crystalline semiconductor material that has no long-range order.

Amorphous Silicon — A thin-film, silicon photovoltaic cell having no crystalline structure manufactured by depositing layers of doped silicon on a substrate.

Amperage Interrupt Capability (AIC) — direct current fuses should be rated with a sufficient AIC to interrupt the highest possible current.

Ampere (amp) — A unit of electrical current or rate of flow of electrons. One volt across one ohm of resistance causes a current flow of one ampere.

Ampere-Hour (Ah/AH) — A measure of the flow of current (in amperes) over one hour; used to measure battery capacity.

Ampere Hour Meter — An instrument that monitors current with time. The indication is the product of current (in amperes) and time (in hours).

Angle of Incidence — The angle that a ray of sun makes with a line perpendicular to the surface. For example, a surface that directly faces the sun has a solar angle of incidence of zero, but if the surface is parallel to the sun (for example, sunrise striking a horizontal rooftop), the angle of incidence is 90°.

Anode — The positive electrode in an electrochemical cell (battery). Also, the earth or ground in a cathodic protection system. Also, the positive terminal of a diode.

Antireflection Coating — A thin coating of a material applied to a solar cell surface that reduces the light reflection and increases light transmission.

Arc ---An explosive release of energy, and molten materials from equipment caused by high amperage arcs.

Array — A mechanically integrated assembly of modules or panels with a support structure and foundation, or a tracker, and other components, as required, to form a direct-current power-producing unit.

Array Operating Voltage — The voltage produced by a photovoltaic array when exposed to sunlight and connected to a load.

Azimuth Angle — The angle between true south and the point on the horizon directly below the sun.

B

Battery — Two or more electrochemical cells enclosed in a container and electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels. Under common usage, the term battery also applies to a single cell if it constitutes the entire electrochemical storage system.

Battery Capacity — The maximum total electrical charge, expressed in ampere-hours, which a battery can deliver to a load under a specific set of conditions.

Battery Cell — The simplest operating unit in a storage battery. It consists of one or more positive electrodes or plates, an electrolyte that permits ionic conduction, one or more negative electrodes or plates, separators between plates of opposite polarity, and a container for all the above.

Battery Cycle Life — The number of cycles, to a specified depth of discharge, that a cell or battery can undergo before failing to meet its specified capacity or efficiency performance criteria.

Battery Energy Capacity — The total energy available, expressed in watt-hours (kilowatt-hours), which can be withdrawn from a fully charged cell or battery. The energy capacity of a given cell varies with temperature, rate, age, and cut-off voltage. This term is more common to system designers than it is to the battery industry where capacity usually refers to ampere-hours.

Battery Life — The period during which a cell or battery is capable of operating above a specified capacity or efficiency performance level. Life may be measured in cycles and/or years, depending on the type of service for which the cell or battery is intended.

BIPV (Building-Integrated Photovoltaics) — A term for the design and integration of photovoltaic (PV) technology into the building envelope, typically replacing conventional building materials. This integration may be in vertical facades, replacing view glass, spandrel glass, or other facade material; into semitransparent skylight systems; into roofing systems, replacing traditional roofing materials; into shading "eyebrows" over windows; or other building envelope systems.

Blocking Diode — A semiconductor connected in series with a solar cell or cells and a storage battery to keep the battery from discharging through the cell when there is no output, or low output, from the solar cell. It can be thought of as a one-way valve that allows electrons to flow forwards, but not backwards.

Boron (B) — The chemical element commonly used as the dopant in photovoltaic device or cell material.

Boule — A sausage-shaped, synthetic single-crystal mass grown in a special furnace, pulled and turned at a rate necessary to maintain the single-crystal structure during growth.

Btu (British Thermal Unit) — The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit; equal to 252 calories.

Bypass Diode — A diode connected across one or more solar cells in a photovoltaic module such that the diode will conduct if the cell(s) become reverse biased. It protects these solar cells from thermal destruction in case of total or partial shading of individual solar cells while other cells are exposed to full light.

C

Cadmium (Cd) — A chemical element used in making certain types of solar cells and batteries.

Cadmium Telluride (CdTe) — A polycrystalline thin-film photovoltaic material.

Captive Electrolyte Battery — A battery having an immobilized electrolyte (gelled or absorbed in a material).

Cathode — The negative pole or electrode of an electrolytic cell, vacuum tube, etc., where electrons enter (current leaves) the system; the opposite of an anode.

Cathodic Protection — A method of preventing oxidation of the exposed metal in structures by imposing a small electrical voltage between the structure and the ground.

Cell (battery) — A single unit of an electrochemical device capable of producing direct voltage by converting chemical energy into electrical energy. A battery usually consists of several cells electrically connected together to produce higher voltages (Sometimes the terms cell and battery are used interchangeably). Also see photovoltaic (PV) cell.

Cell Barrier — A very thin region of static electric charge along the interface of the positive and negative layers in a photovoltaic cell. The barrier inhibits the movement of electrons from one layer to the other, so that higher-energy electrons from one side diffuse preferentially through it in one direction, creating a current and thus a voltage across the cell. Also called depletion zone or space charge.

Cell Junction — The area of immediate contact between two layers (positive and negative) of a photovoltaic cell. The junction lies at the center of the cell barrier or depletion zone.

Charge — The process of adding electrical energy to a battery.

Charge Controller — A component of a photovoltaic system that controls the flow of current to and from the battery to protect it from over-charge and over-discharge. The charge controller may also indicate the system operational status.

Charge Rate — The current applied to a cell or battery to restore its available capacity. This rate is commonly normalized by a charge control device with respect to the rated capacity of the cell or battery.

Chemical Vapor Deposition (CVD) — A method of depositing thin semiconductor films used to make certain types of photovoltaic devices. With this method, a substrate is exposed to one or more vaporized compounds, one or more of which contain desirable constituents. A chemical reaction is initiated, at or near the substrate surface, to produce the desired material that will condense on the substrate.

Cleavage of Lateral Epitaxial Films for Transfer (CLEFT) — A process for making inexpensive Gallium Arsenide (GaAs) photovoltaic cells in which a thin film of GaAs is grown atop a thick, single-crystal GaAs (or other suitable material) substrate and then is cleaved from the substrate and incorporated into a cell, allowing the substrate to be reused to grow more thin-film GaAs.

Cloud Enhancement — The increase in solar intensity caused by reflected irradiance from nearby clouds.

Conductor — The material through which electricity is transmitted, such as an electrical wire, or transmission or distribution line.

Copper Indium Diselenide (CuInSe2, or CIS) — A polycrystalline thin-film photovoltaic material (sometimes incorporating gallium (CIGS) and/or sulfur).

Crystalline Silicon — A type of photovoltaic cell made from a slice of single-crystal silicon or polycrystalline silicon.

Cutoff Voltage — The voltage levels (activation) at which the charge controller disconnects the photovoltaic array from the battery or the load from the battery.

Cycle — The discharge and subsequent charge of a battery.

Czochralski Process — A method of growing large size, high quality semiconductor crystal by slowly lifting a seed crystal from a molten bath of the material under careful cooling conditions.

D

DC-to-DC Converter — Electronic circuit to convert direct current voltages (e.g., photovoltaic module voltage) into other levels (e.g., load voltage). Can be part of a maximum power point tracker

Deep-Cycle Battery — A battery with large plates that can withstand many discharges to a low state-of-charge.

Deep Discharge — Discharging a battery to 20% or less of its full charge capacity.

Depth of Discharge (DOD) — The ampere-hours removed from a fully charged cell or battery, expressed as a percentage of rated capacity. For example, the removal of 25 ampere-hours from a fully charged 100 ampere-hours rated cell results in a 25% depth of discharge. Under certain conditions, such as discharge rates lower than that used to rate the cell, depth of discharge can exceed 100%.

Design Month — The month having the combination of insolation and load that requires the maximum energy from the photovoltaic array.

Diffuse Insolation — Sunlight received indirectly as a result of scattering due to clouds, fog, haze, dust, or other obstructions in the atmosphere. Opposite of direct insolation.

Diffuse Radiation — Radiation received from the sun after reflection and scattering by the atmosphere and ground.

Diode — An electronic device that allows current to flow in one direction only. See blocking diode and bypass diode.

Direct Current (DC) — A type of electricity transmission and distribution by which electricity flows in one direction through the conductor, usually relatively low voltage and high current. To be used for typical 120 volt or 220 volt household appliances, DC must be converted to alternating current, its opposite.

Direct Insolation — Sunlight falling directly upon a collector.

Discharge — The withdrawal of electrical energy from a battery.

Discharge Rate — The rate, usually expressed in amperes or time, at which electrical current is taken from the battery.

Disconnect — Switch gear used to connect or disconnect components in a photovoltaic system.

Distributed Generation — A popular term for localized or onsite power generation.

Dopant — A chemical element (impurity) added in small amounts to an otherwise pure semiconductor material to modify the electrical properties of the material. An n-dopant introduces more electrons. A p-dopant creates electron vacancies (holes).

E

Edge-Defined Film-Fed Growth (EFG) — A method for making sheets of polycrystalline silicon for photovoltaic devices in which molten silicon is drawn upward by capillary action through a mold.

Electric Circuit — The path followed by electrons from a power source (generator or battery), through an electrical system, and returning to the source.

Electric Current — The flow of electrical energy (electricity) in a conductor, measured in amperes.

Electrical grid — An integrated system of electricity distribution, usually covering a large area.

Electricity — Energy resulting from the flow of charge particles, such as electrons or ions.

Electrochemical Cell — A device containing two conducting electrodes, one positive and the other negative, made of dissimilar materials (usually metals) that are immersed in a chemical solution (electrolyte) that transmits positive ions from the negative to the positive electrode and thus forms an electrical charge. One or more cells constitute a battery.

Electrode — A conductor that is brought in conducting contact with a ground.

Electrolyte — A nonmetallic (liquid or solid) conductor that carries current by the movement of ions (instead of electrons) with the liberation of matter at the electrodes of an electrochemical cell.

Electron — An elementary particle of an atom with a negative electrical charge and a mass of 1/1837 of a proton; electrons surround the positively charged nucleus of an atom and determine the chemical properties of an atom. The movement of electrons in an electrical conductor constitutes an electric current.

Energy — The capability of doing work; different forms of energy can be converted to other forms, but the total amount of energy remains the same.

Energy Audit — A survey that shows how much energy used in a home, which helps find ways to use less energy.

Equalization — The process of restoring all cells in a battery to an equal state-of-charge. Some battery types may require a complete discharge as a part of the equalization process.

Equalizing Charge — A continuation of normal battery charging, at a voltage level slightly higher than the normal end-of-charge voltage, in order to provide cell equalization within a battery.

Equinox — The two times of the year when the sun crosses the equator and night and day are of equal length; usually occurs on March 21st (spring equinox) and September 23 (fall equinox).

F

Fill Factor — The ratio of a photovoltaic cell's actual power to its power if both current and voltage were at their maxima. A key characteristic in evaluating cell performance.

Fixed Tilt Array — A photovoltaic array set in at a fixed angle with respect to horizontal.

Frequency — The number of repetitions per unit time of a complete waveform, expressed in Hertz (Hz).

Full Sun — The amount of power density in sunlight received at the earth's surface at noon on a clear day (about 1,000 Watts/square meter).

G

Gallium (Ga) — A chemical element, metallic in nature, used in making certain kinds of solar cells and semiconductor devices.

Gallium Arsenide (GaAs) — A crystalline, high-efficiency compound used to make certain types of solar cells and semiconductor material.

Gassing — The production of hydrogen and oxygen from the electrolytic liquid.

Gel-Type Battery — Lead-acid battery in which the electrolyte is composed of a silica gel matrix.

Gigawatt (GW) — A unit of power equal to 1 billion Watts; 1 million kilowatts, or 1,000 megawatts.

Grid-Connected System — A solar electric or photovoltaic (PV) system in which the PV array acts like a central generating plant, supplying power to the grid.

Grid Lines — Metallic contacts fused to the surface of the solar cell to provide a low resistance path for electrons to flow out to the cell interconnect wires.

H

Harmonic Content — The number of frequencies in the output waveform in addition to the primary frequency (50 or 60 Hz.). Energy in these harmonic frequencies is lost and may cause excessive heating of the load.

High Voltage Disconnect — The voltage at which a charge controller will disconnect the photovoltaic array from the batteries to prevent overcharging.

Hole — The vacancy where an electron would normally exist in a solid; behaves like a positively charged particle.

Hybrid System — A solar electric or photovoltaic system that includes other sources of electricity generation, such as wind or diesel generators.

I

Incident Light — Light that shines onto the face of a solar cell or module.

Infrared Radiation — Electromagnetic radiation whose wavelengths lie in the range from 0.75 micrometer to 1000 micrometers; invisible long wavelength radiation (heat) capable of producing a thermal or photovoltaic effect, though less effective than visible light.

Input Voltage — This is determined by the total power required by the alternating current loads and the voltage of any direct current loads. Generally, the larger the load, the higher the inverter input voltage. This keeps the current at levels where switches and other components are readily available.

Insolation — The solar power density incident on a surface of stated area and orientation, usually expressed as Watts per square meter or Btu per square foot per hour. See diffuse insolation and direct insolation.

Interconnect — A conductor within a module or other means of connection that provides an electrical interconnection between the solar cells.

Intrinsic Semiconductor — An undoped semiconductor.

Inverter — A device that converts direct current electricity to alternating current either for stand-alone systems or to supply power to an electricity grid.

Ion — An electrically charged atom or group of atoms that has lost or gained electrons; a loss makes the resulting particle positively charged; a gain makes the particle negatively charged.

Irradiance — The direct, diffuse, and reflected solar radiation that strikes a surface. Usually expressed in kilowatts per square meterIrradiance multiplied by time equals insolation.

ISPRA Guidelines — Guidelines for the assessment of photovoltaic power plants, published by the Joint Research Centre of the Commission of the European Communities, Ispra, Italy.

I-V Curve — A graphical presentation of the current versus the voltage from a photovoltaic device as the load is increased from the short circuit (no load) condition to the open circuit (maximum voltage) condition. The shape of the curve characterizes cell performance.

J

Joule — A metric unit of energy or work; 1 joule per second equals 1 watt or 0.737 foot-pounds; 1 Btu equals 1,055 joules.

Junction — A region of transition between semiconductor layers, such as a p/n junction, which goes from a region that has a high concentration of acceptors (p-type) to one that has a high concentration of donors (n-type).

Junction Box — A photovoltaic (PV) generator junction box is an enclosure on the module where PV strings are electrically connected and where protection devices can be located, if necessary.

Junction Diode — A semiconductor device with a junction and a built-in potential that passes current better in one direction than the other. All solar cells are junction diodes.

K

Kilowatt (kW) — A standard unit of electrical power equal to 1000 watts, or to the energy consumption at a rate of 1000 joules per second.

Kilowatt-Hour (kWh) — 1,000 thousand watts acting over a period of 1 hour. The kWh is a unit of energy1 kWh=3600 kJ.

L

Lead-Acid Battery — A general category that includes batteries with plates made of pure lead, lead-antimony, or lead-calcium immersed in an acid electrolyte.

Life-Cycle Cost — The estimated cost of owning and operating a photovoltaic system for the period of its useful life.

Line-Commutated Inverter — An inverter that is tied to a power grid or line. The commutation of power (conversion from direct current to alternating current) is controlled by the power line, so that, if there is a failure in the power grid, the photovoltaic system cannot feed power into the line.

Liquid Electrolyte Battery — A battery containing a liquid solution of acid and water. Distilled water may be added to these batteries to replenish the electrolyte as necessary. Also called a flooded battery because the plates are covered with the electrolyte.

Load — The demand on an energy producing system; the energy consumption or requirement of a piece or group of equipment. Usually expressed in terms of amperes or watts in reference to electricity.

Load Circuit — The wire, switches, fuses, etc. that connect the load to the power source.

Load Current (A) — The current required by the electrical device.

Lock-Out --- A method for keeping equipment from being set in motion and endangering workers.

Low Voltage Cutoff (LVC) — The voltage level at which a charge controller will disconnect the load from the battery.

Low Voltage Disconnect — The voltage at which a charge controller will disconnect the load from the batteries to prevent over-discharging.

Low Voltage Warning — A warning buzzer or light that indicates the low battery voltage set point has been reached.

M

Maintenance-Free Battery — A sealed battery to which water cannot be added to maintain electrolyte level.

Maximum Power Point (MPP) — The point on the current-voltage (I-V) curve of a module under illumination, where the product of current and voltage is maximum. For a typical silicon cell, this is at about 0.45 volts.

Maximum Power Point Tracker (MPPT) — Means of a power conditioning unit that automatically operates the photovoltaic generator at its maximum power point under all conditions.

Megawatt (MW) — 1,000 kilowatts, or 1 million watts; standard measure of electric power plant generating capacity.

Megawatt-Hour — 1,000 kilowatt-hours or 1 million watt-hours.

Microgroove — A small groove scribed into the surface of a solar cell, which is filled with metal for contacts.

Modified Sine Wave — A waveform that has at least three states (i.e., positive, off, and negative). Has less harmonic content than a square wave.

Modularity — The use of multiple inverters connected in parallel to service different loads.

Module — See photovoltaic (PV) module.

Module Derate Factor — A factor that lowers the photovoltaic module current to account for field operating conditions such as dirt accumulation on the module.

Monocrystalline --- Material that is composed of a single crystal formation. See Single-Crystal Silicon.

Multi-Stage Controller — A charging controller unit that allows different charging currents as the battery nears full state_of_charge.

N

National Electrical Code (NEC) — Contains guidelines for all types of electrical installations. The 1984 and later editions of the NEC contain Article 690, "Solar

Photovoltaic Systems" which should be followed when installing a PV system.

National Electrical Manufacturers Association (NEMA) — This organization sets standards for some non-electronic products like junction boxes.

Nickel Cadmium Battery — A battery containing nickel and cadmium plates and an alkaline electrolyte.

Nominal Voltage — A reference voltage used to describe batteries, modules, or systems (i.e., a 12-volt or 24-volt battery, module, or system).

Normal Operating Cell Temperature (NOCT) — The estimated temperature of a photovoltaic module when operating under 800 w/m2 irradiance, 20ºC ambient temperature and wind speed of 1 meter per second. NOCT is used to estimate the nominal operating temperature of a module in its working environment.

N-Type — Negative semiconductor material in which there are more electrons than holes; current is carried through it by the flow of electrons.

N-Type Semiconductor — A semiconductor produced by doping an intrinsic semiconductor with an electron-donor impurity (e.g., phosphorus in silicon).

N-Type Silicon — Silicon material that has been doped with a material that has more electrons in its atomic structure than does silicon.

O

Ohm — A measure of the electrical resistance of a material equal to the resistance of a circuit in which the potential difference of 1 volt produces a current of 1 ampere.

Open-Circuit Voltage (Voc) — The maximum possible voltage across a photovoltaic cell; the voltage across the cell in sunlight when no current is flowing.

Operating Point — The current and voltage that a photovoltaic module or array produces when connected to a load. The operating point is dependent on the load or the batteries connected to the output terminals of the array.

Orientation — Placement with respect to the cardinal directions, N, S, E, W; azimuth is the measure of orientation from north.

Overcharge — Forcing current into a fully charged battery. The battery will be damaged if overcharged for a long period.

P

Parallel Connection — A way of joining solar cells or photovoltaic modules by connecting positive leads together and negative leads together; such a configuration increases the current, but not the voltage.

Peak Demand/Load — The maximum energy demand or load in a specified time period.

Peak Power Current — Amperes produced by a photovoltaic module or array operating at the voltage of the I-V curve that will produce maximum power from the module.

Peak Power Point — Operating point of the I-V (current-voltage) curve for a solar cell or photovoltaic module where the product of the current value times the voltage value is a maximum.

Peak Sun Hours — The equivalent number of hours per day when solar irradiance averages 1,000 w/m2. For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for six hours been 1,000 w/m2.

Peak Watt — A unit used to rate the performance of solar cells, modules, or arrays; the maximum nominal output of a photovoltaic device, in watts (Wp) under standardized test conditions, usually 1,000 watts per square meter of sunlight with other conditions, such as temperature specified.

Phosphorous (P) — A chemical element used as a dopant in making n-type semiconductor layers.

Photon — A particle of light that acts as an individual unit of energy

Photovoltaic(s) (PV) — Pertaining to the direct conversion of light into electricity.

Photovoltaic (PV) Array — An interconnected system of PV modules that function as a single electricity-producing unit. The modules are assembled as a discrete structure, with common support or mounting. In smaller systems, an array can consist of a single module.

Photovoltaic (PV) Cell — The smallest semiconductor element within a PV module to perform the immediate conversion of light into electrical energy (direct current voltage and current). Also called a solar cell.

Photovoltaic (PV) Conversion Efficiency — The ratio of the electric power produced by a photovoltaic device to the power of the sunlight incident on the device.

Photovoltaic (PV) Device — A solid-state electrical device that converts light directly into direct current electricity of voltage-current characteristics that are a function of the characteristics of the light source and the materials in and design of the device. Solar photovoltaic devices are made of various semiconductor materials including silicon, cadmium sulfide, cadmium telluride, and gallium arsenide, and in single crystalline, multicrystalline, or amorphous forms.

Photovoltaic (PV) Effect — The phenomenon that occurs when photons, the "particles" in a beam of light, knock electrons loose from the atoms they strike. When this property of light is combined with the properties of semiconductors, electrons flow in one direction across a junction, setting up a voltage. With the addition of circuitry, current will flow and electric power will be available.

Photovoltaic (PV) Generator — The total of all PV strings of a PV power supply system, which are electrically interconnected.

Photovoltaic (PV) Module — The smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts, such as interconnections, terminals, [and protective devices such as diodes] intended to generate direct current power under unconcentrated sunlight. The structural (load carrying) member of a module can either be the top layer (superstrate) or the back layer (substrate).

Photovoltaic (PV) Panel — often used interchangeably with PV module (especially in one-module systems), but more accurately used to refer to a physically connected collection of modules (i.e., a laminate string of modules used to achieve a required voltage and current).

Photovoltaic (PV) System — A complete set of components for converting sunlight into electricity by the photovoltaic process, including the array and balance of system components.

Physical Vapor Deposition — A method of depositing thin semiconductor photovoltaic films. With this method, physical processes, such as thermal evaporation or bombardment of ions, are used to deposit elemental semiconductor material on a substrate.

P-I-N — A semiconductor photovoltaic (PV) device structure that layers an intrinsic semiconductor between a p-type semiconductor and an n-type semiconductor; this structure is most often used with amorphous silicon PV devices.

Plates — A metal plate, usually lead or lead compound, immersed in the electrolyte in a battery.

P/N — A semiconductor photovoltaic device structure in which the junction is formed between a p-type layer and an n-type layer.

Polycrystalline Silicon — A material used to make photovoltaic cells, which consist of many crystals unlike single-crystal silicon.

Power Conditioning — The process of modifying the characteristics of electrical power (for e.g., inverting direct current to alternating current).

Power Conditioning Equipment — Electrical equipment, or power electronics, used to convert power from a photovoltaic array into a form suitable for subsequent use. A collective term for inverter, converter, battery charge regulator, and blocking diode.

Power Conversion Efficiency — The ratio of output power to input power of the inverter.

Power Factor (PF) — The ratio of actual power being used in a circuit, expressed in watts or kilowatts, to the power that is apparently being drawn from a power source, expressed in volt-amperes or kilovolt-amperes.

P-Type Semiconductor — A semiconductor in which holes carry the current; produced by doping an intrinsic semiconductor with an electron acceptor impurity (e.g., boron in silicon).

Pulse-Width-Modulated (PWM) Wave Inverter — A type of power inverter that produce a high quality (nearly sinusoidal) voltage, at minimum current harmonics.

PV — See photovoltaic(s)

Pyranometer — An instrument used for measuring global solar irradiance.

Pyrheliometer — An instrument used for measuring direct beam solar irradiance. Uses an aperture of 5.7° to transcribe the solar disc.

Q

Quad — One quadrillion Btu (1,000,000,000,000,000 Btu).

Qualification Test — A procedure applied to a selected set of photovoltaic modules involving the application of defined electrical, mechanical, or thermal stress in a prescribed manner and amount. Test results are subject to a list of defined requirements.

R

Rated Battery Capacity — The term used by battery manufacturers to indicate the maximum amount of energy that can be withdrawn from a battery under specified discharge rate and temperature. See battery capacity.

Rated Module Current (A) — The current output of a photovoltaic module measured at standard test conditions of 1,000 w/m2 and 25 C cell temperature.

Rated Power — Rated power of the inverter. However, some units can not produce rated power continuously. See duty rating.

Recombination — The action of a free electron falling back into a hole. Recombination processes are either radiative, where the energy of recombination results in the emission of a photon, or nonradiative, where the energy of recombination is given to a second electron which then relaxes back to its original energy by emitting phonons. Recombination can take place in the bulk of the semiconductor, at the surfaces, in the junction region, at defects, or between interfaces.

Regulator — Prevents overcharging of batteries by controlling charge cycle-usually adjustable to conform to specific battery needs.

Resistance (R) — The property of a conductor, which opposes the flow of an electric current resulting in the generation of heat in the conducting material. The measure of the resistance of a given conductor is the electromotive force needed for a unit current flow. The unit of resistance is ohms.

Resistive Voltage Drop — The voltage developed across a cell by the current flow through the resistance of the cell.

Reverse Current Protection — Any method of preventing unwanted current flow from the battery to the photovoltaic array (usually at night). See blocking diode.

Ribbon (Photovoltaic) Cells — A type of photovoltaic device made in a continuous process of pulling material from a molten bath of photovoltaic material, such as silicon, to form a thin sheet of material.

S

Sacrificial Anode — A piece of metal buried near a structure that is to be protected from corrosion. The metal of the sacrificial anode is intended to corrode and reduce the corrosion of the protected structure.

Scribing — The cutting of a grid pattern of grooves in a semiconductor material, generally for the purpose of making interconnections.

Sealed Battery — A battery with a captive electrolyte and a resealing vent cap, also called a valve-regulated battery. Electrolyte cannot be added.

Self Contained Breathing Apparatus (SCBA) --- A portable respiratory device designed to protect the wearer from oxygen deficient or other hazardous atmospheres. It supplies respirable atmosphere that is either carried on, in, or generated by the apparatus and is independent of the ambient environment. It is supplied with a full-face mask and is approved by the US Mine Safety and Health Administration and the National Institute for Occupational Safety and Health.

Semiconductor — Any material that has a limited capacity for conducting an electric current. Certain semiconductors, including silicon, gallium arsenide, copper indium diselenide, and cadmium telluride, are uniquely suited to the photovoltaic conversion process.

Series Connection — A way of joining photovoltaic cells by connecting positive leads to negative leads; such a configuration increases the voltage.

Series Controller — A charge controller that interrupts the charging current by open-circuiting the photovoltaic (PV) array. The control element is in series with the PV array and battery.

Series Regulator — Type of battery charge regulator where the charging current is controlled by a switch connected in series with the photovoltaic module or array.

Shallow-Cycle Battery — A battery with small plates that cannot withstand many discharges to a low state-of-charge.

Shelf Life of Batteries — The length of time, under specified conditions, that a battery can be stored so that it keeps its guaranteed capacity.

Short-Circuit Current (Isc) — The current flowing freely through an external circuit that has no load or resistance; the maximum current possible.

Shunt Controller — A charge controller that redirects or shunts the charging current away from the battery. The controller requires a large heat sink to dissipate the current from the short-circuited photovoltaic array. Most shunt controllers are for smaller systems producing 30 amperes or less.

Shunt Regulator — Type of a battery charge regulator where the charging current is controlled by a switch connected in parallel with the photovoltaic (PV) generator. Shorting the PV generator prevents overcharging of the battery

Siemens Process — A commercial method of making purified silicon.

Silicon (Si) — A semi-metallic chemical element that makes an excellent semiconductor material for photovoltaic devices. It crystallizes in face-centered cubic lattice like a diamond. It's commonly found in sand and quartz (as the oxide).

Sine Wave — A waveform corresponding to a single-frequency periodic oscillation that can be mathematically represented as a function of amplitude versus angle in which the value of the curve at any point is equal to the sine of that angle.

Sine Wave Inverter — An inverter that produces utility-quality, sine wave power forms.

Single-Crystal Silicon — Material with a single crystalline formation. Many photovoltaic cells are made from single-crystal silicon.

Single-Stage Controller — A charge controller that redirects all charging current as the battery nears full state-of-charge.

Site Operations --- The activities undertaken at a specific site to manage rescue efforts.

Size-Up --- The on-going observation and evaluation of factors that are used to develop strategic goals and tactical objectives.

Solar Cell — see photovoltaic (PV) cell.

Solar Constant — The average amount of solar radiation that reaches the earth's upper atmosphere on a surface perpendicular to the sun's rays; equal to 1353 Watts per square meter or 492 Btu per square foot.

Solar Energy — Electromagnetic energy transmitted from the sun (solar radiation). The amount that reaches the earth is equal to one billionth of total solar energy generated, or the equivalent of about 420 trillion kilowatt-hours.

Solar-Grade Silicon — Intermediate-grade silicon used in the manufacture of solar cells. Less expensive than electronic-grade silicon.

Solar Noon — The time of the day, at a specific location, when the sun reaches its highest, apparent point in the sky; equal to true or due, geographic south.

Solar Resource — The amount of solar insolation a site receives, usually measured in kWh/m2/day, which is equivalent to the number of peak sun hours.

Solar Spectrum — The total distribution of electromagnetic radiation emanating from the sun. The different regions of the solar spectrum are described by their wavelength range. The visible region extends from about 390 to 780 nanometers (a nanometer is one billionth of one meter). About 99 percent of solar radiation is contained in a wavelength region from 300 nm (ultraviolet) to 3,000 nm (near-infrared). The combined radiation in the wavelength region from 280 nm to 4,000 nm is called the broadband, or total, solar radiation.

Solar Thermal Electric Systems — Solar energy conversion technologies that convert solar energy to electricity, by heating a working fluid to power a turbine that drives a generator. Examples of these systems include central receiver systems, parabolic dish, and solar trough.

Specific Gravity — The ratio of the weight of the solution to the weight of an equal volume of water at a specified temperature. Used as an indicator of battery state-of-charge.

Square Wave — A waveform that has only two states, (i.e., positive or negative). A square wave contains a large number of harmonics.

Square Wave Inverter — A type of inverter that produces square wave output. It consists of a direct current source, four switches, and the load. The switches are power semiconductors that can carry a large current and withstand a high voltage rating. The switches are turned on and off at a correct sequence, at a certain frequency.

Staebler-Wronski Effect — The tendency of the sunlight to electricity conversion efficiency of amorphous silicon photovoltaic devices to degrade (drop) upon initial exposure to light.

Stand-Alone System — An autonomous or hybrid photovoltaic system not connected to a grid may or may not have storage, but most stand-alone systems require batteries or some other form of storage.

Stand-Off Mounting — Technique for mounting a photovoltaic array on a sloped roof, which involves mounting the modules a short distance above the pitched roof and tilting them to the optimum angle.

Standard Reporting Conditions (SRC) — A fixed set of conditions (including meteorological) to which the electrical performance data of a photovoltaic module are translated from the set of actual test conditions.

Standard Test Conditions (STC) — Conditions under which a module is typically tested in a laboratory.

Starved Electrolyte Cell — A battery containing little or no free fluid electrolyte.

State-of-Charge (SOC) — The available capacity remaining in the battery, expressed as a percentage of the rated capacity.

Storage Battery — A device capable of transforming energy from electric to chemical form and vice versa. The reactions are almost completely reversible. During discharge, chemical energy is converted to electric energy and is consumed in an external circuit or apparatus.

Stratification — A condition that occurs when the acid concentration varies from top to bottom in the battery electrolyte. Periodic, controlled charging at voltages that produce gassing will mix the electrolyte. See equalization.

String — A number of photovoltaic modules or panels interconnected electrically in series to produce the operating voltage required by the load.

Substrate — The physical material upon which a photovoltaic cell is applied.

Sulfation — A condition that afflicts unused and discharged batteries; large crystals of lead sulfate grow on the plate, instead of the usual tiny crystals, making the battery extremely difficult to recharge.

Superstrate — The covering on the sunny side of a photovoltaic (PV) module, providing protection for the PV materials from impact and environmental degradation while allowing maximum transmission of the appropriate wavelengths of the solar spectrum.

Surge Capacity — The maximum power, usually 3-5 times the rated power, that can be provided over a short time.

System Availability — The percentage of time (usually expressed in hours per year) when a photovoltaic system will be able to fully meet the load demand.

System Operating Voltage — The photovoltaic array output voltage under load. The system operating voltage is dependent on the load or batteries connected to the output terminals.

System Storage — See battery capacity.

T

Tag-Out --- A method of tagging, labeling, or otherwise marking an isolation device during a hazard abatement operation to prevent accidental removal of device.

Temperature Compensation — A circuit that adjusts the charge controller activation points depending on battery temperature. This feature is recommended if the battery temperature is expected to vary more than ±5°C from ambient temperature.

Temperature Factors — It is common for three elements in photovoltaic system sizing to have distinct temperature corrections: a factor used to decrease battery capacity at cold temperatures; a factor used to decrease PV module voltage at high temperatures; and a factor used to decrease the current carrying capability of wire at high temperatures.

Thin Film — A layer of semiconductor material, such as copper indium diselenide or gallium arsenide, a few microns or less in thickness, used to make photovoltaic cells.

Thin Film Photovoltaic Module — A photovoltaic module constructed with sequential layers of thin film semiconductor materials. See amorphous silicon.

Tilt Angle — The angle at which a photovoltaic array is set to face the sun relative to a horizontal position. The tilt angle can be set or adjusted to maximize seasonal or annual energy collection.

Total AC Load Demand — The sum of the alternating current loads. This value is important when selecting an inverter.

Tracking Array — A photovoltaic (PV) array that follows the path of the sun to maximize the solar radiation incident on the PV surface. The two most common orientations are (1) one axis where the array tracks the sun east to west and (2) two-axis tracking where the array points directly at the sun at all times. Tracking arrays use both the direct and diffuse sunlight. Two-axis tracking arrays capture the maximum possible daily energy.

Transformer — An electromagnetic device that changes the voltage of alternating current electricity.

Trickle Charge — A charge at a low rate, balancing through self-discharge losses, to maintain a cell or battery in a fully charged condition.

U

Ultraviolet — Electromagnetic radiation in the wavelength range of 4 to 400 nanometers.

Uninterruptible Power Supply (UPS) — The designation of a power supply providing continuous uninterruptible service. The UPS will contain batteries.

Utility-Interactive Inverter — An inverter that can function only when tied to the utility grid, and uses the prevailing line-voltage frequency on the utility line as a control parameter to ensure that the photovoltaic system's output is fully synchronized with the utility power.

V

Ventilation— The changing of an atmosphere of any space by natural or mechanical means.

Vented Cell — A battery designed with a vent mechanism to expel gases generated during charging.

Volt (V) — A unit of electrical force equal to that amount of electromotive force that will cause a steady current of one ampere to flow through a resistance of one ohm.

Voltage — The amount of electromotive force, measured in volts, that exists between two points.

Voltage at Maximum Power (Vmp) — The voltage at which maximum power is available from a photovoltaic module.

Voltage Protection — Many inverters have sensing circuits that will disconnect the unit from the battery if input voltage limits are exceeded.

Voltage Regulation — This indicates the variability in the output voltage. Some loads will not tolerate voltage variations greater than a few percent.

W

Wafer — A thin sheet of semiconductor (photovoltaic material) made by cutting it from a single crystal or ingot

Watt — The rate of energy transfer equivalent to one ampere under an electrical pressure of one volt. One watt equals 1/746 horsepower, or one joule per second. It is the product of voltage and current (amperage)

Waveform — The shape of the phase power at a certain frequency and amplitude

Z

Zenith Angle — the angle between the direction of interest (of the sun, for example) and the zenith (directly overhead).

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WEB RESOURCES AND REFERENCES

California Energy Commission

The Energy Commission's program provides market-based incentives for new and existing utility-scale facilities powered by renewable energy. It offers consumer rebates for those installing new renewable energy systems. The program also helps educate the public regarding renewable energy *http://www.energy.ca.gov/renewables/index.html*

California Solar Energy Industries Association

California Solar Energy Industries Association supports the adoption of solar thermal and photovoltaic systems by educating consumers, and supporting solar legislation *http://www.CAL SEIA.org/*

Californiasolarcenter.org

Californiasolarcenter.org was created to promote greater use of renewable energy through education, research, program and policy development. Californiasolarcenter.org exists only on the internet *http://www.californiasolar-center.org/aboutcsc.html*

The Clean Energy States Alliance (CESA)

The Clean Energy States Alliance (CESA) provides information and technical services to its members to build and expand clean energy markets in the United States *http://www.cleanenergyfunds.org/*

The Interstate Renewable Energy Council (IREC)

The Interstate Renewable Energy Council (IREC) supports market-oriented services targeted at education, coordination, procurement, the adoption and implementation of uniform guidelines and standards, workforce development, and consumer protection *http://www.irecusa.org/*

The North American Board of Certified Energy Practitioners (NABCEP)

The North American Board of Certified Energy Practitioners (NABCEP) supports and works with the renewable energy industries to develop and implement quality credentialing and certification programs for practitioners *http://www.nabcep.org/*

PV Now

PV Now is a coalition of the world's leading photovoltaic companies joined to aggressively expand North American distributed, grid-connected PV market opportunities and eliminate market barriers *http://www.pvnow.com/*

The Solar Energy Industries Association (SEIA)

The Solar Energy Industries Association (SEIA) is the national trade association of solar energy manufacturers, dealers, distributors, contractors, installers, architects, consultants, and marketers. They work to expand the use of solar technologies in the global marketplace *http://www.seia.org/*

Sacramento Municipal Utility District (SMUD)

SMUD provides programs that preserve our natural resources and reduce pollution. SMUD is nationally recognized as a leader in renewable resources and electric transportation *http://www.smud.org/green/index.html*

Solar Energy International (SEI)

SEI provides education and training to decision makers, technicians and users of renewable energy sources SEI also provides the expertise to plan, engineer and implement sustainable development projects *http://www.solarenergy.org/about/*