FLORIDA SOLAR ENERGY CENTER®

Photovoltaic Applications for Disaster Relief

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PHOTOVOLTAIC APPLICATIONS FOR DISASTER RELIEF

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PREFACE

Hurricane Andrew struck the coast of South Florida at Homestead on Monday, August 24, 1992. The storm was a level four hurricane with sustained winds of 140 miles per hour and waves reaching 18 feet pounded the shoreline flooding buildings and washing boats on shore. At least 85,000 buildings were severely damaged and an estimated 34,000 homes will have to be replaced like the one shown in Figure 1. More than two hundred-thousand people were left homeless and 51 deaths were attributed to the storm. Storm-damaged residences were without electrical service, functional water and sewage systems for days and weeks in some locations in the aftermath of the storm. This included many clinics, hospitals, fire stations, and police stations that suffered damages and loss of services.

Figure 1. Mobile home destroyed by Hurricane Andrew in Homestead

Emergency management teams, medical personnel, the military, and countless public and private organizations participated in the massive relief effort to provide the immediate need for life-supporting resources, such as food, water, and medical supplies. Food, water, and medical supplies poured into the disaster area to relieve human emergency needs, but the destruction was so overwhelming that it would be months before the area would be even partially restored to its pre-storm condition. The difficult task of rebuilding businesses and homes required the usual services of water, sewer, and electricity. Medical, fire, and police services were essential during the reconstruction. Several buildings that received little damage served as make-shift shelters and medical clinics as shown in Figure 2.

Figure 2. Community Center converted into a Medical Clinic.

The call for help rang out from Dade County Emergency Management and various nationwide businesses and organizations hurt by the storm. The University of Miami, Field Epidemiology Survey Team (FEST), having worked in situations similar to this before, knew the value of photovoltaic power as one solution to their energy needs. Sandia National Laboratories and the Florida Solar Energy Center (FSEC) were asked if they could supply any photovoltaic (PV) systems to provide power at several temporary medical clinics. FSEC teamed with Sandia National Laboratory to assist FEST and the Metro-Date Fire Department by providing five portable PV stand-alone systems.

At the time, FSEC was not prepared to supply extensive portable PV power systems as most of the photovoltaic equipment at the Center was used in experiments and was undergoing test for various manufacturers. Old PV equipment not used at the time was dismantled from previous projects and reassembled with new batteries and controllers into portable stand-alone systems. With this equipment, energy from the sun would be converted to electrical energy by the photovoltaic cells (solar electric cells) to power vaccine refrigerators, lights, radios, fans and other general electrical needs. These PV systems were designed to be used in the relief effort until utility power was fully restored. The PV systems were comprised of a 1 -kWp PV array, 21-kWp battery bank, a controller, and a 2.2- kWh dc/ac inverter. In a short period of time the systems were completed and transported to the damaged area in Dade county.

Installation of each system was completed in a day as shown in Figure 3 of St. Anne's Mission. The relief workers were unsure of what they were getting as the systems were installed at each of the selected sites. One by one fans, lights and other equipment were plugged in and started to operate. With amazement, the new users watched their equipment operate without a sound as if utility power was restored.

Figure 3. Installing a PV system at St. Anne's Mission.

In Homestead, the temporary medical clinics were manned 24 hours per day. Medical services were provided to people injured in the storm, as well as during cleanup and later during rebuilding. Control of disease was important as the medical teams surveyed the health conditions of the people still living and working in the disaster area. Simple laboratory work and medical treatment was carried out at the clinics, due to the difficulty in transporting people and supplies through the damaged areas.

The PV systems operated for weeks providing quite electrical power without the need for refueling as the sun provided plenty of clean energy. One by one the PV systems were returned as utility power was restored to each site.

PHOTOVOLTAIC APPLICATIONS FOR DISASTER RELIEF

Florida Solar Energy Center

1.0 INTRODUCTION

Hurricanes, floods, tornados, and earthquakes are natural disasters that can happen at any time destroying homes, businesses, and natural surroundings. One such disaster, Hurricane Andrew, devastated South Florida leaving several hundred-thousand people homeless. Many people were without electrical service, functioning water and sewage systems, communications, and medical services for days, even weeks in the aftermath of the storm. Emergency management teams, the military, and countless public and private organizations staged a massive relief effort.

The sun shining on the earth each day provides vast amounts of solar energy. This inexhaustible source of energy can be applied to power a variety of equipment. Solar energy can be converted to thermal or photovoltaic (solar electric) energy. Photovoltaic (PV) power generated from solar energy is quiet, safe, and pollution-free. The electricity generated by a PV system can be used as a mobile power source anywhere the sun shines.

Many of the energy needs of emergency management organizations, relief workers, and the general public can be satisfied with photovoltaic power systems. Previously, photovoltaics have supplied emergency power for Hurricanes Hugo and Andrew, and the Earthquake at Northridge in Southern California. This document focuses on photovoltaic technology and its application to disaster relief efforts.

2.0 DISASTER MANAGEMENT

The burden of disaster management, and the resources for it, require a close working partnership among all levels of government (federal, regional, state, county, and local) and the private sector (business, industry, voluntary organizations, and the general public). The federal government provides guidance and assistance to state and local governments in preparing for and coordinating recovery from a disaster. State governments provide compressive plans and systems to assist local governments with preparedness and recovery activities along with support from various governmental agencies. Local governments are responsible for providing the primary resources for public protection concerning all types of hazards and management of the disaster. Local governments provide and maintain police and fire protection, highway resources, facilities, supplies, and personnel capabilities to resolve the problem. When local government are without sufficient resources, they can ask the State or Federal Governments for assistance. One of the greatest resources that the State and Federal Government provide is the National Guard and the Military.

Disasters can occur any time, night or day, and season of the year. Each occurrence has a life cycle which must be matched by a series of management phases that include strategies to mitigate hazards, prepare for and respond to emergencies, and recover from the disasters effects. Local and State governments prepare and maintain an Emergency Operations Plans (EOP) that describes how citizens and property will be protected in a potential disaster. The EOP describes actions that may be required for any natural or technological hazard, including tasks to be carried out by specified organizations, administrations, and authorities; the plan may also include definition of responsibilities; standard operating procedures; logistics activities and a list of available resources. The EOP resource list provides both personnel and equipment requirements including responsibility level and where available. This resource list should contain renewable as well as conventional energy resources.

Emergency management personnel from public agencies and utilities are organized into teams for resolution of emergency situations within a major disaster or incident. There are short term Immediate Response and long term Relief Effort teams responding to a disaster, each with its designated function. Response teams are deployed within the first 24 to 72 hours immediately after a disaster or incident. As immediate needs and problems are resolved, Response teams are either dismantled because they are no longer needed or are replaced with Relief teams for the long term restoration effort. The teams are organized into service areas called Emergency Support Functions (ESF) and are defined as follows:

ESF1 - Transportations	Coordinate busses, transport of evacuees
ESF2 - Communications	Provide communications where needed
ESF3 - Public Works	Debris removal, flood water control
ESF4 - Fire Rescue	Fires and immediate rescue
ESF5 - Information & Planning	Message control, resource allocation
ESF6 - Red Cross	Mass care, institutional responsibility
ESF7 - Purchasing	Expedite procurement of resources
ESF8 - Public Health	Assess contamination dangers
ESF9 - Search & Rescue	Finding lost persons
ESF10 - Hazardous Materials	Neutralizing spills and toxic gases
ESF11 - Food & Water	Feeding and potable water
ESF12 - Energy	Provision of electrical energy and fuel
ESF13- Military Support	Coordinates with military for security
ESF14 - Public Information	Interfaces with public media for information
ESF15 - Volunteers & Donations	Coordinates walk-in volunteers and donations
ESF16 - Law Enforcement	Wide area & road block
ESF17 - Animal Issues	Pet shelter resources

3.0 ENERGY NEEDS IN RESPONSE TO DISASTERS

Natural disasters, such as hurricanes, floods, tornados, and earthquakes destroy homes and businesses along with electric generating facilities and distribution systems. Many people experience disruptions in electrical service, functioning water and sewage systems, communications, and medical services for days and often weeks in the aftermath of a disaster. Emergency management teams, the military, and countless public and private organizations become involved in a massive relief effort when a disaster strikes an area and require varying amounts of electrical power both small and large.

Clinics, hospitals, fire stations, and police stations may have utility services interrupted or their facilities damaged beyond use. Life supporting resources, such as food, water, and medical supplies, may be urgently needed and may be insufficient to meet immediate demands. The destruction can be so overwhelming that it might require months before the area is restored to its pre-storm condition, if ever. Medical, fire and police services may be essential during reconstruction efforts. Rebuilding businesses and homes is extremely difficult without the usual services of water, sewer, and electrical power.

Make-shift shelters and temporary medical clinics may be constructed from buildings that received little damage and are safe to occupy. These temporary medical clinics may be manned 24 hours per day and emergency personnel will need communication equipment to request assistance, supplies, and information. Medical services need to be provided to people injured in the disaster, and during cleanup and rebuilding requiring monitoring equipment. Control of disease may be a major issue as the medical teams survey health conditions of the people still living and working in the disaster area requiring vaccinee refrigerators. Also, hot water and sterilization are needed to preserve good health. Due to the difficulty in transporting people and materials, simple laboratory work may need to be carried out at the local clinics. Electrical energy needs can vary from two watts to charge the batteries in a flashlight to 1,000 watts to power a saw.

4.0 THE BASICS OF PHOTOVOLTAICS

The photovoltaic effect is the process by which sunlight is converted directly into electricity. Photovoltaic cells, or solar cells, are typically made of a thin wafer-like silicon semiconductor material that is treated with other elements to create a negative and positive electric field as shown in Figure 1. A voltage potential of one-half volt is created between the positive and negative sides of the photovoltaic cell. When a photon of light strikes an atom of silicon in the solar cell, the transfer of energy frees an electron. The freed electrons flow in one direction from the force of the electric field, through a connection of wires to form an electric circuit. This direct current flows from the negative layer through a connecting wire to a load or some electrical device and returns to the positive layer after performing useful work. The cell acts as a current generator, as more light strikes the cell, higher levels of current are generated with little effect on voltage. Also, the amount of current generated is proportional to the amount of surface area of the cell. A typical 10 centimeter solar cell will produce about 3.5 amperes in peak sunlight. The output of a cell is affected by temperature, the higher the operating temperature, the lower the output power and efficiency along with a decrease in cell life.

The cells are connected in series and parallel combinations to generate a desired voltage and current output. By connecting the cells in series, higher voltages are produced typically to match the load voltage. The array of cells is then connected, encapsulated, and sealed to form a module. A typical commercial module contains 36 cells connected in series to generate a nominal 12 volts at about 3 amperes.

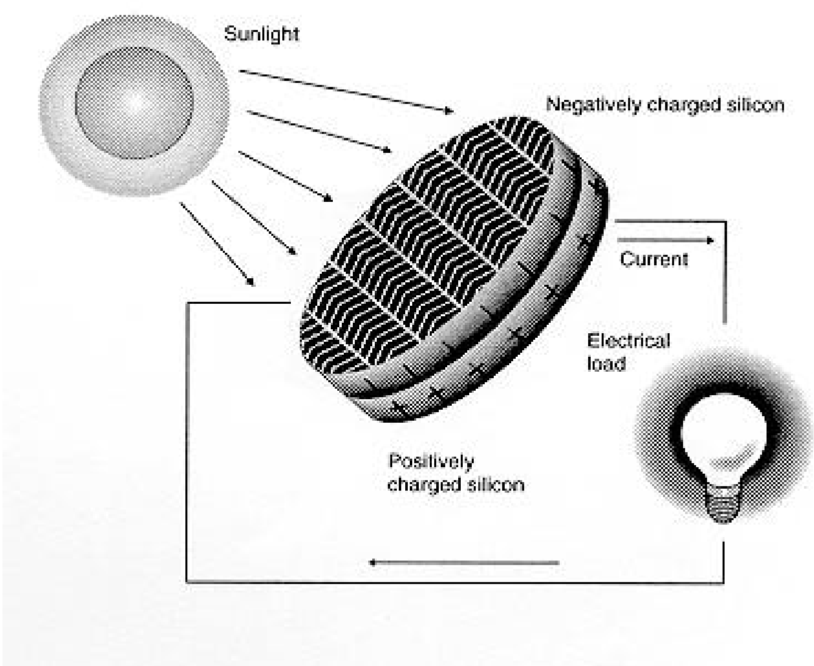


Figure 1.PHOTOVOLTAIC CELL CREATES NEGATIVE AND POSITIVE ELECTRIC FIELD

PV modules are the standard working blocks for building a PV system. These blocks are modular in design and come in typical voltage and current outputs. An array is designed to provide a desired amount of power from a series and/or parallel combination of modules as shown in Figure 2.

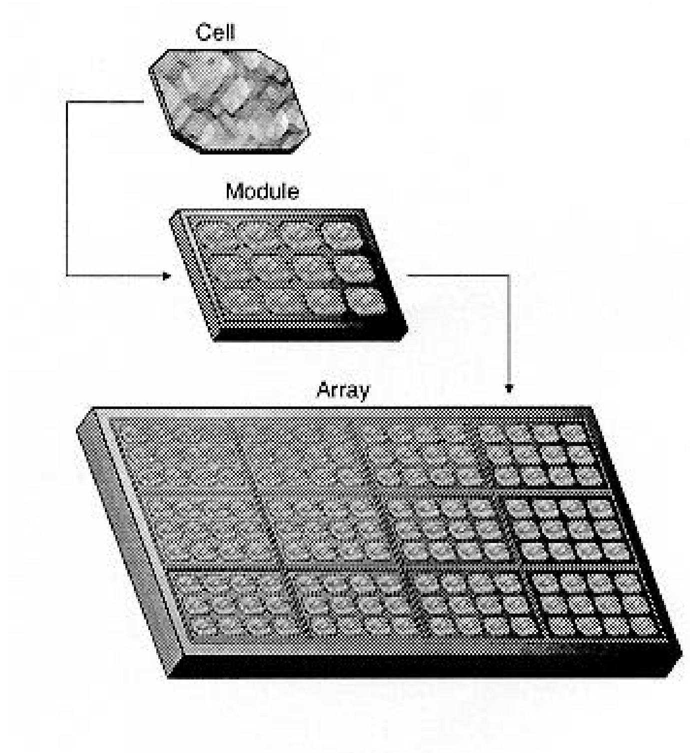


Figure 2. PV ARRAY

5.0 SOLAR ENERGY

The orientation of the PV array is important and should be perpendicular to the sun for maximum collection of solar energy. However, the compass and elevation angle of the sun for a location changes throughout the day. The earth's rotation about its axis produces hourly variations in power intensities of light at a given location on the ground during the day and receives complete shading during the night. Seasonal variations affect the position of the sun. Each location on the earth has a solar window that represents the effective area through which useful levels of sunlight pass throughout the year as shown in Figure 3. The amount of solar insolation is determined by summing solar irradiance over time and is expressed in kWh/m2 per day. The amount of solar energy at the earth's surface varies greatly, not only from the position of the sun, but also from cloud cover, air pollution, and other factors. Therefore, 1000 watts per square meter of full sun are available at the earth’s surface for only a few hours per day. Insolation values can be obtained from tables for specific locations.

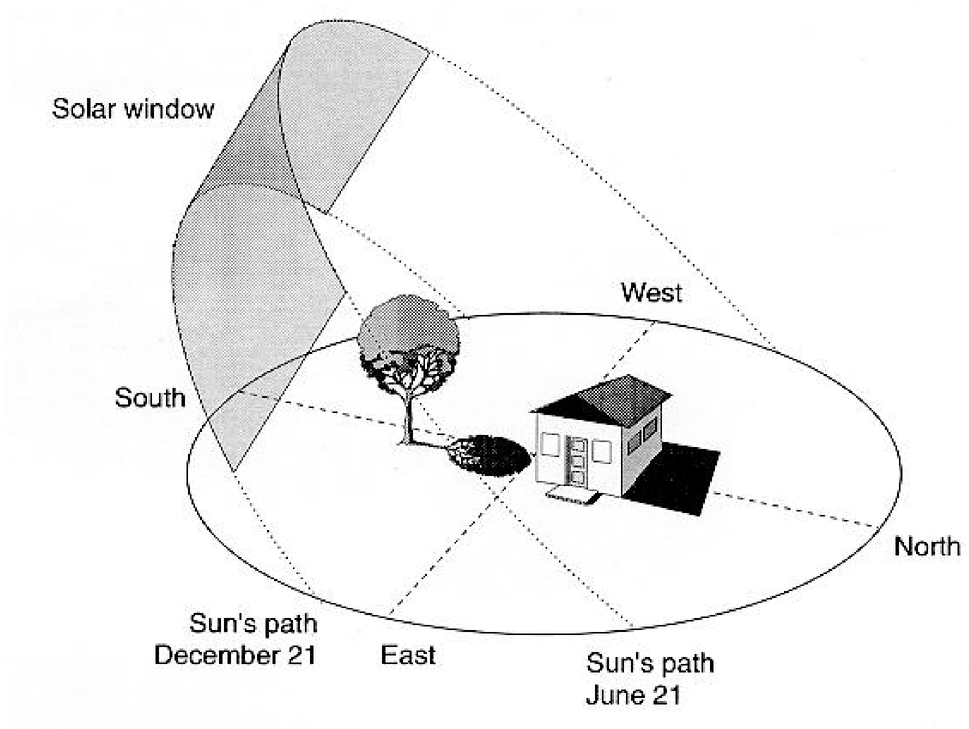


Figure 3.
SOLAR WINDOW YEARLY MOVEMENT

The amount of solar energy generated is determined from the amount of time that peak sun illuminance is within the solar window for a special location and the size of the PV array. To maximize the energy generated, the PV array could track the sun or the array could be sized and oriented for optimum energy collection. The type of array (fixed or tracking) and its orientation to the sun is influenced by the type of application to be powered. Since many system applications require operation at night, storage characteristics need to be considered in the design of the PV array. Typically, arrays should be tilted facing the noon sun and positioned facing south as close as possible. Shading of any type reduces the amount of energy received by the PV.

6.0 PHOTOVOLTAIC SYSTEMS

PV cells by themselves are limited in use. In a system, however, they are capable of powering a variety of electrical and electronic equipment. One of the most widely used system designs is standalone, where utility power is not available. Solar energy, as a single source is converted directly to electrical energy to power a load. Standalone PV systems do not require refueling as the sun is their source of energy. Other system designs using PV power are utility interactive and hybrid.

A simple standalone PV system consists of a PV array, system controller, electrical hardware, support structure, and load. The PV array supplies DC power through a controller to power the load. The system controller's purpose is to control the energy flow between the array and load for efficient transfer of energy and to ensure safe and reliable operation of the system. This type of stand-along system operates only when the sun is shining. Therefore, it is most useful in applications such as water pumping, which may only be needed during the day.

This simple stand-along system can be expanded to include continuous 24-hour operation, seven days a week and to operate at various voltages and power requirements. Batteries added to the system store energy from the PV array so the load can also operate during cloudy days and at night. If the load requires alternative current, an inverter can be added to convert the DC power to AC power. For this type of design, the PV supplies power through the system controller to the batteries to power the DC or AC load as shown in Figure 4.

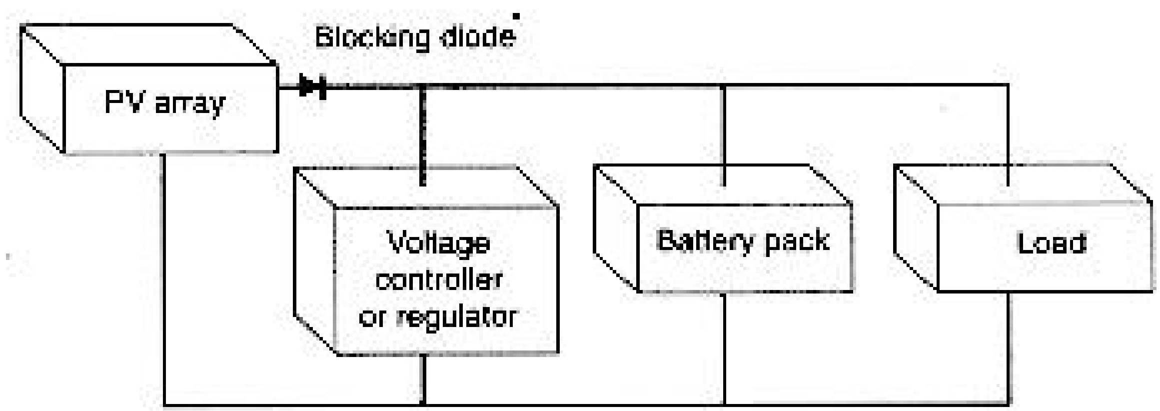


Figure 4. PV system supplies additional power with batteries.

Other sources of energy can be added to a PV system, such as AC generators and utility power. A hybrid system can switch between PV, generator or utility power based on user requirements and system design. PV systems are modular and flexible, allowing the user to start small and expand to meet future needs. The system user needs to be aware of the type of service desired and the application the system was designed to serve. Most systems operate at low voltage offering a safety advantage.

The PV system needs to be designed to generate sufficient energy during peak sun hours to power the load during its total hours of operations. By knowing the power supplied by the PV in the system, the number of peak sun hours alone, the amount of energy required by the load, battery capacity (if needed) and its hours of operations, a user can determine if the PV system will meet current needs. Understanding the load and capabilities of the PV system is critical to successful implementation of an application.

7.0 SYSTEM COST

Photovoltaics cost varies depending on the type of system and quantity. An array of PV modules may sell for as low as $4 per watt, whereas a complete standalone system may cost as high as $15 per watt installed. The initial cost of PV systems is generally greater than the cost of conventional equipment or systems. As an example, the PV system to power a radio may cost $40 or more, whereas a conventional AC power supply that plugs into the wall may cost as little as $10. A complete PV system for a home may cost as much as $40,000. However, in many applications, especially remote locations, the life cycle cost of PV systems is small compared to the cost of conventional power systems.

PV systems installed in remote locations offer a cost-effective application when compared to utility or generator power. The cost of running utility power in remote locations can be substantial when the cost is calculated on a linear foot basis for running power lines to the site. The Coast Guard has found PV to be cost-effective in powering buoy lights rather than providing utility power or periodic batteries.

Life cycle cost of a generator set, including the maintenance and fuel expense, can be greater than the cost of a PV system. Therefore, the high initial cost of a PV system is often offset by the higher operating cost of a generator set for the life-cycle of the application. A generator may present difficulties in refueling depending on the location of the system, such as a communication station located on top of a mountain. In a disaster, a PV system may be more cost-effective from the point of refueling a generator or possibly the only choice, if fuel is not available. After Hurricane Andrew hit, fuel was difficult to obtain as gasoline stations were either destroyed or those gasoline stations that survived had no electricity to power the pumps to get the fuel out of the tanks.

The cost-effectiveness of some PV-powered systems is much greater when compared to utility power systems depending on the application. This is because the application equipment costs are usually added to the utility interconnection costs and the availability of utility distribution lines.

8.0 SYSTEM PERFORMANCE

There are tens of thousands of PV systems installed around the world producing megawatts of power daily. Most applications operate beyond daylight hours, requiring batteries for storing energy. The average battery storage capacity designed into a PV system is approximately 10 days, although storage capacities range from 2 days (streetlights) to more than 20 days (call boxes). The power generated by the PV system is of a form that its source is transparent to the load.

This brochure describes actual PV system installations that performed successfully in various regions of the country, operating in varying climates, different seasons, and under differing solar resources. Operating experience and system testing indicates that on partly cloudy days, PV systems can produce up to 80% of their rated energy, while on hazy and humid days, about 50%. On heavy overcast days, when the full brightness of the sun is not available, they still produce about 30%of their rated energy.

Photovoltaics are environmentally benign, except for the land used for the array. Even if batteries are used, they are 98% recyclable. Additionally, if the system is standalone, there is no need for fueling as the sun supplies an inexhaustible source of energy. No pollutants or wastes are released, while their operation is silent, another added benefit.

9.0 SYSTEM RELIABILITY

Studies by a national laboratory indicate that today's PV modules are exhibiting lifetimes of about 20 years. This statistic is supported by users experiences over many years. PV modules contain no moving parts to wear out. Degradation from the environment is minimal. Manufacturers are providing warranties which range from 5 up to 12 years.

The Jet Propulsion Laboratories developed stringent testing procedures which most manufacturers follow. A module passing the test has met environmental, electrical, and mechanical requirements that will ensure many years of reliable operation. An example of the acceptance testing: a PV module is shot with a hailstone at 60 miles per hour without failure.

In 1984, the U.S. Coast Guard started converting battery power navigational aids to PV power. PV reliability is so high that the Coast Guard has more than 14,000 PV-powered navigational aids operating in coastal locations throughout the United States. Also, the military employs remote communications stations, radar, and monitoring equipment powered by PV for more reliable operation and lower operating cost.

10.0 MAINTENANCE REQUIREMENTS

Regular maintenance is required for any PV system, just as it is required for any equipment. Maintenance for standalone PV systems usually consists of monitoring and preventive measures several times a year (as required). Battery replacement only occurs after several years of operation. Without proper maintenance, PV systems have similar failure probabilities as any other system type.

Preventive maintenance schedules vary from annually to six times or more per year. PV modules require no maintenance unless located in a very sandy or dirty location where they need periodic cleaning. Sealed batteries require little or no maintenance, but flooded (non-sealed conventional) batteries need to be watered periodically. The battery manufacturer typically recommends a particular preventive maintenance schedule to follow for their batteries. The application or powered equipment may need other specific periodic maintenance or repair, such as lamp replacement. Grounding and surge protection against lightning needs monitoring. The effects of corrasion and weathering needs the usual maintenance as any other equipment would. Unless the system is a hybrid system, there is no need for refueling.

11.0 APPLICATIONS SOLVING ENERGY NEEDS

Loss of life, buildings, property, and equipment are not the only losses experienced by those surviving a disaster. The loss of electrical power after a disaster makes us realize how dependent our society is on electricity. Outages of hours, days, or even weeks after a disaster make renewables, such as photovoltaics, a natural solution when applied to the proper application.
Electrical power can be supplied by various sources such as gasoline and diesel generators, wind generators, and photovoltaics until utility power is restored. Photovoltaics can be a natural application in disaster relief efforts such as hurricanes, tornados, earthquakes, and floods, as well as man made ones.

There are however, inappropriate applications for photovoltaics. Large scale power needs in sewer and water facilities, hospitals, large shelters, distribution and emergency operations centers are better met with generators. Locations or equipment requiring hundreds of kilowatts of emergency power would require large areas of open space and cost hundreds of thousands of dollars for PV arrays. If the location effected by the disaster is small and utility power can be restored in a short period of time, then PV may not be the correct solution.

Where PV makes sense, is in large-scale disasters where power will be out for long periods of time and survivor support is difficult to provide. Massive infrastructure damage makes refueling generators a challenge as pumping stations are inoperative and roads are impassable. Power distribution lines are difficult to get to by impassable roads much less transporting materials for reconstruction. Some needs like communications and clinics require quiet non-polluting operation, which PV is capable of providing. Solar energy is a valuable cost-effective resource for small portable and standalone electrical power applications due to lower operating cost. Permanent site-built PV systems designed to supplement grid-supplied electricity are also feasible.

In a large scale disaster, solar powered systems are a natural solution because they are designed specifically for stand-alone operation without utility power. Solar systems are designed and sized for varying needs and applications. Modular PV system designs are adaptable, allowing small systems to easily become large systems as needs increase. Since refueling is not required, length of operation poses no problem when the PV system is properly designed.

This section contains examples of PV systems that have met or can meet the needs of emergency management and disaster relief organizations. There has been limited use of solar power during disasters such as Hurricanes Hugo and Andrew, but this is rapidly changing as more people learn about the benefits of PV power.

In response to a disaster, essentials for the health and welfare of victims need to be addressed first. Table 1 lists equipment needed under various Emergency Support Functions (ESF) requiring electric power that can be supplied by PV.

Need	ES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Call boxes		X	X															
Flashing arrow board		X		X														
Flashing warning signals		X																
Folding man packs			X		X		X		X	X				X			X	
Hand-held radios			X		X				X	X	X						X	X
Highway advisory radio		X	X	X			X											
Medical equipment			X		X		X		X	X								
Message signs		X	X	X														
Personnel lights					X		X		X	X				X			X	
Photovoltaic generators			X	X	X		X		X	X			X	X			X	
Portable cellular phones			X		X	X									X			
Portable AM/FM radios			X			X	X								X			
Portable pumping stations				X	X					X								
Radio base stations			X		X					X							X	
Refrigerators							X		X	X		X						
Sampling/monitoring/ detention equipment					X					X	X							
Security lighting							X				X			X			X	
Small battery chargers			X	X	X		X		X	X								
Small generators			X	X	X		X		X	X			X	X			X	
Street lighting		X															X	
Traffic signals		X															X	
UPS/Backup power			X	X			X		X	X	X	X	X	X			X	
Victim detection equipment					X					X								
Water purification				X			X		X	X		X						

Table 1.ESSENTIAL EQUIPMENT REQUIRING ELECTRICITY

11.1 LIGHTING

Lighting, both indoor and outdoor, has become a way of life and in some locations a necessity. Street, security, reading and portable lighting can be powered by photovoltaics. Photovoltaic powered lighting can be installed in a relatively short period of time in any location to either replace destroyed conventional lighting or provide temporary lighting where utility power has not been restored. High efficient lighting sources used in present PV lighting systems makes a reliable stand-alone unit useful after disasters.

Many different types and sizes of lights are PV powered. Their performance is representative of conventional lights, except that consumers do not have to replace the batteries when low or plug them into an electrical outlet. After several hours in the sun, the PV power light is charged and ready to operate.

The system typically consist of PV modules, batteries, controller/timer, sensors and lamps. The lamps are typically controlled by timers, photo cells and sensors. Lighting systems typically operate at 12 or 24 volts DC and use fluorescent, low-pressure sodium or halogen lamps.

Street Lighting

Before Hurricane Andrew, PV-powered streetlights had been installed in a Miami suburb. After the storm, the only street lighting in the area came from these PV lights until utility power was restored 33 hours later. Several more of these lights were installed at security stations, temporary medical clinics, and shelters as shown .

This outdoor street lighting system used at a security check point during Hurricane Andrew, consists of two PV modules that charge batteries to power a fluorescent lamp. With the batteries fully charged by the sun, these lights have the capacity to operate for up to 12 hours a night.

Security Lighting

Areas around shelters and medical facilities can be made more secure with PV security lighting. Here a small unit still functional is shown outside a home after Hurricane Erin.

Personnel Lights

Portable personnel lights can be PV powered from flash lights to lanterns. This lantern is shown being recharged from being used during relief efforts after Hurricane Andrew.

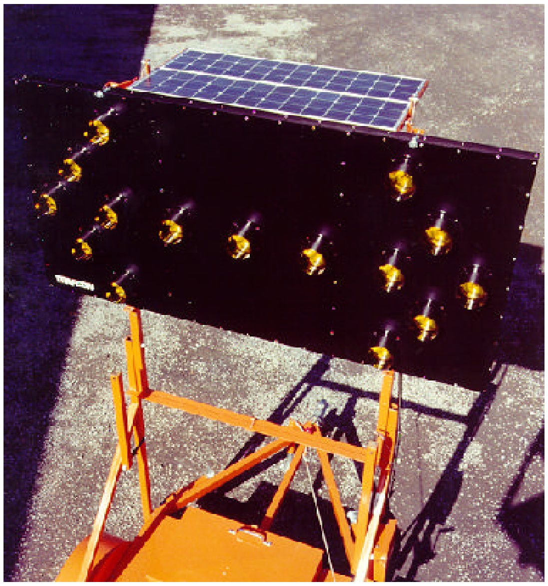
11.2 TRANSPORTATION

Travel becomes hazardous after a disaster as shown in this picture where the traffic signals is inoperable, street signs are gone, and roads are covered with debris. If the traffic signals are still standing they may not have power to operate and traffic becomes congested. To assist with traffic control, portable PV powered traffic control devices are used such as changeable message signs, flashing arrow boards and signs, and highway advisory radios.

PV powered traffic devices with battery storage helps emergency vehicles to move freely with 24 hours a day operation. Conveys of supplies and survivors of the disaster can be directed to shelters and stagging areas. The traffic problem becomes greater as people return home and the rebuilding effort increases.

Highway Changeable Message Sign

After Hurricane Andrew, several PV-powered changeable highway message signs were installed in the disaster area in Miami. The message signs informed drivers of closed and hazardous roads, locations of shelters and emergency relief centers and other relief effort information. Four PV modules charge the batteries to power an array of LED lamps and the message controller.



Flashing Arrow Boards

These flashing arrow boards are normally used for highway construction, but after Hurricane Andrew they were used to direct disaster relief efforts. They usually have two PV modules that charge batteries which powers the lamp that forms the arrow.

Flashing Warning Signals

These flashing warning signals can be used for traffic control and added safety after a disaster. The PV modules charge batteries during the day that power the flashing lamps for twenty four hour per day operation.

Highway Advisory Radio

After Hurricane Andrew, several PV-powered highway advisory radio units were installed along I-75 in the disaster area in Miami. The PV modules charged the batteries that powered an AM radio transmitter. The radio transmitted messages about alternative routes for travelers and reporting stations for volunteers.

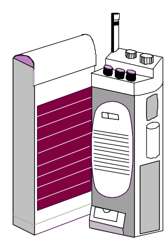
11.3 COMMUNICATIONS

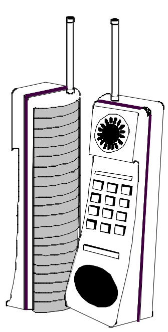
Communications was one of the first applications of PV power.

Call boxes

This call box allows travelers to communicate with the Highway Patrol. The unit is powered by one PV module which charges two batteries to operate a radio transmitter/receiver. With the batteries fully charged, battery capacity enables the call box to operate up to 20 days without recharging by the sun.

Portable AM/FM Radios
One widely used consumer product that is solar powered is a portable AM/FM radio. There are many different types and sizes of radios that are PV powered. Their performance is representative of conventional radios, except that consumers do not have to replace batteries or plug the radio into an electrical outlet. After just several hours in the sun, the PV-powered radio is ready to operate.

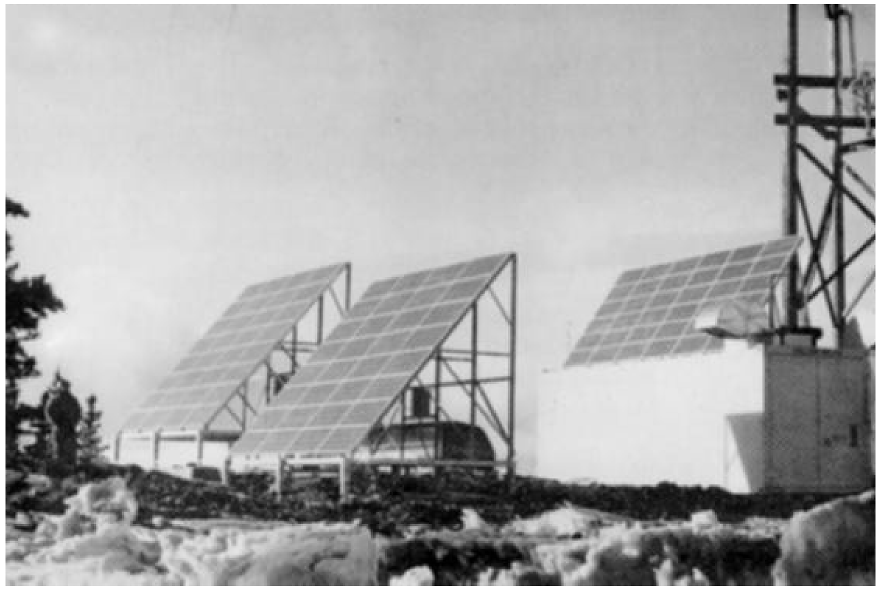


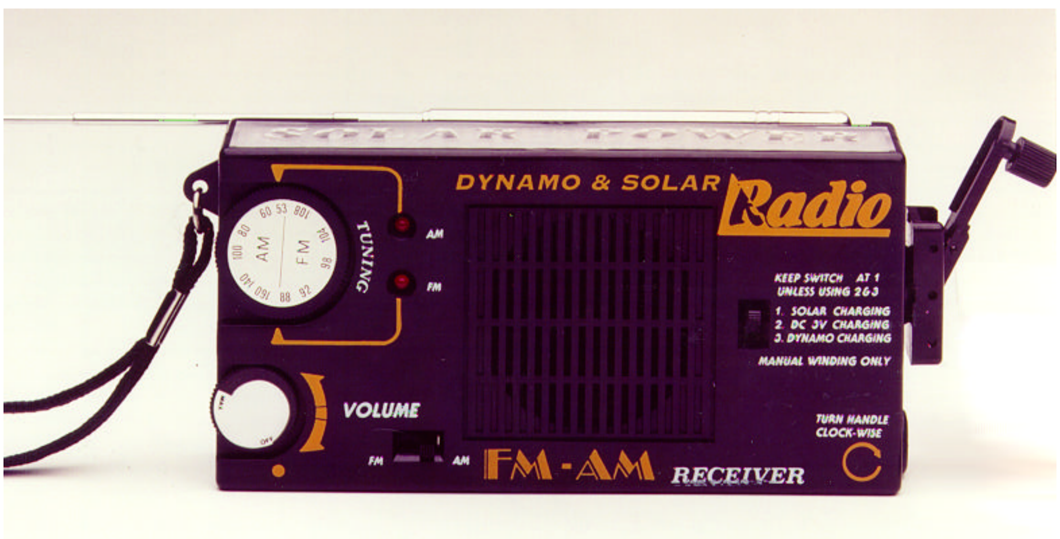


Portable Cellular Phones
Cellular phones have drastically increased communication capabilities at affordable prices for many people. These small battery packs can be charged by PV modules. This is an example of a solar powered cellular phone.

Radio Base Stations

Communication capability after a disaster is extremely important. Shown below is a PV-powered generator powering a radio transmitter/receiver, a large PV power system for a base\relay radio station that is both modular and transportable. Smaller PV systems are available for smaller radios with lower power requirements.

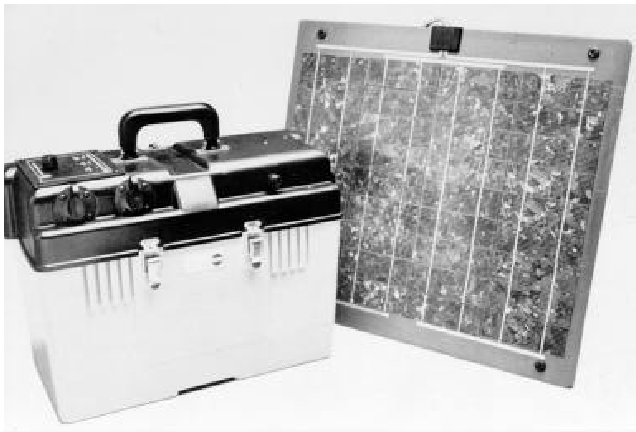




Portable Hand-Held Radios

Hand-held radios are powered by small batteries. These batteries can be charged by small PV modules, usually less than 10 watts. Some modules are purposely made for powering hand-held radios. However, any small PV module can be outfitted with the right connector to plug into a radio for recharging.

11.4 GENERATORS

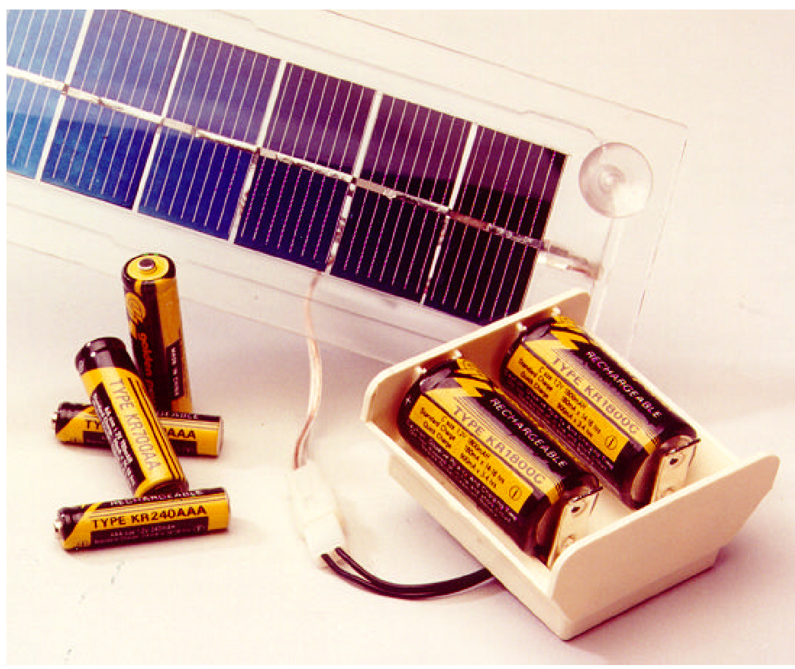


Small Generators

Generators are available in all sizes, whether they are gasoline or solar. Numerous sizes and designs of solar generators can power various electric equipment. Below is an example of a small portable generator composed of two 10 watt PV modules installed in a case.

Small Battery Chargers

Small battery chargers are available in many sizes and shapes to charge various battery sizes and types. This is an example of a small battery charger in a case.

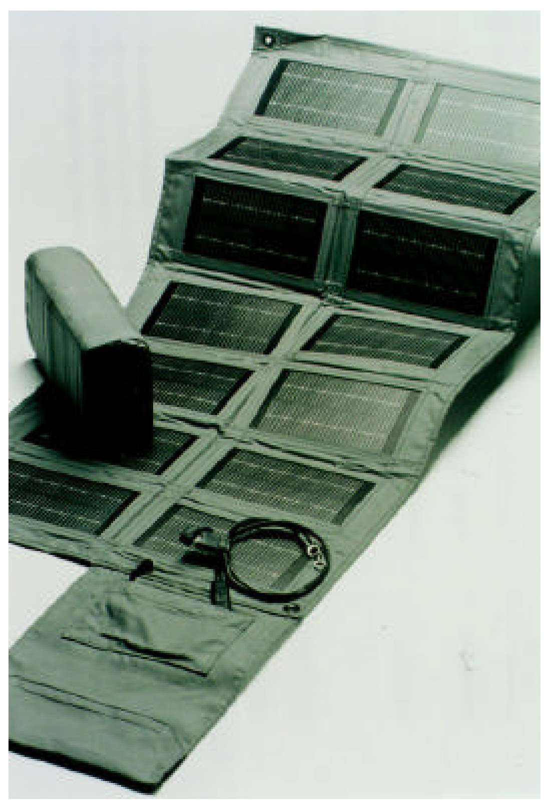


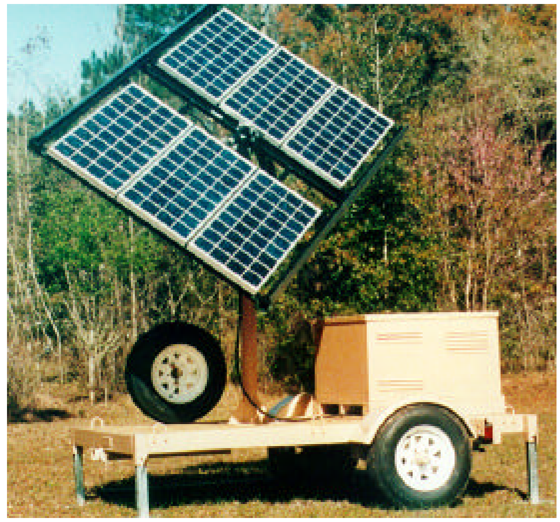
UPS/Backup Power

When the electrical power is out, a uninterrupted power supply (UPS) or a backup power unit comes into operation. Solar power backup power units operate in two modes: operating on standby until needed or operating as a charger until needed. These PV power generators come in different sizes and supply various power outputs from 100 to 1000 watts. Different voltage outputs can be obtained including 12 or 24 VOC and 120 VAC or greater.

Folding Man Packs

The military has found PV to be a useful source of electric power. Man packs that fold up to fit in a soldier's backpack were developed for the military. They can power radios, lights, and monitoring/detection equipment. Below is an example of a folding man pack.



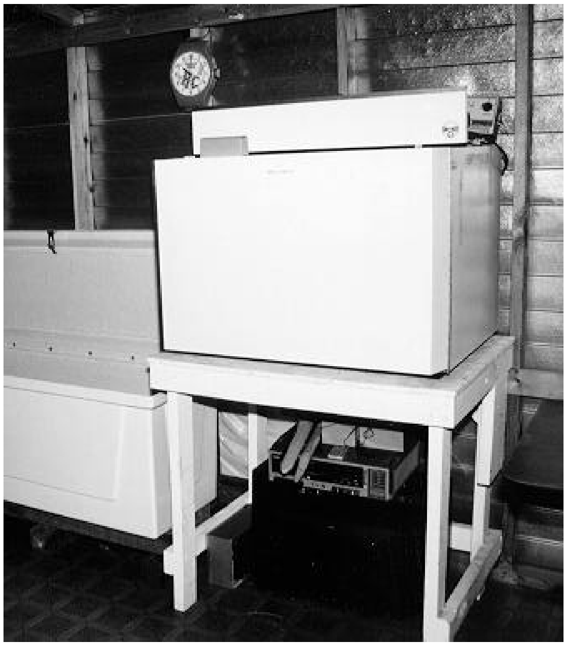
Photovoltaic Generators

Generators are readily available in a variety of sizes, whether they are gasoline or solar. Numerous sizes and designs of solar generators can power various electric equipment. Here is an example of a generator that produces from 100 to over 1000 watts. Inverters are usually part of the generator to supply 120 VAC. A variety of battery capacities are built into the units that provide various periods of operation.

11.5 EQUIPMENT

Portable Pumping Stations

A portable pumping station after any disaster is quite an asset. The portable pumping station can be used for obtaining fresh water or removing rain water as well as other uses. This small water pump requires one 60-watt PV module to operate. Since this unit has no batteries, it will only operate during the day. However, larger units with batteries are available for continuous operation and large volume flows.



Refrigerators

After Hurricane Andrew, several PV-powered refrigerators were installed in the Miami disaster area. These systems were originally developed for the World Health Organization for use in Third World countries. Most are powered by four 48-watt PV modules to charge four batteries that power the refrigerator. With the batteries fully charged, battery capacity enables the refrigerator to operate for 24 continuous hours for four days without recharging from the sun.

Water Purification

Sailboats have become extensive users of DC power water purification units. PV power systems have been designed to power these purification units both on and off sailboats. Usually, four 48-watt PV modules charge two batteries that power the water purification unit. With the batteries fully charged, battery capacity enables the light to operate six hours a day for four days without recharging from the sun.

12.0 MAKING THE RIGHT CHOICE

Photovoltaic power systems are a viable source of electrical power. An endless supply of energy from the sun is converted to electrical energy without pollution and noise. Batteries store energy supplied each day by the sun so refueling is effortless by design. The systems are reliable, durable and require little maintenance. PV systems are capable of being designed to meet specific requirements of portability, standalone operation, various loads, and operating times.

Applications presented in this report demonstrate the usefulness of PV power for disaster relief efforts. However, photovoltaic power system may not be the right answer for every power need. For large power needs greater than 2 kW may be better met by generators or utility power systems. PV systems have higher initial cost making it difficult to obtain or store many units. Because PV requires sun light, they can not be located anywhere and presents a certain footprint. Permanent PV installations suffer from the same destructive forces during disasters as conventional power. Understanding your application and energy needs helps in making the right choice.

13.0 GLOSSARY

ALTERNATING CURRENT (AC): Electric current (flow of electrons) in which the direction of flow is reversed at constant intervals, such as 60 cycles per second.

AMPERE (AMP or A): A measure of electrical charge that equals the quantity of electricity flowing in one second passed any point in a circuit, or defined as one coulomb per second.

AMPERE-HOUR (AMP-HOUR or AIR): A measure of electrical charge that equals the quantity of electricity flowing in one hour passed any point in a circuit. Battery capacity is measured in amp-hours.

ARRAY: A collection of photovoltaic modules electrically wired together in one structure to produce a specific amount of power.

AUTONOMOUS OPERATIONS: Self-contained operation. Capable of existing independently.

AZIMUTH: The angular measure between due south and the point on the horizon directly below the sun.

BALANCE OF SYSTEM (BOS): Components of a photovoltaic system other than the photovoltaic array and load.

CELL (PHOTOVOLTAIC): A semiconductor device that converts light directly into DC electricity.

CHARGE CONTROLLER: A component of a photovoltaic system that controls the flow of current to and from the battery subsystem to protect batteries from overcharge, over discharge or other control functions. The charge controller may also monitor system operational status.

DIRECT CURRENT (DC): Electric current (flow of electrons) in which the flow is in only one direction.

ENERGY: The capacity for doing work.

GRID-CONNECTED: A photovoltaic system that is connected to a centralized electrical power network such as a utility.

HYBRID SYSTEM: A power system consisting of two or more power generating subsystems.

INSOLATION: The amount of energy in sunlight reaching an area. Usually expressed in watts per square meter (W/M2), but also expressed on a daily basis as watts per square meter per day (W/M2/day).

INVERTER: A device that converts direct current (DC) to alternating current (AC) electricity.

KILOWATT (KW): 1000 watts.

KILOWATT-HOUR (KWH): 1000 watt-hours. A typical residence in the United States consumes about 1000 kilowatt-hours each month at a price in the range of $.06 to $.15 per kilowatt-hour.

LIFE CYCLE COST (L.C.) ANALYSIS: A form of economic analysis to calculate the total expected costs of ownership over the life span of the system. L.C. analysis allows a direct comparison of the costs of alternative energy systems, such as photovoltaics, fossil fuel generators, or extending utility power lines.

LOAD: Any device or appliance in an electrical circuit that uses power, such as a light bulb.

MAINTENANCE COSTS: Any costs incurred in the upkeep of a system. These costs may include replacement and repair of components.

MODULE: A number of photovoltaic cells wired together to form a unit, usually in a sealed frame of convenient size for handling and assembling into arrays. Also called a "panel".

OPERATING COSTS: The costs of using a system for a selected period.

PARALLEL CONNECTION: A wiring configuration where positive terminals are connected together and negative terminals are connected together to increase current (amperage).

PEAK SUN HOURS: The equivalent number of hours when solar insolation averages 1000 watts per square meter and produces the same total insolation as actual sun conditions.

PEAK WATTS (WP): The maximum power (in watts) a solar array will produce on a clear, sunny day while the array is in full sunlight and operating at 25 deg. Celsius. Actual wattage at higher temperatures is usually somewhat lower.

PHOTOVOLTAIC (PV) SYSTEM: A complete set of interconnected components for converting sunlight into electricity by the photovoltaic process, including array, balance-of-system components, and the load.

POWER: The rate of doing work or energy is consumed or generated. Power is measured in watts or horsepower.

POWER CONDITIONER: The electrical equipment used to convert electrical power from a photovoltaic array into a form suitable for subsequent use, such as an inverter, transformer, voltage regulator, and other power controls.

SERIES CONNECTION: A wiring configuration where negative to positive terminal is connected together to increase voltage.

SILICON: A non-metallic element that is the basic material of beach sand and is the raw material used to manufacture most photovoltaic cells.

STANDALONE PHOTOVOLTAIC SYSTEM: A solar electric system, commonly used in a remote location, that is not connected to the main electric grid (utility). Most standalone systems include some type of energy storage, such as batteries.

VOLTAGE (V): A measure of the force or "push" given the electrons in an electrical circuit; a measure of electric potential. One volt produces one amp of current when acting against a resistance of one ohm.

WATT (W): A measure of electric power or amount of work done in a unit of time and equal to the rate of current flow (amps) multiplied by the voltage of that flow (volts). One amp of current flowing at a potential of one volt produces one watt of power.

WATT-HOUR (WH): A measure of electrical energy equal to the electrical power multiplied by the length of time (hours) the power is applied.

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Energy Efficiency and Renewable Energy Clearinghouse (EREC), P.O. Box 3048, Merrifield, VA 22116, ph: 1-800-363-3732; FAX 1-703-893-0400; Internet e-mail: energyinvo@delphi.com.

Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, Florida, USA, 32922, ph: 407-638-1000, fax 407-638-1010.

National Renewable Energy Laboratory (NREL, formerly SERI), Technical Inquiry Service, 1617 Cole Blvd, Golden, CO 80401, USA, ph: (303)275-4099; FAX (303)275-4091; E-mail: rubin@tcplink.nrel.gov.

National Technical Information Service (NTIS), U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22161, USA, ph: 703-487-4650.

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SunAmp Power Company, P.O.Box 6346, Scottsdale, AZ, 85261,USA.
