

Welcome to the World of Solar Electric Power

Wireless solar electric power systems are now in use around the world, servicing many different remote electrical needs. Thousands of residences - from full-time off-grid homes and vacation cabins to remote villages - are powered by a solar system. You may not realize that wireless solar electric systems provide the power to enhance cellular phone signals from remote mountain-top sites across the globe. Millions of gallons of water are moved daily by solar electric pumping systems. Recreational vehicles and pleasure boat owners, because of on-board solar electric systems, need not depend on utility hook-ups or unreliable generators for their safe passage.

In most remote locations on the globe, solar electric systems are working silently and reliably every day to protect pipelines from corrosion, monitor air quality, and accomplish many important jobs for industry. This Design Guide is intended to give you an overview of wireless solar electric systems. It explains how systems work, what the important components are, and how to choose the proper system for your needs.

This publication is used in conjunction with our "Solar Electric Products Catalog" to provide you with all the information you need to make an informed decision. If you intend to purchase a solar electric system, this guide will provide you with the information to ask the right questions and understand the operation of your proposed system. Included are worksheets so that you can calculate the size of your own system.

It is understood that when purchasing a solar electric system, you should work with an industry professional; a company that is knowledgeable in sales and service. Our network of Authorized Dealers can help you make the right choices to solve your energy problems.

How do Photovoltaics work?

We can easily explain how the Photovoltaic effect produces a flow of electrons. In short, electrons are excited by particles of light and find the attached electrical circuit the easiest path to travel from one side of the cell to the other. Envision a piece of metal such as the side panel of a car. As it sits in the sun the metal warms. This warming is caused by the exciting of electrons, bouncing back and forth creating friction and therefore heat. The solar cell merely takes a percentage of these electrons and directs them to flow in a path. This flow of electrons is, by definition, electricity.

Are Photovoltaics cost effective?

Yes, PV is cost effective in the right location. By this we mean where the extension of utility lines are a major factor. We use the figure of one-third of a mile as a rule of thumb for cost effectiveness, yet rates vary substantially from site to site. This third-of-a-mile figure is only a rule of thumb. If you haven't already, get a quote from your local power company.

If you are on utility power at present - PV is not a cost effective move. Utility power is much cheaper than PV power. Why? Because we have not yet begun to pay for the externalities of fossil fuel and nuclear generating plants. When this country begins to pay for the sulfur emissions which cause acid rain, global warming and nuclear waste disposal, to name a few, we will see power costs increase. With this in mind we need to ask and answer the question again. We believe, over the working life of a PV system, it can very well be a cost effective move. It all depends on the real price increases of utility power, 2, 5, 10 and more years from today.

Powering Your Heating Loads

Photovoltaic systems and the power they produce are best suited and most economical for operating motors, pumps, electronic equipment, lighting and the like.

PV's are not recommended to run your heating loads. Appliances such as toasters and microwaves are not a

problem because of the low running times. Yet electric ranges, water heaters or baseboard heaters simply require enormous amounts of power, and cannot be run by photovoltaics in an economically effective manner. To power these loads we recommend thermal solar systems for space and water heating. In cloudy weather; wood and gas, either natural or propane, run these appliances efficiently and economically. In many systems we recommend propane for cooking, water heating and sometimes refrigeration.

The Whole Home Approach

When considering energy efficiency it is important to consider the home as a system. Most loads are related to each other. For example: a well insulated house requires not only less heating and cooling but also less energy to distribute and circulate this conditioned air. Correctly placed windows not only heat the home, but can also contribute a great deal of natural light, thus reducing both heating and lighting requirements. The home that is designed from the ground up with energy efficiency in mind will require much less of a photovoltaic power system.

Trying to utilize photovoltaics to power the conventional American home with its conventional appliances can be an unnecessarily expensive project. Reflection on these costs has prompted most of our customers to look first to conservation to reduce their loads. This is a cost effective move even for those still on utility power. For those going with PV, it can mean a much smaller and less expensive system.

Most of the houses which we have powered with PV do not appear noticeably different from conventional houses in terms of comfort and convenience. Some people do decide to adapt their life style when producing their own energy, and most of these changes have to do with simply being more conscious of shutting off loads not in use. The largest change of being your own utility is the responsibility that this entails. Almost without exception, however, the increased independence that this decision brings is cited by PV home owners as a great source of satisfaction.

Solar vs. Wind vs. Hydro Power

How do PV' s compare to other alternative power sources?

Wind generating plants require a good steady wind at regular intervals over the four seasons. If you have a site where you have this resource, power production will not be a problem.

Hydroelectric generators are another option. These small generators require a healthy flow of water with good vertical drop throughout the year.

Two points to look at are the site specific nature of these power sources and the difference in moving parts. Solar electricity many times has the advantage with both factors, sunlight being fairly universal and PV' s having no moving parts to wear and eventually fail.

A combination of systems often work the best. Many times when the clouds reduce your solar output, wind or hydro systems are performing at full power.

Solar Water Heating

Different solar technologies are often confused. While the conversion of sunlight to electricity is photovoltaics, the collection of radiant energy to produce heat is Solar Thermal. We do not utilize photovoltaics to create heat as this is an unnecessarily complex, very indirect and inefficient way to do so. "Heating with electricity", as Amory Lovins has put it, "is like cutting butter with a chainsaw." The direct capture of solar radiation by heating a black collection surface, however, can be a very cost effective and efficient way to produce hot air or hot water.

We do not deal with solar thermal space heating. As sensible and efficient as this technology can be, it requires a good deal of on-site engineering and is the province of solar architects. Solar water heating for household uses can also be complex, but it can also be quite simple.

Electricity for Beginners

Electricity can be thought of as a flow of electrons through a conductor, generally wire. This flow is often compared to the flow of water through a pipe. In this analogy, if you wish to have increased flow through the pipeline, you will need either a bigger pipe or you will have to push the water (or electricity) through at a more rapid rate. To push water through a pipeline at high speed requires high pressure. Pressure in water is measured in p.s.i., pounds per square inch. You can envision water under high pressure squirting out very rapidly from a nozzle, such as a fire hose, with enough speed and force (power) to carry it to great heights or to

do the work of knocking someone off their feet if they get in the way. Similarly, the "pressure" of electron flow is called voltage and is measured in volts. Generally speaking, the higher the voltage of an electrical current, the more force behind it.

Many water towers are physically shaped like a mushroom. Electrically speaking, batteries are mushroom shaped as well. A tower designed to produce 50 p.s.i. for household pressure might be built like this. The amount of flow at a given pressure is determined by the size of the cross-section of the pipe. If you were to open a spigot twice as big as another with the water in both at the same pressure, twice the amount of water will flow from the larger. The amount of flow in electricity is called amperage or "current" and is measured in amperes, or "amps" for short.

Taking our analogy further, a battery stores electricity much as a water tower stores water. The taller this tower, the higher the pressure present at its base. If you open a valve at the base, water will flow out at a high pressure. In the same way, if you flip a switch connecting batteries to a load, electricity begins to flow. The higher the voltage of a battery bank, the greater the "pressure" of the electron flow. And just as with a tower of water, as electricity is drained from the battery, the pressure (voltage) slowly drops.

Most of the water available in such a tower is available from 45 to 60 p.s.i.. Once drained below 40 p.s.i., usage will rapidly deplete the supply at an ever decreasing pressure. In the same way, a nominal 12-volt battery has most of its stored electricity available from just below 12 volts to 12.6 volts. When drained below 12 volts, little amperage remains.

Just as a pump designed to fill such a tower would need to be able to produce at least 60 p.s.i. (that is, be able to lift 138 feet,) so does a solar PV module need to be able to produce at least 15 or 16 volts in order to charge a 12 volt battery.

Electrical power (the ability to do work) is a function of pressure (voltage) and amount (amperage). Double either one and you double the power the current is carrying through the circuit. The rule "VOLTS MULTIPLIED BY AMPERES EQUALS WATTS" defines this relationship. This is known as Ohm' s Law. The watt is the measure of the power of electricity and will be our basic unit of measure for determining the size of our electrical loads.

A one watt load that is powered for one hour will consume one watthour of power. A 100 watt load powered for 2 hours will consume 200 watthours. And so on.

A 100 watt load could consist of a 12 volt appliance drawing 8.3 amperes or it might consist of a 120 volt appliance drawing .83 amperes. If the 120 volt, 100 watt unit is run for one hour it will consume .83 amperehours. And so on.

Another unit of measure that you will come across is the kilowatt. A kilowatt is 1000 watts. A kilowatthour could result from a 100 watt load being powered for 10 hours or a 1000 watt load being powered for 1 hour.

NOTE: the terms 110 volt, 117 volt and 120 volt, all refer to the same common household AC current.

Planning and Sizing a Solar Electric System

In sizing a PV system the first two factors we work from are the sunlight levels or insolation values from your area and the daily power consumption of your electrical loads.

Insolation:

Insolation or sunlight intensity is measured in equivalent full sun hours. One hour of maximum, or 100% sunshine, received by a module equals one equivalent full sun hour. Even though the sun may be above the horizon, for example, 14 hours a day, this site may only receive six hours of equivalent full sun. Why? For two main reasons. One is reflection due to a high angle of the sun in relationship to your array. The second is also due to the high angle and the amount of the earth' s atmosphere the light is passing through. When the sun is straight overhead the light is passing through the least amount of atmosphere. Early or late in the day the sunlight is passing through much more of the atmosphere due to its position in the sky.

Sun trackers can help reduce reflectance but cannot help with the increased atmosphere in the sun' s path.

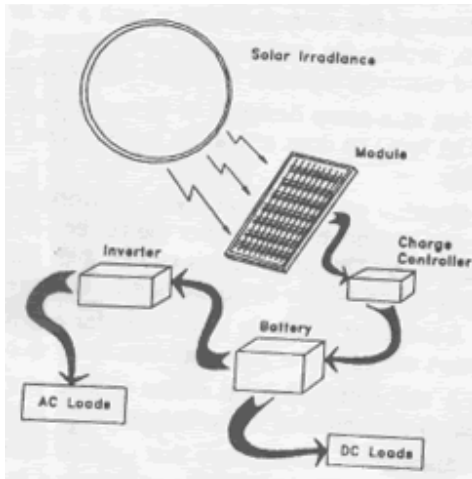
Because of these factors our most productive hours of sunlight are from 9:00 a.m. to 3:00 p.m. around solar noon. Before and after these times we are making power but at much lower levels. When we size solar modules, we take these equivalent full sun hour figures per day and average them over a given period.

We like to work with two figures here: average annual equivalent full sun hours and average winter equivalent full sun hours. In most locations in the United States winter yields the least sunlight because of shorter days and increased cloud cover, as well as the sun' s lower position in the sky.

Many solar sites are quite uncomplicated in terms of shading and aspect. You may already have a good idea of where the sun appears in the morning and disappears in the evening, as well as how low it swings in the winter sky. If your site is partially shaded, it may be necessary to determine exactly where the best placement of modules will be. We do have site analysis tools. If you need a more sophisticated site analysis, please contact us. We also have world-wide insolation data.

The Basic Idea Is Simple

Photovoltaic modules (solar panels) convert sunlight into electricity. Wire conducts the electricity to batteries where it is stored until needed. On the way to the batteries, the electrical current passes through a controller (regulator) which will shut off the flow when the batteries become full.



For some appliances, electricity can be used directly from the batteries. This is "direct current" and it powers "DC" appliances such as car headlights, flashlights, portable radios, etc. To run most appliances found in the home, however, we need to use "alternating current" or "AC", the type which is found in wall sockets. This we can produce utilizing an inverter which transforms DC electricity from the batteries into AC. The inverter' s AC output powers the circuit breaker box and the common outlets in your home.

Calculating Power Consumption

After determining the amount of solar radiation available, we must next determine the size of the load that we are supplying with power. The unit of measure for sizing is either watthours or amphours. We normally use watthours because it applies to both AC and DC circuits. The procedure is the same for all systems, regardless of whether the load is a telecommunications repeater or a house. What we need to end up with is a figure of the average daily watthours consumed. This will allow us to determine how many modules will be needed to produce the power and how many batteries will be needed to store the power.



Incorrectly assessing loads can end up being frustrating and expensive. Underestimating your loads can lead to major system inadequacies. Overestimating will lead to excess capacity. While many of our hybrid systems have a range of flexibility in providing power, some systems do not. But both problems can be avoided by careful assessment of loads.

We cannot overemphasize the importance of putting together the most accurate information you can. Without it we are only guessing.

YOU HAVE BEEN PROMOTED

You are no longer just a consumer. You now manage your own power plant and enjoy the benefits and responsibilities entailed. It is critical that you know where your power is going. It is important that you compile the best information you can for the design process. It is important that you understand the basic elements of how your system functions.

We are here as an information resource and as a backup should you need to troubleshoot a problem. You do not need to know all the electronic components that make up the internal workings of each controller or inverter. It is important that you are comfortable and knowledgeable with the day to day operation and maintenance requirements of your equipment, and that you rely upon yourself to ask us questions if there is something you do not understand.

Power Consumption Tables

These figures are approximate representations. The actual power consumption of your appliances may vary substantially from these figures. Check the power tags, or better yet, measure the ampere draw with an amp meter.

Multiply the hours used on the average day by the watts per hour listed below. This will give you the watt hours consumed per day, which you can then plug into the load calculation. We have approximated some of the duty cycle times (hours used each day) for a theoretical average household. Actual use varies a great deal from house to house, and even seasonally within the same home.

Remember that some items, such as garage door openers, are used only for a fraction of an hour or minute per day. A 300 watt item used for 5 minutes per day will only consume 25 watt hours per day.

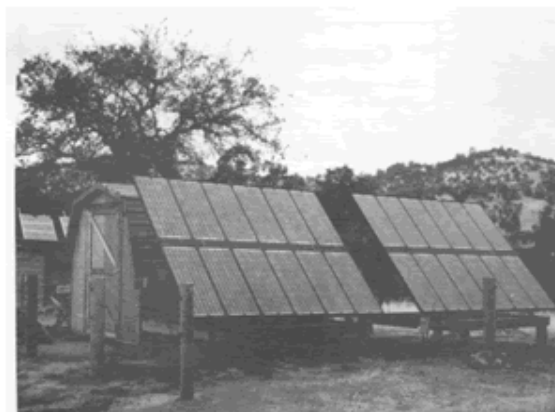
Where a range of numbers are given, the lower figure often denotes a technologically newer and more efficient model. The letters "NA" denote appliances which would normally be powered by non-electric sources in a PV powered home.

Appliance	Watts per Hour	Appliance	Watts per Hour
coffee pot	200	coffee maker	800
toaster	800-1500	blender	300
microwave	600-1500	waffle iron	1200
hot plate	1200	frying pan	1200
dishwasher	1200-1500	waste disposal	450
washing machine	500	vacuum cleaner	200
sewing machine	100	clothes dryer	4000 (NA)
portable heater	1500	furnace blower	300-1000
garage door opener	350	ceiling fan	10-50
electric blanket	200	blow dryer	1000
computer	20-50	printer	100
TV	100-150	VCR	40
stereo	10-30	regular light bulbs	50-100 each
refrigerator	500-1000	compact fluor. bulbs	10-30 each
high efficiency fridge	400-500	freezer	400-700

We strongly suggest that you invest in a multimeter if you are considering making your own power. Also helpful are clamp-on type amp-meters. It actually makes sense to know where your power is being used, even if you are not producing it, and if you are, these meters are essential diagnostic tools.

Considerations

Does it really cost more to purchase a generator that requires no refueling for 20 to 30 years or more, needs no maintenance and is as environmentally benign as a window in your home? Our customers have invested in PV for a diversity of reasons: economics of producing power in remote locations, security of home power supplies, taking a personal stand on environmentally threatening issues, or just to get away from the noise and inefficiency of a motor generator.



Your Electrical Inspector and PV

We have found that some electrical inspectors are not familiar with photovoltaics and the section of the National

Electrical Code which deals with it. For this reason we find it generally best for the system owner to communicate with your inspector early on in the process. You can install the system first and ask questions second, but the possibility of inconvenient and costly changes is very real. While we recommend following national code where applicable, local codes may vary; your inspector can tell you how they differ. Please remember that it is the inspector' s job to keep your wiring safe, now and for the future.

AC or DC

The AC versus DC debate goes back to at least the time of Mr. Edison and Mr. Westinghouse. High voltage AC has the advantage of being efficiently conducted over very long distances with relatively low transmission losses. AC has thus become the standard for industry and domestic usage.

DC is generally used in low voltages, where trans-mission efficiencies are low. In some cases however, DC does have the advantage of efficiency in operation; as much as twice that of AC for some applications. A disadvantage of DC is that many appliances and equip-ment in 12 Volt DC versions are hard to find and are expensive.

Both have their advantages. With water pumping systems, we generally use all DC. In home systems we typically run all or the majority of loads with AC power. For maximum efficiency certain specific loads can easily be powered by DC circuits. Cabins or RV' s use mostly DC and can use regular gauge wire because of small loads and short transmission distances.

How much room will the system require?

For a home system, a heated room in the utility area or near the circuit breaker box is normally utilized. The batteries are contained in an enclosure vented to the outside perhaps the size of a washing machine or, in a larger home, the size of a chest freezer. Controllers, meters and inverters are generally mounted on the wall in a space a couple feet square and may project out one foot.

Outside, the space required is dependent on the number of modules. A space the size of two or three 4X8 sheets of plywood will accommodate a medium household system.

Another option is to utilize a separate power house. This offers a safe, convenient space for electrical components, the genera-tor and possibly the mounting of the solar array.

System Components

Systems vary greatly due to variation in size and run times of differing loads. They can use as little as a single 5 watt module or hundreds of large modules. There really is no such thing as an "average" system, even within a single kind of use. However, the basic PV system can be divided into several major components. The following section lists these components and their functions.

Modules		generates electricity from sunlight	
Controller		regulates power to and from batteries	
Fusing/Breakers and Disconnects		overcurrent protection	
Combiner Box		enclosure for paralleling module output	
Batteries		stores electricity	
Monitors and Meters		reports system status and power flows both instantaneously and cumulatively	
Inverter		changes low voltage DC power to high voltage AC power	
Generator		provides backup AC power	
Battery Charger		converts AC(generator power) to DC	
Fixed Mount or Tracking Mounts		aims modules toward sun	
Powercenter		combines controllers, overcurrent protection and monitors	

Charge Controllers/Regulators

Why you need a controller

The main function of a controller or regulator is to fully charge a battery without permitting overcharge. If a solar array is connected to lead acid batteries with no overcharge protection, battery life will be compromised. Simple controllers contain a relay that opens the charging circuit, terminating the charge at a pre-set high voltage and, once a pre-set low voltage is reached, closes the circuit, allowing charging to continue. More sophisticated controllers have several stages and charging sequences to assure the battery is being fully charged. The first 70% to 80% of battery capacity is easily replaced. It is the last 20% to 30% that requires more attention and therefore more complexity.

How Controllers Work and Available Options

The circuitry in a controller reads the voltage of the batteries to determine the state of charge. Designs and circuits vary, but most controllers read voltage to reduce the amount of power flowing into the battery as the battery nears full charge. Features that can be included with controllers include:

- Reverse current leakage protection- by disconnecting the array or using a blocking diode to prevent current loss into the solar modules at night.
- Low-voltage load disconnect (LVD)- to reduce damage to batteries by avoiding deep discharge.
- System monitoring- analog or digital meters, indicator lights and/or warning alarms.
- Overcurrent protection- with fuses and/or circuit breakers

- Mounting options- flush mounting, wall mounting, indoor or outdoor enclosures
- System control- control of other components in the system; standby generator or auxiliary charging system, diverting array power once batteries are charged, transfer to secondary batteries.
- Load control- automatic control of secondary loads, or control of lights, water pumps or other loads with timers or switches
- Temperature compensation - utilized whenever batteries are placed in a non-climate controlled space. The charging voltage is adjusted to the temperature. Recommended on most systems.
- Central wiring- providing terminals to interconnect system wiring.

Some systems require all of these functions, others require only one or a certain combination. We can help you select a unit to meet your specific needs.

Sizing a Controller

Charge controllers are rated and sized to the systems they protect by the array current and voltage. Most common are 12, 24 and 48 volt controllers. Amperage ratings run from 1 amp to over 100.

For example, if one module in your 12 volt system produces 3.5 amps and four modules are utilized, we produce 14 amps of current at 12 volts. Because of light reflection and the edge of cloud effect, sporadically increased current levels are not uncommon. For this reason we increase the controller amperage by a minimum of 25% bringing our minimum controller amperage to 18.7. Looking through the products we find a 20 amp controller, as close a match as possible. There is no problem with going to a 30 amp or larger controller, besides possible additional cost. If you think the system may increase in size, additional amperage capacity at this time should be considered.

On small systems where a 10 watt or smaller module charges 100 amp hour battery or larger, no regulator is required. Typically this module to battery ratio cannot overcharge the battery.

Will a controller be included in my powercenter?

Yes, all powercenters include a solar charge controller. In fact, if you are building a system that utilizes an inverter, we recommend looking strongly at utilizing a powercenter. Why? Simply because they are typically more reliable, save time and money.

The controller, array and battery disconnects, monitoring and central wiring can all be handled with one enclosure instead of five or more.

Some owners prefer to purchase their system component by component, and others would rather buy the carburetor with the rest of the vehicle. Whatever your personal preference, we would like to work with you.

Pump or Motor Controllers

Different than the above battery charge controller, these units work in systems that directly link the solar module to a motor, no battery storage is utilized.

These controllers alter the incoming amperage and voltage to what is required by the motor. In low light conditions, modules produce little current yet relatively constant voltage. These motor controllers will reduce the voltage to increase the amperage, starting and running the motor in low light. The effect is an increased motor run time throughout the day, moving more air or water in a day than an array direct system with no controller.

System Voltage Selection 12, 24 or 48 volts?

The nominal voltage of your system is usually determined by the system size. Small to medium systems, where most loads are DC, or a few loads are AC through an inverter, lend themselves to 12 volts nicely. Many lights and small



appliances can be found at this voltage and efficiencies are high.

On the down side, 12 volt suffers from high line loss problems. The solar modules and loads cannot be far from the battery bank.

24 volt systems are suggested for medium to large systems. With 24 volts we have less wire loss problems and larger inverters are available.

24 volt DC appliances are more rare than 12 volt units. For this reason we lean heavily toward AC loads from these larger inverters. This simplifies wiring of the home to conventional AC wiring which exists in most homes and which any electrician can wire economically.

With the increased efficiency of AC lighting and the unlimited variety of low cost AC appliances, 24 volt systems, as well as 48 for large systems, have many advantages.

Solar Module Power Characteristics

The current and power output of photovoltaic modules are approximately proportional to sunlight intensity. At a given intensity, a module' s output current and operating voltage are determined by the characteristics of the load. If that load is a battery, the battery' s internal resistance will dictate the module' s operating voltage.

A module which is rated at 17 volts will put out less than its rated power when used in a battery system. This is because the working voltage will be between 12 and 15 volts. As wattage (power) is the product of volts times amps, the module output will be reduced.

For example: a 50 watt module working at 13.0 volts will produce 39.0 watts (13.0 volts x 3.0 amps = 39.0 watts).

This is important to remember when sizing a PV system.

An I-V curve as illustrated to the right is simply all of a module' s possible operating points (voltage/ current combinations) at a given cell temperature and light intensity. Increases in cell temperature increase current but decrease voltage.

Maximum power is derived at the knee of the curve. Check the amperage generated at your batteries operating voltages to better illustrate the actual power developed at your voltages and temperatures.

Mixing Sizes and Brands of Modules

In most cases mixing dissimilar modules in the same array is not a problem. When paralleling units of different amperage ratings, the output of the array will simply be the sum of the combined amperages. When paralleling units of different voltages, the lower voltage units will simply begin to taper off sooner as high battery voltage is reached. If used for array direct power, the array voltage will be the approximate average module voltage.

When series connecting strings of dissimilar modules, however, the amperage will be approximately that of the weakest module in the string. It pays then, to pay attention to matching the modules connected in series.

Shading

PV modules are very sensitive to shading. Unlike a solar thermal panel which can tolerate some shading, many brands of PV modules cannot even be shaded by the branch of a leafless tree.

Once a solar cell or a portion of a cell is shaded it becomes a load and draws power instead of producing it. Watch the amp meter of your system when a hand is passed over a module and you will see a substantial drop in output.

Some solar modules offer protection from partial shading. The advanced design of these modules include a diode between every cell, reducing partial shading problems.

Ask us for more information if shade protection is needed.

Another rule of thumb - make sure no shading occurs between 9:00 a.m. and 3:00 p.m. around solar noon. Shading early or late is not much of a problem because these are low power producing hours anyway.

Reverse current protection

PV modules will leak power back from your batteries during no sun periods if not protected. This leakage is very small but over long, no-sun periods, this loss can accumulate. To prevent this we install a diode or protecting circuitry in the controller.

All controllers that we sell have reverse leakage protection. The circuit opens over periods of no sun, allowing the charging circuit to stop any reverse flow. A diode can also be used. This unit acts as a one way check valve-letting power flow in one direction to the batteries but not back to the PV module.

Module Mounting

Solar modules perform best when perpendicular to the sun's rays. Because tracking the sun is not always possible, we typically mount the modules facing due south.

A common question is the effectiveness of facing one module to the southeast, one due south and another southwest. While this may sound like a good idea, it is not. All modules facing due south will net the largest amount of power of any other arrangement second only to a sun tracker. Remember that the true south and magnetic south vary upon your site's declination. Call your local airport or us if you do not have this figure.

Tilt angle

Because the sun's position in the sky varies through the year (higher in summer and lower in winter), it's a good idea to provide for seasonal adjustment. The rule of thumb goes: latitude plus 15 degrees angle in winter and latitude minus 15 degrees in summer. Your latitude can be found on any good map of your area.

If you wish to permanently mount the modules and not seasonally adjust the structure, fix your mount at a winter (minimal sun period) angle. This is when sunlight is limited, days are shorter and you want the system maximizing the available power. We offer a wide variety of mounts both fixed and tracking.

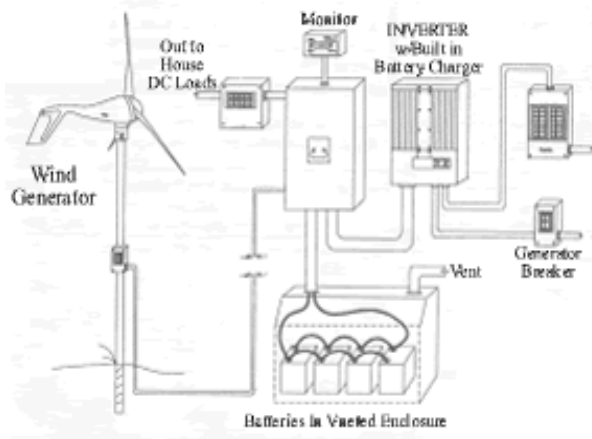


To Track the Sun ... or Not To Track...

Trackers are used to increase the daily output of PV modules by keeping them faced as directly as possible toward the sun. The sun sees a wider surface, and the increased reflectivity that occurs at low angles of incidence is avoided. During the long days of summer when the sun is rising north of east and setting north of west, a tracker can increase the daily output of modules by 25 to 40 percent (we can help determine what you can expect). During the winter when the sun takes a low, short arc above the horizon, the tracker will contribute much less, perhaps 10 to 15 percent.

The output of a tracker remains much more constant throughout the year in tropical climates. We generally recommend trackers for spring, summer and fall applications, such as water pumping for livestock summer pasture or small scale irrigation. For home power systems, we often do not recommend them because a household's power requirements are generally greatest in the winter just when the efficiency of the tracker is least. It often is a better choice to use a less expensive static mount and put the money into extra modules. In tropical and subtropical regions with less seasonal variation of sun and loads a tracker can make sense for a home system.

When calculating aiming error, rule of thumb is that a 10 degree aiming error will result in a loss of 2% of the solar module output, 20 degree-6%, 30 degree-14%, 40 degree-22%, 50 degree-35%, 60 degree-50%.



Is Wind Generation for you?

Electricity produced by wind generation can be used directly, as in water pumping applications, or it can be stored in batteries for household usage. Wind generators can be used alone, or they may be used as part of a hybrid system, in which their output is combined with that of photovoltaics, and/or a fossil fuel generator. Hybrid systems are especially useful for winter backup of home systems where cloudy weather and windy conditions occur simultaneously.

The most important decision when considering wind power is determining whether or not your chosen site has enough wind to generate the power for your needs, whether it is available consistently, and if it is available in the season that you need it.

The power available from the wind varies as the cube of the wind speed. If the wind speed doubles, the power of the wind (the ability to do work) increases 8 times. For example, a 10 mile per hour wind has one eighth the power of a 20 mile per hour wind. ($10 \times 10 \times 10 = 1000$ versus $20 \times 20 \times 20 = 8000$).

One of the effects of the cube rule is that a site which has an average wind speed reflecting wide swings from very low to very high velocity may have twice or more the energy potential of a site with the same average wind speed which experiences little variation. This is because the occasional high wind packs a lot of power into a short period of time. Of course, it is important that this occasional high wind come often enough to keep your batteries charged. If you are trying to provide smaller amounts of power consistently, you should use a generator that operates effectively at slower wind velocities.

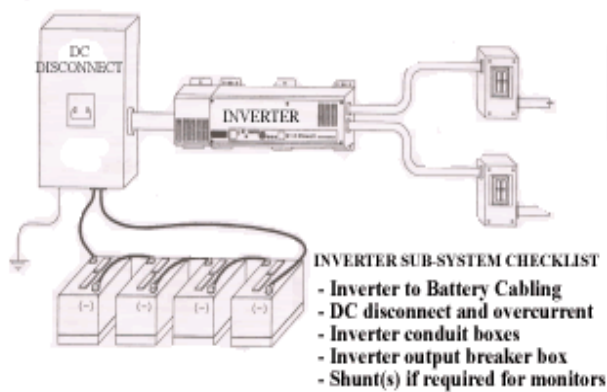
Wind speed data is often available from local weather stations or airports, as well as the US Dept. of Commerce, National Climatic Center in Asheville, N.C. You can also do your own site analysis with an anemometer or totalizer and careful observation.

Installation of generators should be close to the battery bank to minimize line loss, and 20 feet higher than obstructions within 500 feet. The tower should be well grounded.

An Introduction To Inverters

The inverter is a basic component on medium to large systems which converts low voltage DC power from the batteries into high voltage (usually 120 or 240) AC power as needed.

Inverters of the past were inefficient and unreliable.



Today's generation of inverters are very efficient (85 to 94%) and very reliable.

Today, the majority, if not all of the loads in a typical remote home operate at 120 VAC from the inverter. The only reason to operate select loads at low voltage DC is to maximize efficiency.

Most inverters we sell produce only 120 VAC, not 120/240 VAC as in the typical utility-connected home. The reason being, once electrical heating appliances are replaced with gas appliances, there is little need for 240 VAC power. Exceptions include good-sized submersible pumps and shop tools which can either be powered by the generator, step-up transformer, or possibly justify the cost of a larger or second inverter.

Two types of inverters predominate the market - modified sine and sinewave inverters.

Modified sinewave units are less expensive per watt of power and do a good job of operating all but the most delicate appliances. Sinewave units produce power which is almost identical to the utility grid, will operate any appliance within their power range, and cost more per watt of output.

Inverter Component Checklist

While an inverter is a good portion of the cost of a system, it is really a sub-system that includes a number of additional components. To make a safe, reliable installation one should provide the following:

Inverter to battery cabling. Because of the high current required on low voltage circuits, this cable is large, commonly #2 to 4/0 in size. Smaller conductors than required are unsafe and will not allow the inverter to perform to its full rating.

DC input disconnect and overcurrent protection: It is important to have a safe installation with a properly sized DC rated, UL listed disconnect. Typically the disconnect works in conjunction with an overcurrent protection device such as a fuse or breaker. These components are installed in an enclosure which can also house shunts.

Shunts - Used to read the amperage flowing between the battery and inverter, this device is installed in the negative conductor. It can easily be housed in the disconnect or its own enclosure.

AC output disconnect and overcurrent protection: If the breaker panel, which is fed from the inverter, is adjacent to the inverter, then the main breaker will serve as the inverter output disconnect and overcurrent protection. If, however, this panel is not grouped with the inverter, then a separate unit should be installed. This also holds true with AC circuits coming to the inverter from a generator or utility source. A second breaker may be needed if these breakers are not grouped.

Inverters with Built-in Battery Chargers

Many of today' s inverters incorporate battery charging circuitry. This is easily and economically accomplished because of the design of most inverters. Inverters step up low voltage and change DC power to AC power. Battery chargers do the reverse of this. Additional circuitry is all that is required to add a whole second function and economically create an Inverter/Charger.

Transfer switches are also incorporated into these Inverter/Chargers so that the AC loads can be powered directly from the generator when the battery charger is operating.

From a reliability, performance, and economical standpoint, built-in battery chargers are the way to go.

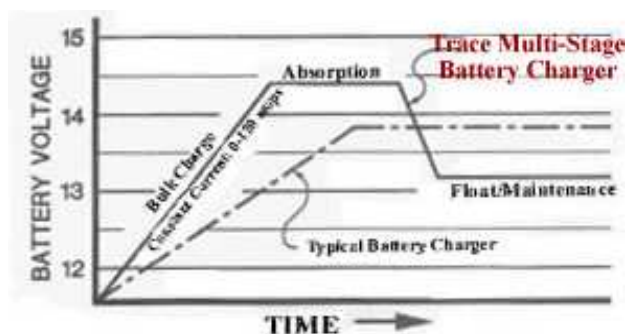
Comparing Inverters

Inverters are compared by three factors:

Continuous wattage rating: Hour after hour, what amount of power in watts can the inverter deliver.

Surge Power: How much power and for how long can an inverter deliver the power needed to start motors and other loads.

Efficiency: How efficient is the inverter at low, medium and high power draws. How much power is used at idle.



Multi-Stage Battery Charging

A typical 12 volt lead-acid battery must be taken to approximately 14.2-14.4 VDC before it is fully charged. (For 24 volt systems double these figures.) If taken to a lesser voltage level, some of the sulfate deposits that form during discharge will remain on the plates.

Over time, these deposits will cause a 200 amp-hour battery to act more like a 100 amp-hour battery, and battery life will be considerably shortened. Once fully charged, batteries should be held at a considerably lower voltage to maintain their charge typically 13.2 to 13.4 volts. Higher voltage levels will "gas" the battery and boil off electrolyte, again shortening battery life.

Most battery charger designs cannot deal with the conflicting voltage requirements of the initial "bulk charge" and subsequent "float" or maintenance stage. These designs can accommodate only one charge voltage, and therefore must use a compromise setting - typically 13.8 volts. The result is a slow incomplete charge, sulfate deposit build-up, excessive gassing and reduced battery life.

The charger available in our inverters automatically cycles batteries through a proper multi-stage sequence to assure a rapid and complete charge without excessive gassing.

Factory battery charger settings on our inverter-charger combinations are optimal for a lead acid (liquid electrolyte) battery bank of 250-300 amp hours in a 60° F environment. If your installation varies from these conditions, you will obtain better performance from your batteries if you adjust the control settings.

The Maximum Charge Rate in amps should be set to 20-25% of the total amp-hour rating of a liquid electrolyte battery bank. For example, a 400 amp-hour bank should be charged at no more than a 80-100 amp rate. Excessive charge rates can damage batteries and create a safety hazard.

The Bulk Charge Voltage of typical liquid electrolyte batteries should be about 14.4 VDC; gel cells like the Deka about 14.1 VDC. There is no one correct voltage for all types of batteries. Incorrect voltages will limit battery performance and useful life. Check your battery maker's recommendations.

The Return Amps setting controls how long the batteries will be held at the bulk charge voltage before dropping to the float/maintenance level. A good setting is 2-4% of the amp hour capacity of a liquid electrolyte battery bank. A fixed, "one-size-fits-all" setting will overcharge a large battery bank (gassing the batteries) and undercharge a small bank (limiting battery performance).

The Float Voltage setting should hold the batteries at a level high enough to maintain a full charge, but not so high as to cause excessive "gassing" which will "boil off" electrolyte. For a 12 volt liquid electrolyte battery at rest, a float voltage of 13.2-13.4 is normally appropriate; gel cells are typically maintained between 13.5 and 13.8. If the batteries are being used while in the float stage, slightly higher settings may be required.

Charge voltage guidelines used here are based on ambient temperatures of 60° F. If your batteries are not in a 60° F environment, the guidelines are not valid. Temperature Compensation allows easy single dial re-scale of the voltage settings to compensate for the differences between ambient temperature and the 60° F baseline. Temperature compensation is important for all battery types, but particularly gel cell, valve-regulated types which are more sensitive to temperature.



Batteries - The Heart of the System

A Solar Electric system is made up of a number of components, and of these, none needs as much attention as the batteries. Though the idea and usage of a battery bank is very simple, if batteries are neglected, degradation can occur at a fast pace. As someone in the industry once put it, "few batteries die a natural death, most are murdered".

The following information is designed to tell you how to get the longest life possible from your battery bank. (This is strictly flooded cell lead-acid battery information; for Alkaline and gel-cell batteries many of these needs and characteristics are completely different.)

Cycling -Deep versus Shallow

A cycle in the battery world occurs when you discharge a battery and then charge the battery back again to the same level. The battery is designed to absorb and give up electricity by a reversible electrochemical reaction. How deep a battery is discharged is termed depth of discharge. A shallow cycle occurs when the top 20% or less of the battery's power is discharged and then recharged. Some batteries, like automotive starting batteries, are designed for this type of cycling only. The plates of active material are thin with large overall surface area. This design can give up lots of power in a very short time.

The second type of cycle is a deep cycle where up to 80% of the battery capacity is discharged and recharged. Batteries designed for deep cycling are built with thicker plates of active material which have less overall surface area. Because of the lessened availability of surface area for chemical reaction, these batteries yield just as much power relative to their size, but do so over a longer period of time. This type of battery design is preferred for a PV system because discharging a battery to a deeper level is normal during extended cloudy weather.

The depth of cycling has a good deal to do with determining a battery's useful life. Even batteries designed for deep cycling are "used up" faster as the depth of discharge is increased. It is common practice for a system to be designed with deep cycle batteries even though the daily or average discharging amounts to a relatively shallow depth of discharge. Shallow cycle your deep cycle battery for the most cycles.

Temperature Effects

The speed of the chemical reaction occurring in a lead-acid battery is determined by temperature. The colder the temperature the slower the reaction. The warmer the temperature the faster the reaction and the more quickly the charge can be drawn from the battery.

The optimum operating temperature for a lead-acid battery is around 77 degrees Fahrenheit. You may have experienced this effect when starting a car on a cold morning; the engine just doesn't turn over as quickly. Warm that same battery and you will see a major improvement. For this reason we like to see batteries placed indoors or in a heated and ventilated space to maintain them between 55 and 80 degrees. If we do install them in a unheated space, battery capacity must be increased to compensate for this derating. High temperatures can drastically shorten the life of the battery and should be avoided.

Self Discharge

Due to impurities in the chemicals used for battery construction, batteries will lose power to local action, an internal reaction which occurs whether we are using the battery or not.

This slow discharging is termed self-discharge. Self-discharge rates vary greatly among battery types and varies with temperature. The rate also increases with the age of a battery, so much so that an old battery may require a significant amount of charging just to stay even. Even new batteries may lose 1 to 2% of charge per day. Lead calcium grid batteries have the lowest self-discharge rates.

Battery Power Conversion Efficiency

Energy is never consumed or produced, it merely changes form. The efficiency of conversion is never 100% and in the case of new batteries ranges from 80 to 90%.

This means that to discharge 100 watts of power from a battery it must be charged with 110 to 120 watts of power.

Determining Battery State of Charge

Battery state of charge is determined by reading either terminal voltage or the specific gravity of the electrolyte.

The density or specific gravity of the sulfuric acid electrolyte of a lead-acid battery varies with the state of charge. The density is lower when the battery is discharged and higher as the cells are charged. See the table to the left; this is because the electrolyte is part of the chemical reaction, it changes as the chemical reaction takes place. Specific gravity is read with a hydrometer. A hydrometer reading will tell the exact state of charge. A hydrometer cannot be used with sealed or gel-cell batteries.

Another important point is freezing. At low densities, the electrolyte contains enough water that the battery can freeze. This is not a problem with PV systems where the batteries are kept both warm and charged. Batteries can survive and operate in a cold location, but the charge level should not be so low that it could freeze.

Battery Voltage

Voltage meters are used to indicate battery state of charge. They are relatively inexpensive and easy to use. The main problem with relying on voltage reading is the high degree of battery voltage variation through the working day. Battery voltage reacts highly to charging and discharging. In a PV system we are usually charging or discharging and many times are doing both at the same time. As a battery is charged the indicated voltage increases and as discharging occurs, the indicated voltage decreases.

These variations may seem hard to track, yet in reality they are not. A good accurate digital meter with a tenth of a volt calibration can be used with success. The pushing and pulling of voltage, once accounted for by experience, can also help indicate the amount of charging or discharging that is taking place.

By comparing voltage readings to hydrometer readings and shutting off various charging sources and loads and watching the resulting voltage changes, the system owner can learn to use indicated voltage readings with good results.

Specific gravity values can vary + or -.015 points of the specified values. This table is for the Trojan L-16 battery in a static condition, no charging or discharging occurring, at 77 degrees F. Discharging or charging will vary these voltages substantially. *Source - Trojan Battery Company.*

Monitoring and Maintenance

Monitoring battery state of charge is the single largest responsibility of the system owner. The battery voltage should be kept at or above a 50% state of charge for maximum battery life. See the battery voltage table.

Keep the battery's electrolyte level to the indicated level and never let the plates be exposed above the electrolyte. Use only distilled water - not tap water, when refilling the batteries. Water is the only element used by your battery. You should never have to add acid to your battery. Do not over-fill the batteries or fill when the batteries are discharged. Over-watering dilutes the acid excessively and electrolyte will be expelled when charging.

Gassing

As batteries are charged they create bubbles of gas, produced when the chemical reaction can not keep up with the energy input. Some gassing is necessary in flooded cell batteries. The amount and duration of gassing varies from one battery to another. Gassing mixes the electrolyte and compensates for the tendency of the acid to stratify with the most dense electrolyte on the bottom. Gassing is the product of splitting water molecules into hydrogen and oxygen. This consumes water and creates the need for its periodic replacement.

Corrosion

A slight acid mist is formed as the electrolyte bubbles upon charging. This mist is highly corrosive, especially to the metallic connectors on the tops of the batteries. Inspect for corrosion and clean these periodically as needed with baking soda and water. Corrosion building can create a good deal of electrical resistance, which contributes to shortened battery life and the waste of power. It's always a good idea to wear goggles and protective gear as the sulfuric acid will eat holes in your clothes.

Equalization

Equalization is the controlled overcharging of a fully charged battery. This overcharge mixes the electrolyte, evens the charge among varying battery cells and reduces permanent sulfation of the battery plates. It is energy invested in lengthening the life of the battery. Though the PV system battery bank receives a good cycling and gassing through normal activity, we believe that equalization is a complement to this activity and as a rule of should be done every 60 to 90 days.

The equalization process consumes water and produces much gassing. Make sure your batteries are well ventilated during overcharging. Equalization charging voltages vary widely, as do duration times, so the batteries should be monitored closely during this process. Check specific gravities of all your cells at the start, noting any low cells. Check periodically during the process. You don't have to check every cell each time, but watch any that show a higher variation. Keep checking electrolyte densities until you receive three readings of 30 minutes apart which indicate no further increase of specific gravity values. Keep a record of individual cell voltages and specific gravity before and after equalizing. Equalization will take your voltage to 15 volts or higher (30 volts on a 24 volt system) so make sure any DC loads are disconnected before you begin.

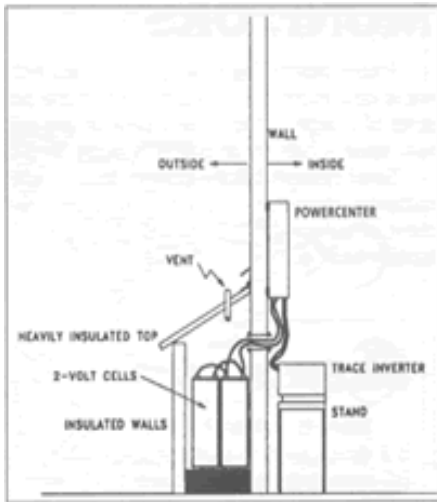
Battery Connections

The connections from battery to battery and on to the charging and load circuits are critical. Terminals should be greased, interconnects should be clean and fastening hardware should be tight. Torquing bolts equally avoids variations in resistance. This is also the reason we prefer to minimize the number of parallel strings in the bank. Higher resistance values on one string of batteries results in less charge to that string and consequently shorter life. We also place the main negative and positive on opposing corners of the battery bank for this reason. The to keep the variation of resistance one cell to another to a minimum.

Note: "Cold cranking amps" is not a usable measure of total amperage capacity of a deep cycle battery. It instead measures the high rate (30 seconds) discharge ability of a battery at zero degrees Fahrenheit. For almost all photovoltaic systems, these conditions are very abnormal.

Battery Enclosures

Install your batteries in a warm, dry location. 55-80 degrees F. is the optimum temperature range; lower or higher than this and performance diminishes significantly.



Because batteries produce a potentially explosive mixture of hydrogen and oxygen, venting is needed to prevent a buildup. Since hydrogen is lighter than air it has a tendency to rise. If venting is placed at the top of the battery enclosure and air is brought in from the bottom, this gas will move up and out of the battery area. When possible, power venting of the battery enclosure to the outside is a wise move.

Also remember that most basements will draw air, not expel air, if not power vented.

Pre-built battery enclosures are used in remote lighting systems or anywhere a battery bank is installed where protection from tampering and weather is required. Large home battery bank enclosures are typically custom built. Banks of one to four batteries for water pumps, automatic lighting, telemetry or radio equipment are often installed in one of our off-the-shelf enclosures. These enclosures can be mounted on the ground or up on a pole behind the array to provide a higher degree of protection from vandals.

Another option here is to place the batteries out-of-doors in a heated outbuilding. You can also place the batteries on the outside of an exterior wall with the control and power conditioning directly through the wall indoors.

Keeping the batteries simultaneously warm and adequately vented can be challenging, yet with proper planning is not that difficult.

Overcurrent Protection

Batteries have the potential to discharge incredible amounts of power over a very short period of time, melting conductors and possibly starting a fire.

This is why we spend so much time and energy on overcurrent protection. It is not so much the PV module that we need to protect against, but the batteries. PV modules are current limited which reduces the danger, yet modules and their conductors also require protection. The idea of a fuse or breaker is to include a "weak link" in each circuit which will open if the current exceeds that which the conductor can safely handle.

In a typical PV system, we deal with both AC and DC power. Standard components purchased at building supply stores are typically rated for AC use. These are fine for inverter output circuit protection.

DC overcurrent devices required between the battery, inverter, controller and modules are much more specialized. They are generally heavier duty and more costly.

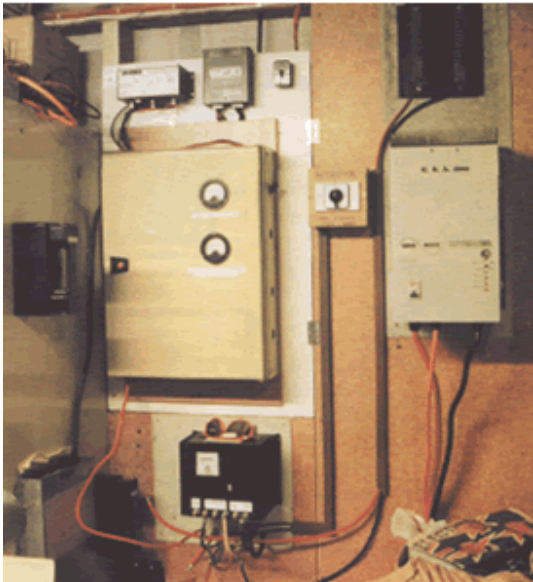
Of primary importance is to place a current limiting fuse and disconnect on the main battery conductor and assure that all components on the DC side are rated for DC use.

If you are installing your own system, please obtain a copy of the National Electric Code, work with your inspector and be safe. We offer and suggest the publication, "PV Power Systems and the N.E.C. Suggested Practices," free to anyone who is interested.

Used Batteries

Used lead acid batteries, especially large two volt telephone type cells can sometimes be found for sale. While used solar modules and inverters are usually an acceptable risk, used batteries are a high risk proposition. Should you consider them? In our experience, it is difficult to know just how an older battery has been used. Has the previous user taken good care of the cells or have they been neglected? Have they actually been load tested or just cleaned up and recharged? Our recommendation is to get as much information as you can on the cells, and load test them, or ask the seller for a load test. Without this test your are really guessing as to the remaining life.

If you are considering telephone cells, realize that they are normally shallow cycle lead calcium grid construction, and should not be used in a system designed for deep cycle use.

**MONITORS**

Proper monitoring of a system should not be overlooked. Typically we want to know how much power is coming into the system from its charging sources and the state of charge of the battery bank at any point in time. A third and equally important value is how much power is being used by the systems loads.

Small systems usually monitor state of charge, or battery voltage and possibly incoming amperage. Medium and larger sized systems typically require a measurement of outgoing power as well, so one can keep track and not over discharge the battery bank.

Instantaneous and Cumulative Information

Common meters report current flow or battery state of charge (voltage) at a single point in time - the present. This type of metering is termed instantaneous. Devices which report instantaneous information are less complex and less expensive and can give a general idea of what' s happening. Several of the Controller/Regulator units

we sell combine metering functions for reduced costs. When reading battery voltage one must fully understand the pushing and pulling effects of battery voltage to use this type of monitoring. (See Battery section).

Cumulative type monitors usually include instantaneous information, but go a step further by recording the power over time. With this information, termed amp hours or watt hours, we can see just how much power we generated yesterday or last month, and how much power was consumed, and with much greater accuracy, determine battery state of charge.

Which ever monitor you select, make sure you have a window, so to speak, of the information you require; without it, you are only guessing and guessing is a common killer of batteries.

Lightning Protection

Lightning presents a potential hazard for systems with exposed conductors and aluminum framing mounted on rooftops or adjacent to a building. Direct and close-in strikes can damage sensitive electronic circuitry through the presence of static charges and electromagnetic fields. These forces can induce voltage surges and may damage the system' s wiring and components, particularly if your system is not properly grounded and protected.

While no lightning protection system is foolproof, practical counter-measures are available and include a lightning rod at the PV source, adequate system grounding, and surge protection on the incoming DC wires and the secondary AC wiring.

Shunts

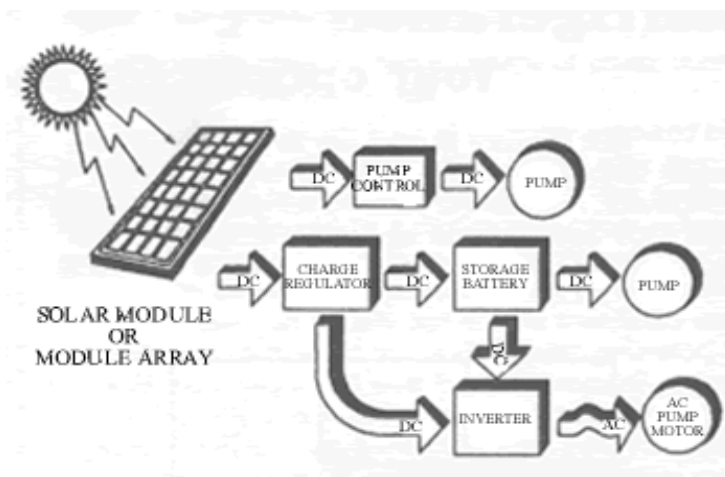
What is a shunt? A shunt is a device used to measure large DC current, typically the current flowing to and from your battery bank. In more detail a shunt is a precision resistor which produces a very accurate voltage drop when current is passed through the unit. This voltage drop is proportional to the amount of amperage flow, therefore by reading the millivoltage one can observe current flow on a properly calibrated meter.

Do you need a shunt? Depending upon the monitor you select, you may! Small meters with low currents may contain their own shunt, usually those less than 30 amps.

Larger and more complex monitors usually require an external shunt. While some units include a shunt, some do not.

Where is a shunt installed? In the main negative conductor from the battery bank. The shunt is placed close to the battery, bank, typically, in the disconnect enclosure for convenience. Since the shunt produces a voltage drop in millivolts we can run this circuit for a good distance with very small conductors. The monitor can be in the battery room or a good distance away.

Sizing? A 1 to 1 shunt produces 1 millivolt drop per 1 amp of current, therefore 100 mv -100 amp shunt would read 100 amps at 100 millivolts. A 10 to 1 shunt such as a 50 mv - 500 amp shunt offers less resistance and drops only 50 mv with 500 amps of current. Select a shunt for the maximum sustained current of which you will draw. This is usually determined by the inverter size.



Water Pumping with Solar Electricity

Pumping water with power from the sun is a natural. As the diagram on the right indicates, there are a number of ways to design solar pumping systems. For the remote home owner who utilizes a battery bank, pump types are less varied.

The two major water systems for domestic use divide by water source. If your water source is shallow (less than 15' vertical) from your pump location, a shallow well or surface pump will suffice. These pumps are less expensive, operate at low voltage DC and are of positive displacement design which increases overall system efficiency.

If your water source is a deep well, then a submersible pump is typically the answer. We offer the complete line of solar powered SolarJack DC submersibles, and AC submersibles that operate directly from inverters.

A typical water delivery system may contain one module to hundreds of modules that deliver current to pumping equipment. For continuous pumping, battery storage may be added, but for most applications a battery is not required since solar systems deliver the most water when the sun is brightest.

With both of these systems you need to provide pressure to charge your pressure/storage tank as well as bring the water into the house. This requires a pressure switch to automatically turn your pump on and off as water is needed. Another way to create pressure is to pump the water from the water source up to a tank substantially higher than the home. To produce 40 lbs. of pressure, the holding tank would need to be 92 feet above the highest outlet in the house. If this resource is available - great, but installing a gravity system can easily far

exceed the cost of a pressure tank and switch.



AC Submersible Pumps

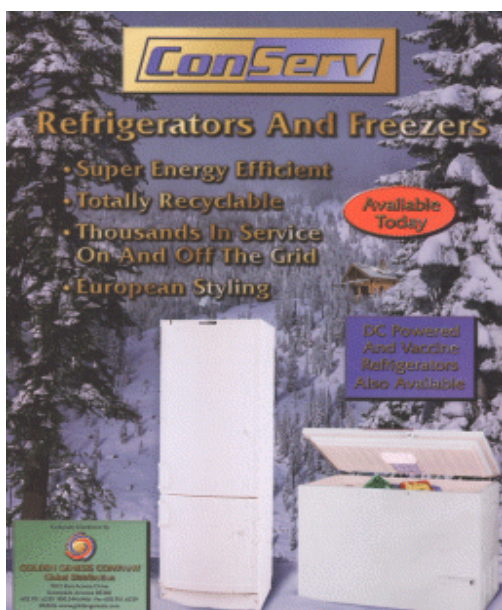
In home systems where a battery bank and an inverter are planned or in place, an AC 117 VAC submersible pump is a good option. Especially where wells are 20 ft. deep or more. These centrifugal pumps provide excellent reliability and long life. These units provide a substantial volume of water per minute and are therefore operated for a short time per day. The size and type of inverter is critical here. water pump and washing machine are usually operated together and both require surge ability from your inverter and batteries.

For livestock or small scale irrigation pumping systems, please request our 20 page Water Pumping Catalog.

Refrigeration

Your options for energy efficient refrigeration:
Next to space heating and air conditioning, the largest single energy user in your home is the kitchen refrigerator.

A typical AC powered refrigerator uses more than 3500 watt hours per day. If this refrigerator is run by a solar electric system whose DC power is inverted to AC by an efficient inverter, then the refrigerator/freezer alone will consume more power than 10 (50 watt) solar electric modules can produce per day. This could be a



very expensive way to provide refrigeration.

However, there are three good refrigerator options available for the off-grid, solar-powered residence; gas powered refrigerators, DC refrigerators and ultra-efficient, AC refrigerators.

Gas powered, absorption, refrigerator/ freezers are the most common solution for off grid refrigeration. In use in thousands of full time homes and vacation cabins, the propane-fueled refrigerator/freezer units are very reliable and efficient - typically using less than three gallons of fuel per week. Since they don't use electricity, your residential solar electric system can be smaller and less costly. Today's absorption refrigerator/ freezers are very quiet and safe. The only drawback to these units is that they are smaller than a traditional home refrigerator. The average gas refrigerator is 8 cubic ft. - approximately 1.5 cu. ft. of freezer and 6+ cu. ft. of refrigerator. If the doors are reversible (such as on a Norcold) then two units can be placed side by side to provide 16 cu. ft. of refrigerator/freezer space.

Another traditional refrigerator solution is the DC refrigerator. These units are the most efficient, electric-powered refrigerator/freezers available. A 16 cu. ft. unit, in a temperate climate, uses less than 800 watt hrs. per day (the power typically produced by four, 50 watt solar electric modules). Many energy saving features are built into each DC refrigerator such as extra insulation, conr pressors located on the top of unit to avoid heating the cabinet if located below, and separate freezer doors.

These reliable units are more expensive than the other options because they are hand built in small factories. The higher initial cost, however, is off-set by the savings in solar system componentry and life-time fuel cost.

The final option is a relatively recent alternative; the ultra efficient AC refrigerator. These units, though using more power than DC units, can still be comfortably run by a solar electric system. A typical 16 cubic ft. refrigerate freezer uses 1500 watt hrs. per day (using approximately the power of six to eight 50 watt modules, in a temperate climate). Usually they are very moderately priced anf feature feature amenities not offered in the other alternatives such as: fresh food section located above freezer section, many compartments and shelves, double door layers in freezer section and fast-freeze options.

Ultra efficient AC chest type freezers are also available. These very affordable units only use 500 watt hrs electricity per day (roughly the power produced by two three solar electric modules).

Though requiring a little more forethought than just going down to the local appliance store and picking out refrigerator/freezer that matches your kitchen, today's efficient refrigerator options are affordable, reliable, aesthetically pleasing and most importantly, work well with solar electric power.



Backup Generators, for PV Systems

We typically use generators as a supplement to photovoltaic power. There are some very large applications for which continuous-use generators may prove more cost-effective than a PV system, but in almost all of the applications with which we work, the economics of generators are maximized by restricting them to providing backup power. Generators are used for backup in situations where seasonal variability of insolation is substantial as in cloudy climates, or for systems where occasional very large loads are powered, as for intermittent use of large shop tools or a deep well pump in a residence.

We typically design residential PV systems to provide 80 to 90 percent of the home' s annual electrical power. The last 10 to 20 percent is more economically supplied by a generator.

The reason for this is simply economics. In many cases we would double the cost of the system to provide this last 10 to 20 percent of annual power. It is much more cost effective to employ a backup source of power during the least sunny time of the year.

The cost per kilowatt hour of electricity produced by a generator used in conjunction with a battery bank and inverter is much cheaper for residential type load profiles than is power produced by a continuously running generator. This is because engine driven generators perform poorly when under loaded. Low-load hours on the engine, especially diesel, can actually age it more than hours under full load. Fuel costs suffer too. A 6500 watt generator, for example, powering a 100 watt load will consume perhaps 50% as much fuel as it would consume if operating at full capacity. Therefore, work the generator near its capacity for shorter periods and then shut it down. Batteries can be charged while washing machines, pumps or other large loads are running. This maximizes efficiency while reducing generator run time, wear, and fuel costs.

Generators and Battery Charging

Battery chargers take the 120 volt AC power from the generator and convert this power to low voltage DC. They are typically the largest consumer of the generator' s output.

Many of today' s inverters incorporate a battery charger and transfer switch as optional or even standard equipment. These chargers are powerful charging the batteries at a high rate and requiring a good sized generator to power them. We recommend a generator of at least 4 to 5 kw in size for full time remote homes. Remember that these inverter/ chargers also include an automatic transfer switch. This switch selects among the two sources of AC power to be delivered to the loads - inverter or generator power. The switch is biased to inverter power which is supplied to the loads whenever the generator is off. Once the generator is staged, the switch senses the presence of generator voltage. It waits a predetermined "warm-up" period then switches over, allowing generator power to flow to the loads.

The generator power is now running all loads in the house as well as powering the battery charger. Therefore the generator should be sized to not only run the battery charger at a high rate, but also any AC loads that may be running at the same time.

If the generator is undersized for the loads being run, the battery charging rate will be reduced. This may mean the generator is run for a very long time to fully charge the batteries. So how do you avoid this problem that many have experienced? Simply select a good-sized battery charger and generator when designing your system. This is not the place to cut the budget, as generator fuel can cost you dearly.

Generator Placement and Powersheds

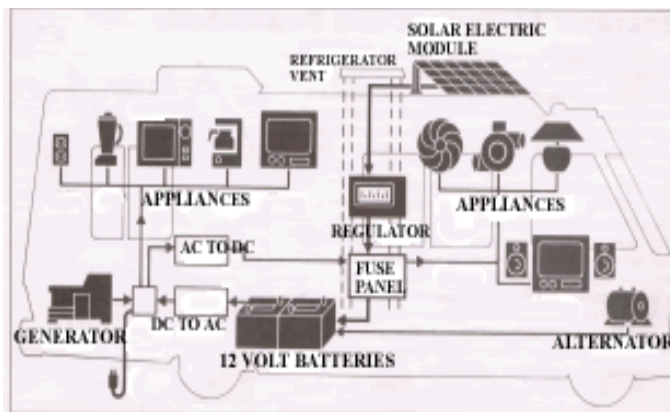
Powersheds are a common outbuilding on the remote homestead. They often serve multiple functions of housing the generator, batteries and power conditioning equipment required with your PV system. Beyond this, they can also house tools and equipment as well as support the solar array if placed in a sunny, non-shaded area. It is a good idea to keep flammable fuels and gasses in a separate building rather than the building in which one sleeps.

The sound insulation qualities of a powershed offer another advantage.. There is nothing like driving up a

beautiful mountain to a picturesque home site, then being greeted by the howling of a generator as you step out of your truck. Powersheds can be placed a distance from living spaces, decks and the like.

If you are thinking of a powershed to house your PV components, don't forget that your batteries are most efficient between 60° and 80°F. In cold climates, the tremendous amounts of heat given off by the generator can aid in heating the space. Propane catalytic heaters with thermostats can also help. Excess heat can also be a problem if the generator is not properly ventilated to the outside.

Another good idea is to install DC lighting in your shed. With battery direct DC power, you will still have light when servicing your AC equipment.



Recreational Vehicle Systems

Solar modules and RV' s with batteries are a natural match.

Since batteries are charged when traveling, RV' s normally depend mostly on the vehicle' s alternator for the primary power source. Power to charge the battery bank is also provided through a converter when plugged into the utility.

However, for those who like to spend days, weeks (or longer) not traveling and not plugged in, photovoltaics can mean freedom. And, because a PV array can put as much power into your batteries during an hour of bright sun as a small gasoline generator, it can also mean reclaiming peace and quiet. As well, the RV' s existing battery bank and fuse box make the transition to solar a smooth and economical one.

While most of our RV systems utilize 1 to 2 modules, it is important to analyze your power needs. Just as with all PV systems, you need to consider the wattage of the appliances and lights you are powering as well as the average hours used each day. Average daily usage can be calculated on the worksheets in the appendix. Unlike most other systems, however, RV' s travel through different regions of climate, park at varying angles to the sun, sometimes in shade and sometimes not. People with similar vehicles can have very dissimilar power usage and patterns of travel. These factors should be considered. If you have any questions about how to go about this, please give us a call.

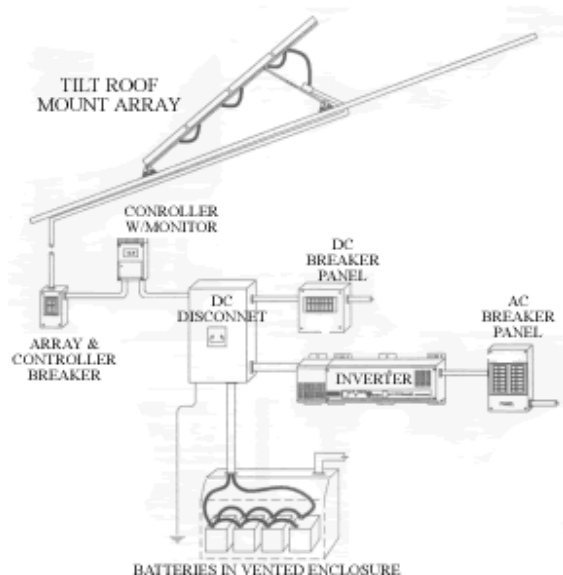
Buy now and save later.

Your Solar Charging System will pay for itself several times over by increasing battery life and reducing the amount of money you spend on campground hook-ups and generator maintenance. Batteries that are "deep cycled" too many times or sit idle for several months can be permanently damaged. Solar modules provide a daily maintenance charge to your batteries and eliminate this problem. By recharging every day, the depth of discharge is reduced, and battery life and performance are greatly improved.

Keeps batteries charged, Summer or Winter.

Solar panel output is dependent on light intensity and exposure time in the sun. You' ll be amazed at how much power your system provides on a bright day. And even in cloudy weather, your panels will produce power although at a lower output.

[Have a look at our RV kit systems](#)

**CABIN Example System**

100 to 500 Watt Array 12 Volts
Nominal* AC and DC Loads

Fixed Module Mount

Stacking Vertical Configuration
Roof Mounted

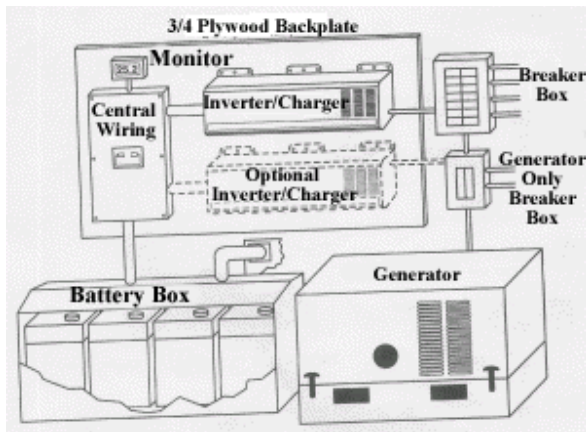
Perfect for the energy conscious homeowner or vacation cabin. This system will provide a combination of 12 volt DC and 120 v ac power without the noise and hassle of a generator. Enjoy the benefits of silent electricity such as music, lighting, pressurized delivered water - all at your perfect "get-away" spot.

Example system power production

830 watt hours daily from a 5 hour equivalent day.

Batteries - 12 volt - 86 amp hour each, sealed type
 Inverter - 1500 watt modified sine with built-in battery charger

*This system could easily be configured to 24 volts. However, 12 volt appliances are much easier to locate than 24 volt units. An inverter and common 117 VAC appliances alleviates this problem.



GENVERTER Example System

Generator/Inverter/Battery

By coupling an existing generator to a battery charger, battery bank and inverter, efficiencies are increased and costs are decreased.

Previously, the most common power source for homes off the utility line was a gas or diesel generator. As long as this generator is run close to its rated capacity, efficiencies are maximized and costs are kept relatively low. However, this is usually not the practice. Many generators without battery banks are run 16 hours a day or more at only a small fraction of their potential power. This results in the cost per kilowatt hour of electricity going sky high.

Now consider the addition of a battery bank, a battery charger which operates whenever the generator is run, and an inverter which powers the AC loads from the battery bank whenever the generator is off. This can reduce daily generator run time and dramatically reduce the cost of power. In some instances, efficiency can be increased even further by sizing the generator to run occasional very large loads and thus avoiding the need for an extra-large inverter and additional battery capacity.

In this type of system (which we term a "genverter"), a transfer switch, either manual or automatic, is utilized. This switch receives power from either the generator or the inverter and passes only one source to the loads.

Many inverters have three of the major components necessary for this system. The inverter, battery charger and transfer switch are designed into one unit.

An option for this type of system which increases efficiencies even further is the addition of select DC loads such as refrigeration which can be powered directly from the batteries.

You will notice this system drawing to be very similar to the other system schematics. In fact the only major difference is the lack of solar modules, mount structure and controller.

PROBLEM: On a budget that prevents you from buying the complete system you need and you already have a generator?

SOLUTION: Start with a working portion of your system as detailed here, adding solar or wind generators as your budget allows. Solar modules and wind modules can easily be added incrementally.

RESIDENTIAL Example System

400 to 1000 Watt Array

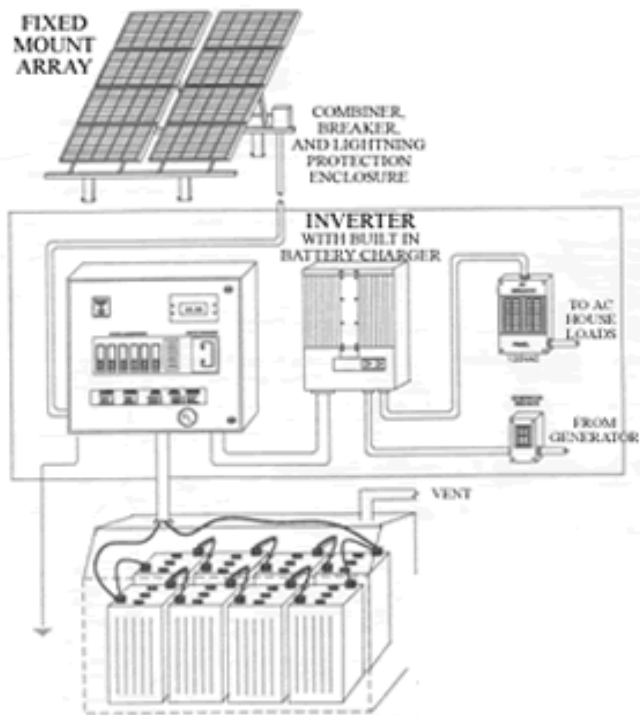
24 Volts Nominal

Primarily AC Loads

Select DC Loads

Typical full time home system or large vacation part-time home. This is a very common remote home system size. The solar array, batteries, or inverter size can be customized to your specific needs easily, giving you the most power for your dollar.

This is one of our most popular systems. The monitor can be installed in the power room or remote, possibly in the living area of the house. Wall space required for the system is typically 4' x 5" and floor space for the battery bank is 2' x 4.5' .



A popular addition to this system is a single DC light fixture to light the control area, providing light in the control room even when the inverter is shut down.

The above drawing illustrates how a PV system breaks down into three major sub-systems. Array at the top. Power Conditioning at page center, and Battery Bank below. We can easily take any of these sub-systems and alter the others. For example, the array or battery systems could vary greatly in size.

Example system power production

1800 watt hours daily from a 5 hour equivalent day.

Batteries - L-16 type, 6 volt, 300-370 amp hours.

Inverter - 1,500 to 3,600 watt modified sine with built-in battery charger and transfer switch.

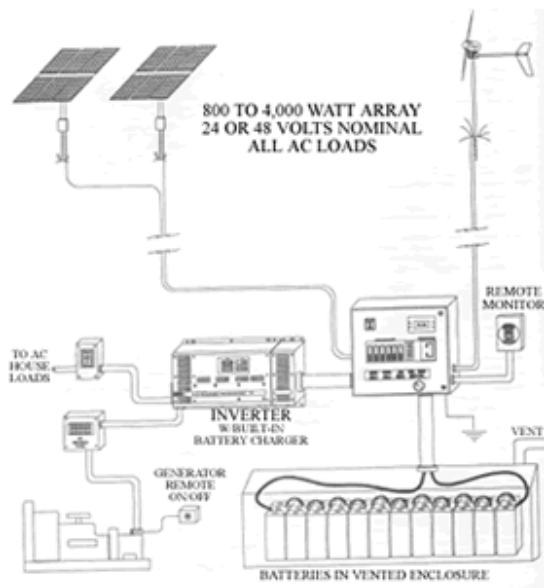
Power conditioning and storage placement - dwelling basement or utility area, powershed or container.

POWERLINE Example System

800 to 4,000 Watt Array

24 or 48 Volts Nominal

All AC Loads



For the serious homeowner with needs for a healthy amount of household power. This homestead system incorporates a good sized array with sinewave power conditioning and heavy duty long-lived two volt batteries. The back up generator allows for annual low sun periods and/or the flexibility of additional power when needed.

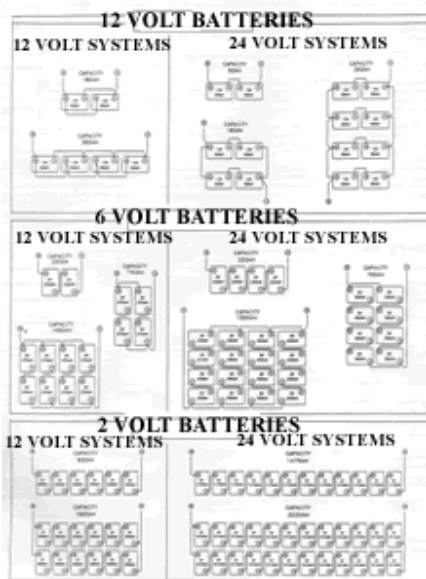
Example system power production- 3700 watt hours daily from a 5 hour equivalent day
 Solar array - Fix mounted on ground, roof or pole mounts. Tracking pole mounts also available.
 Batteries - 2 volt cells in 3 cell trays, flooded or sealed type.
 Inverter - sinewave inverter/charger.
 Power conditioning and storage placement -Basement, powershed or container.

Remote monitoring and generator start/stop.
 Wind generator for diversity of charging sources.
 Propane generator for battery charging during prolonged no-sun periods.

- A second inverter can easily be added to this system for additional capacity and 230 VAC loads.
- The Powercenter can also include Inverter AC output breakers.

Battery Installation and Wiring

Batteries may be wired in either series or parallel configuration. When a battery is wired in series the positive terminal is wired to the next battery' s negative terminal. This increases the voltage while maintaining



amperage of the two batteries. With parallel wiring the positive terminal is wired to the next battery's positive terminal, and the negative to the next negative. This arrangement increases amperage while maintaining voltage.

One common mistake is to believe that both amperage and voltage will increase when wiring batteries together. It will not; only one value will increase with respect to the arrangement. A battery bank may combine both series and parallel wiring configurations. Series strings of batteries are used to achieve the correct voltage, then a number of these series strings are attached in parallel to increase the amp hours of the total battery bank.

GLOSSARY

Definitions and explanations of terms and words used when working with solar electric systems.

AC - Alternating current. Electrical energy which reverses its direction at regular intervals.

AC Daily Power Budget - The daily amount of watts your AC appliances use.

AC Inverter and Battery Power Allowance - Running an inverter draws a small amount of power from your battery. So does keeping power stored. The inverter and battery allowance in your power calculations help make certain enough power will be produced to keep your battery from running in the red.

Adjusted Total Daily Power Budget - A total daily power budget may be changed to meet certain situations. For instance, if you spend only weekends at a house, then your adjusted total daily power budget will be lower. Adding a generator to your system also reduces your total daily power budget. The adjusted daily power budget provides the figure that determines the size of your solar electric power system.

Ampere or amp - Electric current is measured in amperes or amps.

Amp Hours - The number of amps used or produced in a given hour equals the number of hours. Batteries are rated in amp hours.

Array - A group of solar electric modules connected together in a power system.

Battery Bank - A group of batteries wired together to store power in a solar electric system. Allows you to use the stored power at night, on cloudy days, or to run more power than the array can produce at one time.

Centrifugal (Water Pumps) - Rotating outward, away from the center, as in centrifugal force.

Controller - Simply put, the controller regulates the current from solar charger to your battery bank

Current - The rate of flow of an electric charge. Current is measured in amps.

DC - Direct current. Electrical energy flowing in one direction and of substantially constant value.

DC Daily Power Budget - The number of watts your DC appliances use daily.

Fall (Water Pump/Hydro Sections) - The vertical descent of water, usually measured in vertical feet. Also called "head".

Flow Rate - Speed at which water moves. GPM - Gallons per minute.

Ground Mount - A piece of equipment upon which solar modules are mounted.

Head - See "Fall".

Hertz or Hz - the frequency of electrical current described in cycles per second. Appliances in the U.S. use 60 Hz. Appliances in other countries generally use 50 Hz.

Hydroelectricity - Electricity created by water power

Hydrometer - An instrument used to measure state-of-charge (voltage) of a battery.

Inverter - An appliance used to convert independent DC power into standard household AC current

Kilowatt or KW - a thousand watts. (See Watts.)

LED- Light emitting diode. These lights are often used to indicate low power on modern electronic equipment.

Line Loss - Voltage drop over the length of electric line wire. Line loss robs your system of power when wire is too small for the load being run through the line — or when voltage is too low for the distance the power must travel.

Load - The lights or appliances run by your electrical system. mA - Milliamps. 1000 mA = 1 amp.

Module - Modular solar electric charger; used interchangeably with solar electric panel.

Parallel Wiring - A system of wiring, for solar electric modules or batteries, which increases amperage. Parallel wiring is "+ to +" (positive to positive) and "- to -" (negative to negative).

Photovoltaic - Converting light into electricity. Photo means "light," voltaic means "electric". Often referred to as "PV" for short. More commonly referred to as "solar electric."

PSI - Pounds per square inch

Self-Regulating - Some modules have a special circuitry which keeps the battery from overcharging. This means that no controller is needed when the self-regulating module is properly matched to battery storage capacity.

Series Wiring - A system of wiring, for solar electric modules or batteries, which increases voltage. Series wiring is "+ to -" (positive to negative).

Single-Crystal Silicon - Many solar chargers use single-crystal solar cells as they are the most efficient cell on the market. Pure silicon is grown into crystalline ingots which are cut into thin slices to make solar electric cells. These cells are then soldered together to meet the charger' s voltage and current requirements.

Solar Cell - The smallest basic solar electric device which generates electricity when exposed to light.

Solar Electric - The preferred term used to describe something which uses sunlight to produce electricity. Photovoltaic is the more technical term.

Thin-Film Silicon - The tiny solar chargers found in calculators and wrist watches are solar thin-film. Thin-film solar chargers are made by spreading a micro-thin layer of silicon on glass and creating the voltage and current circuits using laser technology. Thin-film chargers are produced in sizes from the microscopic calculator chip, up to the 1 x 4 power module.

Total Daily Power Budget - In a DC system, the daily amount of watts your DC appliances use, plus the battery power allowance. In a DC and AC system, the daily amount of watts DC and AC appliances use, plus battery and inverter power allowances.

Voltage or Volts - Voltage is the rating of the amount of electrical pressure that causes electricity to flow in the power line. If electricity were water, voltage would measure the amount of pressure at the faucet.

Watts - A watt is a measurement of total electrical power. Volts x amps = watts.

Watt Hour - The quantity of electrical energy used or produced when one watt is used for one hour