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 electric 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. And, 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.

Table of Contents

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.

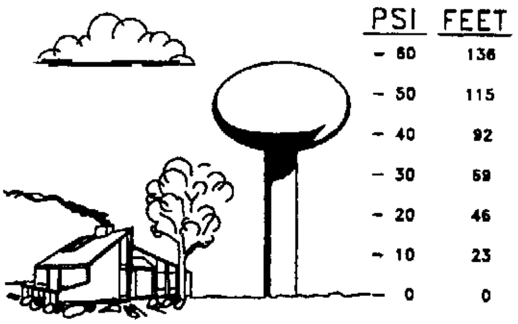
We do not deal with solar thermal space heating. As sensible and efficient as this technology can be, it requires a good deal of on-site engineering and is the province of solar architects. Solar water heating for household uses can also be complex, but it can also be quite simple.

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.

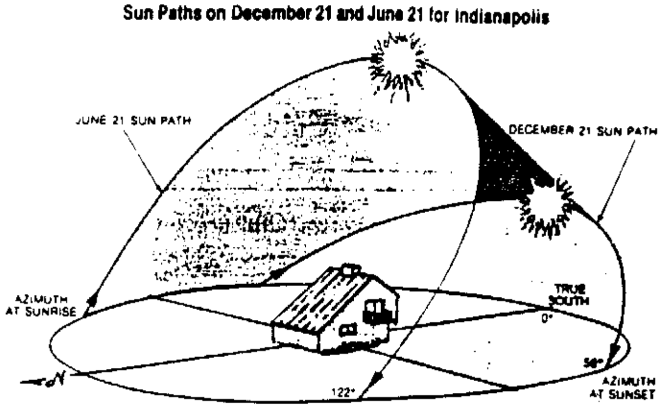
Our sun trackers can help reduce reflectance but cannot help with the increased atmosphere in the sun's path.

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. See the charts below.

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.

Sun Paths on December 21 and June 21 for Indianapolis



This diagram illustrates the path of the sun over varying seasons. Remember when selecting a site for your solar modules to pick a spot that is clear of shade from a minimum of 10 A.M. to 2 P.M. on December 21st. Even a limb from a deciduous tree will substantially reduce power output.

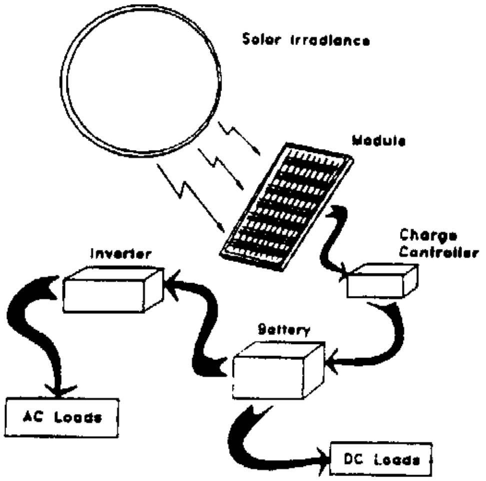
These are averages, contact us for your exact insolation data.

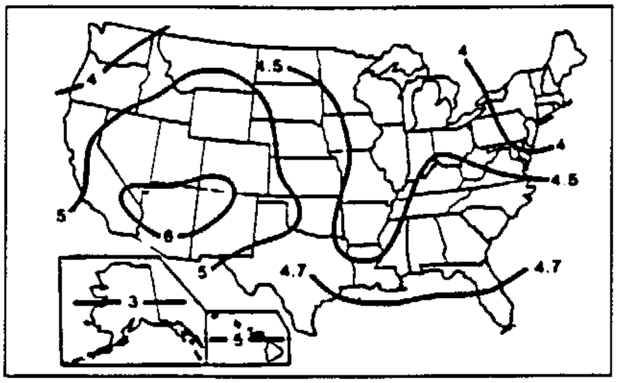
Many solar sites are quite uncomplicated in terms of shading and aspect. You may already have a good idea of where the sun appears in the morning and disappears in the evening, as well as how low it swings in the winter sky. If your site is partially shaded, it may be necessary to determine exactly where 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

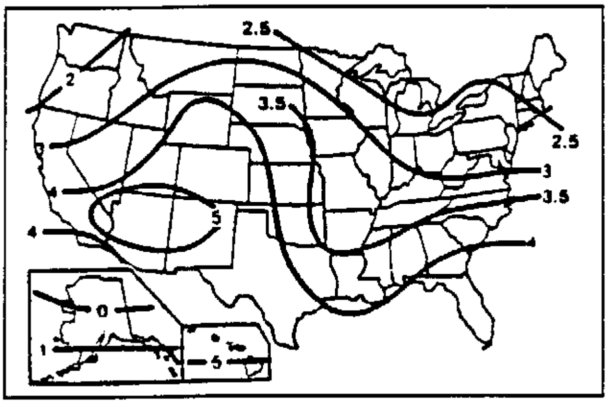
Photovoltaic modules (solar panels) convert sunlight into electricity. Wire conducts the electricity to batteries where it is stored until needed. On the way to the batteries, the electrical current passes through a controller (regulator) which will shut off the flow when the batteries become full.

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.





Yearly average equivalent sun hours per day.



Equivalent full sun hours per day for a four-week period from December 7th to January 4th.

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.

The table on this page is an analysis of energy usage for a representative small home. We have itemized each appliance and its individual run time per day and per week. We then summed the watt hours of all the individual units for a total daily watt hour figure. Making up a chart such as this will allow you to understand where your power is going and may give you ideas for how to reduce your loads in the most effective manner.

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.

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.

Volts x Amperes = Watts
Watts x Hours of Use = Watt hours

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

A load evaluation form is included in the appendix for your use.

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/Hour
Coffee pot	200
Coffee maker	800
Toaster	800-1500
Popcorn popper	250
Blender	300
Microwave	600-1500
Waffle iron	1200
Hot plate	1200
Frying pan	1200
Dishwasher	1200-1500
Sink waste disposal	450
Washing machine	
automatic	500
Manual	300
Vacuum cleaner	
upright	200-700
hand	100
Sewing machine	100
Iron	1000
Clothes dryer	
electric NA	4000
gas heated	300-400
Heater	
engine block NA	150-1000
portable NA	1500
waterbed NA	400
stock tank NA	100
Furnace blower	300-1000
Air conditioner NA	
room	1000
central	2000-5000

Appliance	Watts/Hour
Garage door opener	350
Ceiling fan	10-50
Table fan	10-25
Electric Blanket	200
Blow dryer	1000
Shaver	15
Waterpik	100
Computer	
laptop	20-50
pc	80-150
printer	100
Typewriter	80-200
TV 25" color	150
19" color	70
12" b&w	20
VCR	40
CD player	35
Stereo	10-30
Clock radio	1
AM/FM car tape	8
Satellite dish	30
CB radio	5
Electric clock	3
Radiotelephone	
receive	5
transmit	40-150
Lights:	
100w incandescent	100
25w compact fluor.	28
50w DC incandescent	50
40w DC halogen	40
20w DC compact fluor.	22

Appliance	Watts/Hour
Compact fluorescent incandescent equivalents	
40 watt equiv.	11
60 watt equiv.	16
75 watt equiv.	20
100 watt equiv.	30
Electric mower NA	1500
Hedge trimmer	450
Weed eater	500
1/4" drill	250
1/2" drill	750
1" drill	1000
9" disc sander	1200
3" belt sander	1000
12" chain saw	1100
14" band saw	1100
7 1/4" circ. saw	900
8 1/4" circ. saw	1400
Refrig/freezer - Conventional	
20cf (15 hours)	540
16cf (13)	475
Sunfrost	
16cf DC (7)	112
12cf DC (7)	70
Vestfrost refrigerator/freezer	
10.5cf	60
Freezer - Conventional	
14cf ff (15)	440
14cf (14)	350
Sunfrost freezer	
19cf (10)	112
Vestfrost refrigerator/freezer	
7.5cf(8)	50

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.

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 transmission 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 equipment 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?

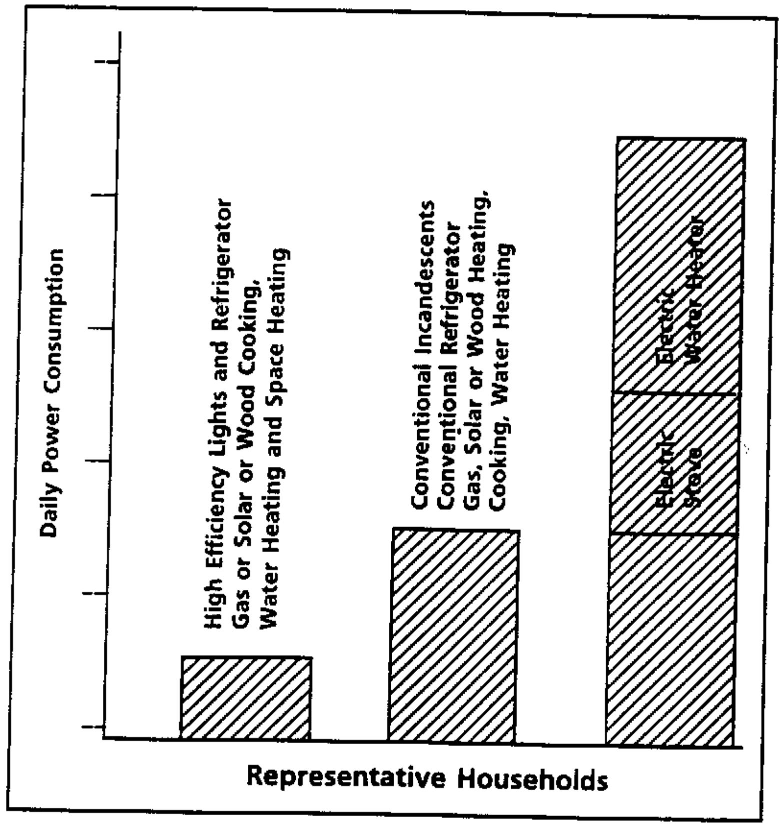
For a home system, a heated room in the utility area or near the circuit breaker box is normally utilized. The batteries are contained in an enclosure vented to the outside perhaps the size of a washing machine or, in a larger home, the size of a chest freezer. Controllers, meters and inverters are generally 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 generator and possibly the mounting of the solar array.

This powerhouse is a locally made mini-barn, now fully insulated. The solar electric fence protects arrays, gen-shed, water storage tank and well area from livestock damage.

The Importance of High Efficiency



Using the best available technologies can save you money by saving energy. Such appliances often provide better service than outdated and inefficient technologies. These newer designs often cost more initially than their cruder counterparts but can have impressively short payback times. The importance of high efficiency appliances becomes doubly important for someone providing their own electricity. For example: a high efficiency refrigerator might be run with three 80 watt PV modules where as a conventional refrigerator might necessitate an additional 9 modules and additional battery capacity. This extra generating and storage capacity will cost many times the investment of the more efficient unit. An additional benefit is that more efficiency means less run time and less wear and tear on components. In the case of the refrigerator this can mean a life span twice that of the conventional unit.

Ghost Loads

Small loads that are not easily discernible but can consume considerable amounts of power each day are termed "ghost loads". Examples include "instant on" circuitry in a television, wall cube transformers for answering machines, and electronic typewriters. These types of loads can sneak far more than their fair share of power. If not anticipated, located and dealt with, ghost loads can waste a substantial quantity of power.

"Power cubes" or "wall cubes" that plug into outlets to convert AC to DC for electronic equipment contain small transformers which can waste incredible amounts of power. A unit for a boom box, for instance, might consume 17 watts of power 24 hours a day, even though the actual device uses only 7 watts.

These kinds of loads are difficult to detect with an AC amp meter. The best way to find them is to shut every load in the home "off", and then shut down all circuits at the breaker box. Using a DC amp meter on the main battery cable, monitor each circuit as they are turned on one by one. If there is a ghost, it will appear.

There are two ways to deal with these troublesome loads.

The first, easiest, and most costly method is to accept them. Accept the fact that your inverter will never go into standby mode, add on to your array to compensate for this power consumption.

The second method minimizes power consumption. Place switches on the appliances that run unnecessarily, turning them truly off and on when required. For small, but necessary, loads – consider operating these at 12 or 24 volts DC. If this is not possible, a second, smaller, inverter can be installed to run select loads more efficiently. By doing this, the inverter can return to a no-load or idle mode, where it uses very little power.

Common Appliances with Ghost Loads

- TV's and VCR's
- Electric clocks
- Clocks built in to appliances (microwaves, ranges, telephones)
- Ni-Cad Battery chargers
- Ground Fault Interrupting Receptacles and breakers (GFCI)
- Cordless telephones
- Answering machines
- Low voltage appliances that can also utilize AC power

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.

Components of a Solar Electric System

Component	Function
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.

Component	Function
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 Mount	Supports and aims modules toward sun
Powercenter	Combines: controllers, overcurrent protection and monitors in one enclosure

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. (Review the wire loss tables in the Appendix.)

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 Modules

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.

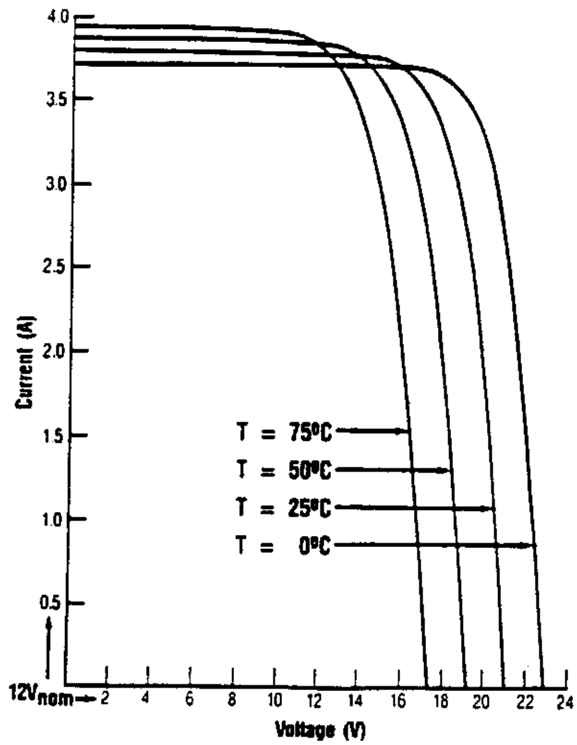
For example: a 50 watt module working at 13.0 volts will produce 39.0 watts (13.0 volts x 3.0 amps = 39.0 watts).

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.

Typical 12 Volt Module I-V Characteristics for Full Sun at 1000 Watts/m²



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 your solar professionals 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%.

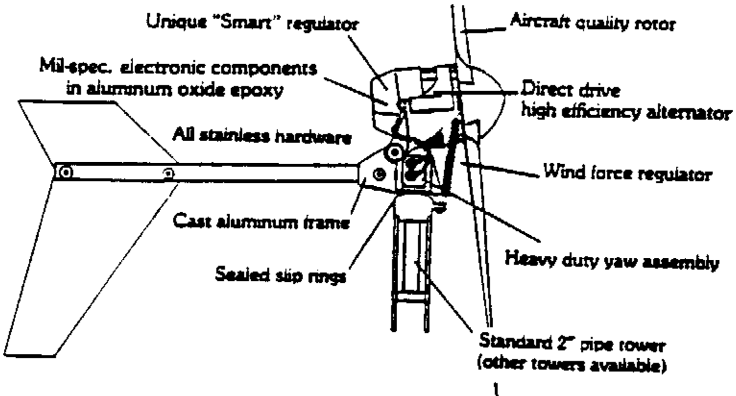
This table below compares insolation for fixed and tracking surfaces at three U.S. cities of varying latitudes. We have data for many locations broken down by the month, call if you would like the figures for your area.

	Fixed Array **Summer position latitude -15 deg.**	Fixed Array **Winter position latitude +15 deg.**	One Axis Tracking **Summer latitude -15 deg.**	One Axis Tracking **Winter latitude +15 deg**	Two Axis Tracking **E&W, N&S**
Albuquerque, NM					
January	4.49	5.74	5.87	6.84	6.92
July	7.78	6.38	10.45	9.48	10.60
Pittsburgh, PA					
January	2.02	2.38	2.36	2.67	2.69
July	5.59	4.69	7.04	6.42	7.14
Great Falls, MT					
January	2.51	3.07	2.96	3.43	3.46
July	7.62	6.24	11.25	10.37	11.44

Values are equivalent full sun hours per day.

Wind Driven Generators

An excellent complement to any battery system



(patent pending)

Is Wind Generation for you?

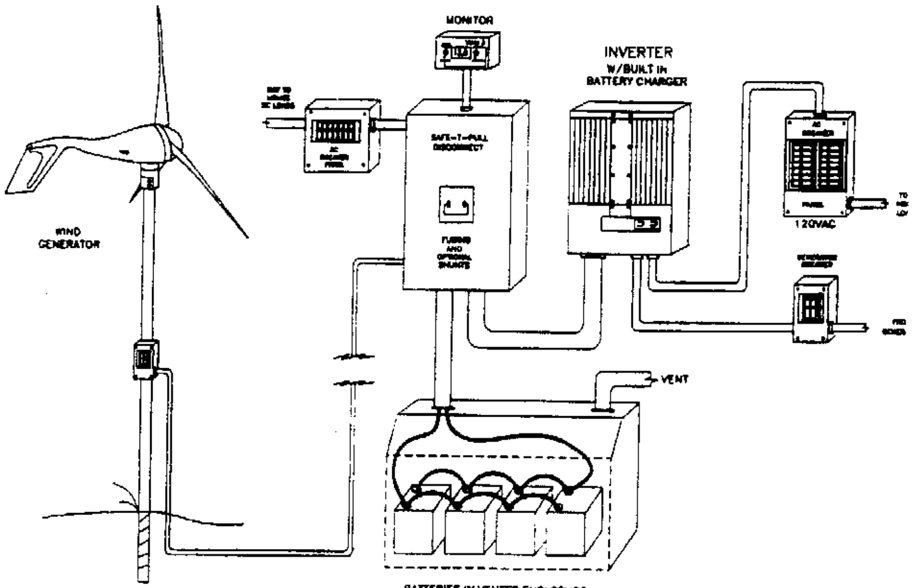
Electricity produced by wind generation can be used directly, as in water pumping applications, or it can be stored in batteries for household usage. Wind generators can be used alone, or they may be used as part of a hybrid system, in which their output is combined with that of photovoltaics, and/or 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 x 10 x 10 = 1000 versus 20 x 20 x 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.

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.

INVERTERS - Introduction

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:

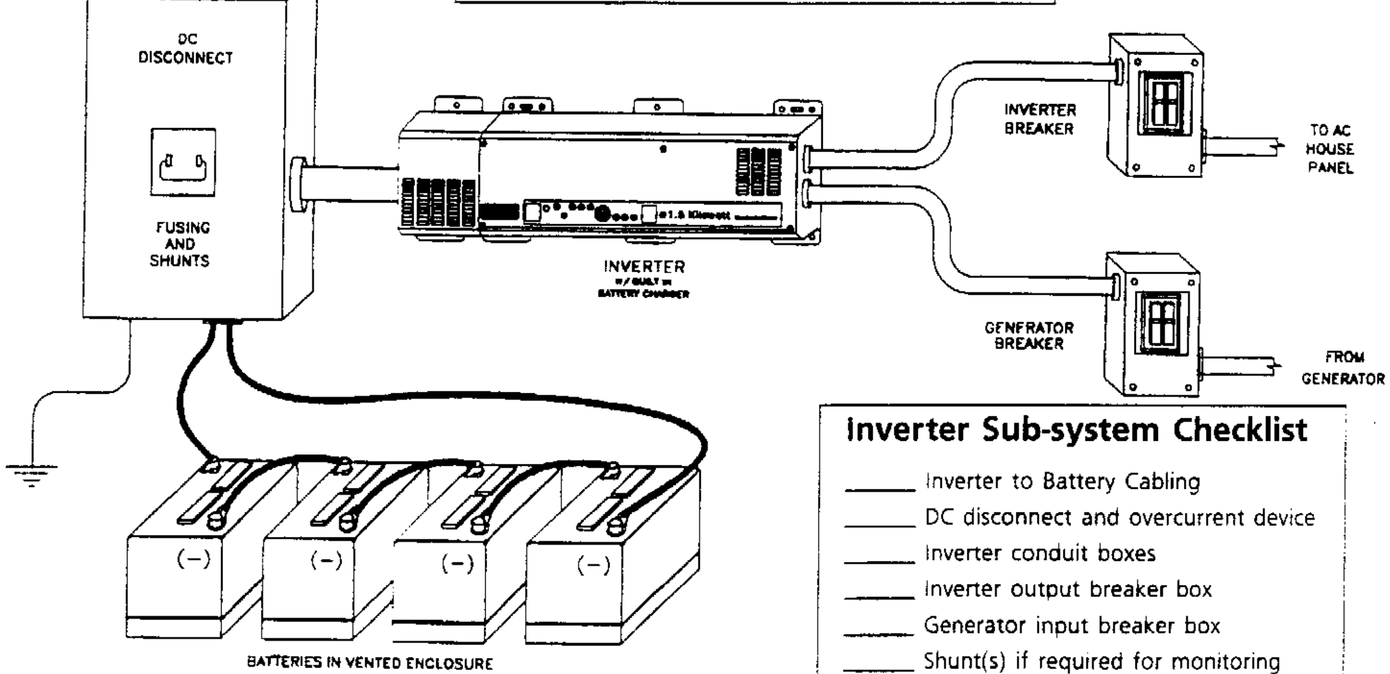
Inverter to battery cabling. Because of the high current required on low voltage circuits, this cable is large, commonly #2 to 4/0 in size. Smaller conductors than required are unsafe and will not allow the inverter to perform to its full rating.

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 a 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.

See the Sizing Tables in the Appendix for cable and overcurrent device sizing for the inverter you select.



Inverter Sub-system Checklist

- ______ Inverter to Battery Cabling
- ______ DC disconnect and overcurrent device
- ______ Inverter conduit boxes
- ______ Inverter output breaker box
- ______ Generator input breaker box
- ______ Shunt(s) if required for monitoring

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.

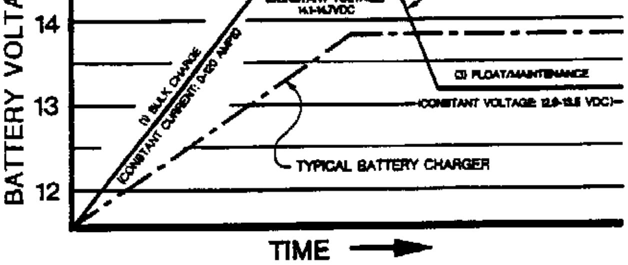
Multi-stage Battery Charging

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.

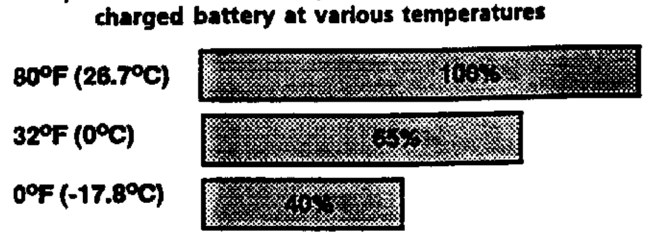
The depth of cycling has a good deal to do with determining a battery's useful life. Even batteries designed for deep cycling are "used up" faster as the depth of discharge is increased. It is common practice for a system to be designed with deep cycle batteries even though the daily or average discharging 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. (See the bar graph of temperature effects to the left and the temperature derating guidelines in the battery sizing worksheet in the Appendix.) 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.

Comparison of short term power available from a fully charged battery at various temperatures



Batteries - continued

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.

Percentage of Charge	12 volt Battery Voltage	24 volt Battery Voltage	Specific Gravity
100	12.70	25.40	1.265
95	12.64	25.25	1.257
90	12.58	25.16	1.249
85	12.52	25.04	1.241
80	12.46	24.92	1.233
75	12.40	24.80	1.225
70	12.36	24.72	1.218
65	12.32	24.64	1.211
60	12.28	24.56	1.204
55	12.24	24.48	1.197
50	12.20	24.40	1.190
45	12.16	24.32	1.183
40	12.12	24.24	1.176
35	12.08	24.16	1.169
30	12.04	24.08	1.162
25	12.00	24.00	1.155
20	11.98	23.96	1.148
15	11.96	23.92	1.141
10	11.94	23.88	1.134
5	11.92	23.84	1.127
Discharged	11.90	23.80	1.120

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.

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.

(continued on next page)

Batteries - continued

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.

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.

> **"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.

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 buildup can create a good deal of electrical resistance, which can contribute 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 deal of cycling and gassing through normal activity, we believe that equalization is a complement to this activity and as a rule of thumb 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 this charging. 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 gravities 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 all 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 goal is to keep the variation of resistance from one cell to another to a minimum.