SYSTEM DESIGN GUIDE

How Renewable Energy Power Systems Work

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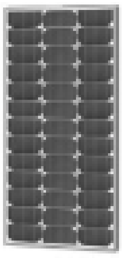
What Components do I Need for an Off-Grid Solar Electric System?

There are many components that make up a complete solar system.

- Solar or PV modules
- Charge controller/regulators
- Batteries
- Inverter/chargers
- Balance of System - Battery Monitors, Mounting Racks, Breakers, Fuses, Cabling etc..

SOLAR OR PV PANELS



Solar panels convert visible sunlight to renewable electrical energy and are often called photovoltaic modules (PV) or solar modules. Solar panels vary in length and width, and are often 30 to 40 mm thick. They generally weigh between 7 and 20 kgs, but the larger solar panels can be cumbersome to carry and install on a roof. Framed solar panels are the industry standard, most cost effective, and applicable for most home solar panel applications.

There are also available foldable solar panels and flexible/rollable solar panels. Generally these thin-film flexible solar panels are more expensive per watt and require more square footage to produce the equivalent wattage of a framed module.

What size solar panels do I need for my home and how many?

The number of solar panels you will need depends primarily upon the amount of electricity you are trying to produce and the insolation in your area. Solar insolation can be thought of as the number of hours in the day that the solar panel will produce its rated output. This is not equivalent to the number of daylight hours. Your local Dealer will have the correct solar insolation figures for your area, and can calculate how many solar panels you will require to supply your required electrical load.
Solar panels come in a variety of wattages. Watts are the main measure of a solar panel, along with nominal voltage .

What types of solar panels are there?

Most solar panels can be classified as mono-crystalline, poly-crystalline or amorphous. This is based on the silicon structure that comprises the cell. A 100 watt mono-crystalline solar panel should have the same output as a 100 watt poly-crystalline solar panel and a 100 watt amorphous solar panel. The main difference is the amount of area which the solar panel occupies. The efficiency of mono-crystalline and poly-crystalline solar modules is nearly equal now, both being more efficient than amorphous An amorphous solar panel of the same wattage will be significantly larger than the mono or poly-crystalline panels. By the way, when talking about efficiency of solar panels, keep in mind that solar panel efficiency is still only about 13-18% efficient in turning sunlight into electricity.

Where to Mount Your Solar Panels

A key factor in the effective use of solar electricity is proper placement of the solar panels. Make sure to locate the panels where they will receive full sunlight between the hours of 10 am and 3 pm. Be sure that the solar panels will not be shaded by shadows from tree branches, chimneys, other structures, etc. Shading of even a small area of a solar panel will greatly reduce the power output of the entire solar array.

How Long will Solar Panels Last?

Solar panels themselves generally last over 25 years, and require little maintenance. Many of the first solar panels produced in the 50s are still in use today. A common solar panel warranty states that the panels will produce at least 90% of their power after 10 years and 80% of their rated power after 20 years.

Reverse Current Protection

Solar PV panels will leak power back from your batteries during no-sun periods and during the night if not protected. This leakage is very small, but over long periods this loss can accumulate. To prevent this install a blocking diode between the battery and solar PV panels. A blocking diode is not necessary if a charge controller/ regulator is being used in the system.

CHARGE CONTROLLERS / REGULATORS

Solar charge controllers are an essential element to any solar electric panel system. At a most basic level charge controllers prevent batteries from being overcharged and prevent the batteries from discharging through the solar panel array at night.

A charge controller is an essential part of nearly all power systems that charge batteries, whether the power source is PV, wind, hydro, fuel, or utility grid. Its purpose is to keep your batteries properly fed and safe for the long term.

The basic functions of a controller are quite simple. Charge Controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery over-discharge, protect from electrical overload, and/or display battery status and the flow of power.

Blocking Reverse Current

Photovoltaic panels work by pumping current through your battery in one direction. At night, the panels may pass a bit of current in the reverse direction, causing a slight discharge from the battery. In most controllers, charge current passes through a semiconductor that passes current in one direction only, and acts like a valve to control the current. It prevents reverse current without any extra effort or cost.
In some controllers, an electromagnetic coil opens and closes a mechanical switch. This is called a relay. The relay switches off at night, to block reverse current.
If you are using a PV array only to trickle-charge a battery (a very small array relative to the size of the battery), then you may not need a charge controller. This is a rare application. An example is a tiny maintenance module that prevents battery discharge in a parked vehicle but will not support significant loads. You can install a simple diode in that case, to block reverse current. A diode used for this purpose is called a "blocking diode."

Preventing Overcharge

When a battery reaches full charge, it can no longer store incoming energy. If energy continues to be applied at the full rate, the battery voltage gets too high. Preventing overcharge is simply a matter of reducing the flow of energy to the battery when the battery reaches a specific voltage. When the voltage drops due to lower sun intensity or an increase in electrical usage, the controller again allows the maximum possible charge. This is called "voltage regulating." It is the most essential function of all Charge Controllers. The controller "looks at" the voltage, and regulates the battery charging in response.

The voltages at which the controller changes the charge rate are called “set points”.

Control Set Points vs. Temperature

The ideal set points for charge control vary with a battery's temperature. Some controllers have a feature called "temperature compensation." When the controller senses a low battery temperature, it will raise the set points. Otherwise when the battery is cold, the controller will reduce the charge too soon.
Some controllers have a temperature sensor built in. Such a controller must be mounted in a place where the temperature is close to that of the batteries. Better controllers have a remote temperature probe, on a small cable. The probe should be attached directly to a battery in order to report its temperature to the controller.

Control Set Points vs. Battery Type

The ideal set points for charge controlling depends on the design of the battery. The vast majority of systems use deep-cycle lead-acid batteries of either the flooded type or the sealed type. Flooded batteries are filled with liquid. These are the standard, economical deep cycle batteries. Sealed batteries use saturated pads between the plates. They are also called "valve-regulated" or "absorbed glass mat," or simply "maintenance-free." They need to be regulated to a slightly lower voltage than flooded batteries or they will dry out and be ruined. Some controllers have a means to select the type of battery. Never use a controller that is not intended for your type of battery.

Low Voltage Disconnect (LVD)

The only way to prevent over-discharge, is to disconnect loads (appliances, lights, etc.), and then to reconnect them only when the voltage has recovered due to some substantial charging. A low voltage disconnect (LVD) circuit will disconnect loads at a set point. It will reconnect the loads only when the battery voltage has substantially recovered due to the accumulation of some charge.
If you have any DC loads, you should have an LVD. Some charge controllers have one built in.
If you purchase a charge controller with built-in LVD, make sure that it has enough capacity to handle your DC loads.

Overload Protection
A circuit is overloaded when the current flowing in it is higher than it can safely handle. This can cause overheating and can even be a fire hazard. Overload can be caused by a fault (short circuit) in the wiring, or by a faulty appliance (like a frozen water pump). Some Charge Controllers have overload protection built in, usually with a push-button reset.
Built-in overload protection can be useful, but most systems require additional protection in the form of fuses or circuit breakers. If you have a circuit with a wire size for which the safe carrying capacity (amperage) is less than the overload limit of the controller, then you must protect that circuit with a fuse or breaker of a suitably lower amp rating.

Displays and Metering
Charge controllers may have various indicators, ranging from a single LED to digital displays of voltage and current. A display system can indicate the flow of power into and out of the system, the approximate state of charge of your battery, and when various limits are reached.
If you want complete and accurate system monitoring it is recommended that you install a Battery Monitor for complete system status.

The control of battery charging is so important that most manufacturers of high quality batteries specify the requirements for voltage regulation, low voltage disconnect and temperature compensation. When these limits are not respected, it is common for batteries to fail after less than one quarter of their normal life expectancy, regardless of their quality or their cost.

A good charge controller is not expensive in relation to the total cost of a power system.

Sizing PWM Charge Controllers	Example
• For PWM and PWM shunt solar controllers, select one that is rated at your system voltage (same nominal voltage all the way through the system). • Divide solar panel array total wattage by system voltage. • Add 20% as a safety margin (i.e., (result of Step 2) x 1.2). • Select a solar controller rated at or above the result.	• Two 125W, 12V nominal modules. System is 250 W, 12 Volt nominal. Solar charge controller will be 12 Volts. • 250 ÷ 12 = 20.83 • 20.83 x 1.2 = 24.996 amps • You could use a Xantrex C35 (35 amp solar charge controller) or a Morningstar PS30/M (a 30 amp charge controller. Any 12 volt solar controller greater than 25 amps will work.

What About MPPT Controllers?

A relatively new feature is showing up in charge controllers. It's called maximum power point tracking (MPPT). It extracts additional power from your Solar PV array, under certain conditions.
Maximum Power Point Tracking solar charge controllers (MPPT) are different than the traditional PWM solar charge controllers in that they are more efficient and in many cases more feature rich. MPPT solar charge controllers allow your solar panels to operate at their optimum power output voltage, improving their performance by as much as 30%. Traditional solar charge controllers reduce the efficiency of one part of your system in order to make it work with another. Several MPPT solar controllers can accept high input voltages (up to 120V+ DC) from your solar array and efficiently down convert the DC voltage to that of your system (e.g. 12, 24, 48VDC, etc) which means you aren't losing any generated power and you are able to use what you generate more efficiently. Additionally, using a much higher DC voltage on the input side allows you to use thinner wire, decreasing your wire cost and making installation easier.

The function of an MPPT can be likened to the transmission in a car.
When the transmission is in the wrong gear, the wheels do not receive maximum power. That's because the engine is running either slower or faster than its ideal speed range. The purpose of the transmission is to couple the engine to the wheels, in a way that lets the engine run in a favourable speed range in spite of varying acceleration and terrain.

Let's compare a PV module to a car engine.

Its voltage is like engine speed. Its ideal voltage is that at which it can put out maximum power. This is called its maximum power point. (It's also called peak power voltage, Vpp). Vpp varies with sunlight intensity and with solar cell temperature. The voltage of the battery is like the speed of the car's wheels. It varies with battery state of charge, and with the loads on the system (any appliances and lights that may be on). For a 12V system, it varies from about 11 to 14.5V.
In order to charge a battery (increase its voltage), the PV module must apply a voltage that is higher than that of the battery. If the PV module's Vpp is just slightly below the battery voltage, then the current drops nearly to zero (like an engine turning slower than the wheels). So, to play it safe, typical PV modules are made with a Vpp of around 17V when measured at a cell temperature of 25°C. They do that because it will drop to around 15V on a very hot day. However, on a very cold day, it can rise to 18V!

What happens when the Vpp is much higher than the voltage of the battery? The module voltage is dragged down to a lower-than-ideal voltage. Traditional charge controllers transfer the PV current directly to the battery, giving you NO benefit from this added potential.

The car's transmission varies the ratio between speed and torque. At low gear, the speed of the wheels is reduced and the torque is increased. Likewise, the MPPT varies the ratio between the voltage and current delivered to the battery, in order to deliver maximum power. If there is excess voltage available from the PV, then it converts that to additional current to the battery. Furthermore, it is like an automatic transmission. As the Vpp of the PV array varies with temperature and other conditions, it "tracks" this variance and adjusts the ratio accordingly. Thus it is called a Maximum Power Point Tracker.

What advantage does MPPT give in the real world?

That depends on your array, your climate, and your seasonal load pattern. It gives you an effective current boost only when the Vpp is more than about 1V higher than the battery voltage. In hot weather, this may not be the case unless the batteries are low in charge. In cold weather however, the Vpp can rise to 18V. If your energy use is greatest in the winter (typical in most homes) and you have cold winter weather, then you can gain a substantial boost in energy when you need it the most!

Sizing MPPT Solar Charge Controllers

Sizing MPPT solar charge controllers by hand can be one of the more difficult tasks for a system designer. Unlike PWM or shunt controllers, many MPPT controllers have the ability to down convert higher voltage PV (solar panel) arrays to lower voltage battery banks. To explain the process is beyond the scope of this article, but we can give a couple of web links to get you close. If you are unsure of the correct controller for you, contact a solar professional to help. Here are some links to manufacturers' websites that include sizing tools for their controllers.

- **http://www.morningstarcorp.com/en/strings/calc.php**
- **http://www.outbackpower.com/resources/string_sizing_tool/**

DEEP CYCLE BATTERIES

Deep Cycle Batteries (also known as 'solar batteries ') provide electrical storage in renewable energy (RE) systems. If you want to use your electricity anytime other than when the system is producing it, you will need batteries. So if during a nice sunny day, your solar array produces a lot of electricity, you'll need batteries to access that power after the sun goes down. And although it may seem counter-intuitive, it's also true that if you have a wind turbine or solar panel array that is connected directly to the electric grid without batteries, you will not be able to use the power they produce during a grid power outage. If you need to be able to use power at any time, you need batteries. But which ones? The first thing to do is to identify the type of battery you will use in your system.

Deep Cycle Batteries used in renewable energy (RE) systems are different from car batteries and that difference is critical. RE systems by nature are cyclical: energy is captured and stored, then later consumed. For example, in a battery-based solar electric system, the energy produced daily by the solar panels is stored in the battery bank, which is then used by loads at night or on not-so-sunny days. This repetitive process subjects the batteries to a slow, daily charge and discharge pattern.
Car batteries are not meant to be used in this way. They can release a great deal of their stored energy at once, to start the engine, then they immediately receive a rapid recharge from the car's alternator. They are not meant to recover their charge slowly, as would happen in a solar electric system. Deep cycle batteries, on the other hand, can be gradually discharged by as much as half of their capacity and will patiently await gradual recharge. When properly maintained, a deep cycle battery can last four to 10 years.

There are two divisions and three main types of deep cycle batteries used in RE systems.

FLOODED AND SEALED

Flooded batteries use a fluid electrolyte, have filler/vents to access fluid reservoirs, and require maintenance (adding fluid). **Sealed batteries** use non-fluid electrolyte contained in inaccessible cells. There's only one flooded type: flooded lead-acid batteries. Sealed batteries include Absorbed Glass Mat (AGM) batteries and GEL cell batteries.

Flooded Lead-Acid Deep Cycle Batteries

Flooded deep cycle lead-acid batteries, also called "wet cells", are commonly used in solar, wind and hydroelectric renewable energy systems. They are often the least expensive type of deep cycle battery and can last the longest. They also come in a wide range of sizes.
In flooded batteries, a sulphuric acid solution reacts with the lead plates in the cells to produce electricity. When flooded deep cycle batteries are recharged, electrolysis occurs, producing hydrogen and oxygen gases in a normal process called "out gassing".

These gases (hydrogen and oxygen) may escape the cells through the filler/vent caps, creating two problems:-

- the fluid loss means that the fluid level in the battery goes down, potentially exposing the normally "flooded" lead plates—not a good thing. So using flooded batteries in your system means that you are committed to regularly monitoring and maintaining them by adding distilled water to each cell as needed. Hydrocaps can help prevent some moisture escape, thus reducing watering frequency.

- The other problem is the presence and accumulation of explosive gases. Hydrogen and oxygen gases are extremely dangerous and must be properly vented—to the outside air. So it's clear that with flooded batteries, battery maintenance is an essential part of system care.

Sealed Deep Cycle Batteries

One great advantage of sealed deep cycle batteries is that they can be placed in any orientation:-
upright, on their sides, and, in some cases, even upside-down.

In a sealed battery, the electrolyte is suspended in either an absorbed glass mat (**AGM**) or in a **GEL**.
Sealed deep cycle batteries cost more than flooded lead-acid batteries and don't last as many charging cycles; however, they are the preferred choice for applications requiring frequent battery handling, or where the system needs to be left unattended in a remote location. Like flooded batteries, sealed batteries have vents to allow hydrogen to escape when necessary, though this should not normally occur. The difference is that because the batteries are sealed, there is no way to replace the escaped moisture by adding water to the cells; that's why a sealed battery won't last as long as an flooded battery.

GEL cell batteries have traditionally been a bit more expensive than **AGM** batteries. They do however have the unique advantage of performing better in very cold temperatures or in very deep-discharge applications and inherently they require less maintenance, since you cannot refill the electrolyte levels. On the other hand, charging them can be more delicate. If you overcharge them, the batteries will off-gas and permanently remove water suspended in the gel or glass mat (since distilled water cannot be re-injected into sealed batteries).

Which deep cycle battery type is right for your application?

In most cases, flooded batteries are an excellent choice for RE systems because of their cost-effectiveness, particularly for those systems which require a lot of energy storage. But flooded batteries do require maintenance! Regular monitoring and maintenance will ensure your system functions properly and your batteries live a long, healthy life. On the other hand, if you're using the deep cycle batteries in a remote area where regular maintenance is not possible, sealed batteries will be a better option. Furthermore, sealed batteries conform to situations with space constraints that require you to store your batteries in unusual orientations or where venting is not possible.

One of the main advantages of sealed batteries versus flooded batteries is increased ease of transportation. Sealed deep cycle batteries can be shipped by air (weight permitting) but flooded batteries are often classed under "hazardous materials" rules, which restrict shipping options.

All batteries are sized based on their nominal voltage and ampere-hours (AHr) of storage.

For an off-grid system, the battery bank voltage must match that of the solar array unless you are using an MPPT charge controller that can accept a higher input voltage than the battery bank voltage.

Available sizes in both flooded and sealed batteries vary greatly. The smallest batteries hold less than 20 Ahr and the largest approach 2,000 Ahr of storage. Usually, these very large batteries are only 2 volts each. If you want to use them in a 48-Volt system, you will need 24 of them, wired in series. Such large batteries could weigh 90 to 140 kilograms or more. Often size and weight constraints affect the final battery choice. Be sure you've got the equipment and space to deal with such oversized batteries before you order them.

Batteries: Flooded Lead Acid

Flooded lead acid batteries have the longest track record in solar electric use and are still used in the majority of stand-alone alternative energy systems. They have the longest life and the least cost per amp-hour of any of the choices. However the other side of the coin is, in order to enjoy these advantages, they require regular maintenance in the form of watering, equalizing charges and keeping the top and terminals clean. Some examples of flooded lead-acid batteries used in solar and wind electric systems are 6 volt golf-cart batteries, 6 volt L-16's and 2 volt industrial cells for large systems.

Batteries: Sealed AGM

AGM batteries are seeing more and more use in solar electric systems as their price comes down and as more systems are getting installed that need to be maintenance free. This makes them ideally suited for use in grid-tied solar systems with battery back-up. Because they are completely sealed they can't be spilled, do not need periodic watering, and emit no corrosive fumes, the electrolyte will not stratify and no equalization charging is required. AGM's are also well suited to systems that get infrequent use as they typically have less than a 2%/month self discharge rate during transport and storage. They can also be transported easily and safely by air. Last, but not least, they can be mounted on their side or end and are extremely vibration resistant. AGM's come in most popular battery sizes and are even available in large 2 volt cells for the ultimate in low maintenance large system storage. When first introduced, because of their high cost, AGM's were mostly used in commercial installations where maintenance was impossible or more expensive than the price of the batteries. Now that the cost is coming down they are seeing use in all types of solar systems as some of today's owners think the advantages outweigh the price difference and maintenance requirements of flooded lead acid batteries.

Batteries: Sealed GEL Cell

Gelled lead acid batteries actually predate the AGM type but are losing market share to the AGM's. They have many of the same advantages over flooded lead acid batteries including ease of transportation, as the AGM type, except the gelled electrolyte in these batteries is highly viscous and recombination of the gases generated while charging, occurs at a much slower rate. This means that they typically have to be charged slower than either flooded lead acid or AGM batteries. In a solar electric system you have a fixed amount of sun hours every day and need to store every solar watt you can before the sun goes down. If charged at too high a rate, gas pockets form on the plates and force the gelled electrolyte away from the plates, decreasing the capacity until the gas finds its way to the top of the battery and is recombined with the electrolyte. For use in a grid-tie with back up system or any system where discharge rates are less than severe, GEL batteries could be a good choice.

INVERTERS AND INVERTER/CHARGERS

An inverter is a device that converts battery power (DC) into alternating current (AC) of a higher voltage. This means that most inverters are installed and used in conjunction with a battery bank of some sort - a common set up in off grid solar installations.

Batteries are the heart of an inverter-powered electrical system, storing power for use on demand. The most basic way to draw electrical power from a battery is direct current (DC) at the nominal voltage of the battery. Your car radio, for example, uses 12 volts DC (12VDC), the same voltage as your car battery.

Many off-grid electrical systems (those not powered by electricity from a utility company) use 12-volt DC power to run simple loads such as lights. (Any consumption of electrical power is called a load.) Such systems are commonly referred to as low-voltage DC systems. Powered by a 12-volt DC system, you can enjoy the benefits of electric lights, entertainment systems, laptop computers, and other devices that can be operated off a car battery. However, you can't run power tools, kitchen appliances, or office machines, without the help of some device that generates "household" electricity - or AC current.

How to Select an Inverter for Your Needs

All inverters convert direct current (DC) electricity into alternating current (AC) electricity. That's where the similarities end between inverters. These days, a huge number of brands and options are available to consumers. The correct choice depends on how you intend to use the inverter. Options range from small mobile power units to mid-sized stationary inverters for powering homes in either remote off-grid or urban on-grid locations.

Portable Inverters

For portable power needs, smaller inverters, ranging in size from 100 to 2,000 watts or more are available for either marine , motor home/RV , or other smaller off-grid applications , such as a tool shed or barn. These portable inverters are meant for locations without utility electricity, and are used to convert DC electricity from a battery that is either charged by your vehicle's motor, or a stand-alone generating source like a PV Solar panel, wind generator , or engine-generator. Marine inverters are built to withstand harsh weather conditions and corrosion from exposure to salt water, so if you're planning to use your inverter on a boat, choose a seaworthy type.

Depending on the types of appliances you will be running and how sensitive they are, you can choose between pure sine wave inverters or what are called square-wave or modified square-wave inverters. Modified square-wave inverters cost less than pure sine-wave inverters because they perform less sophisticated power conversions, delivering choppier transitions in the alternating current's output. When running appliances that have motors (such as refrigerators, drills, fans, etc.), modified square-wave inverters will run these motors hotter and consume 30% more energy than if you used a pure sine-wave inverter. It's a bit like running a car on square wheels instead of round ones. The car will go forward, but it will run far less efficiently

For some appliances and electronics, such as motors, televisions, computers, and battery chargers for cordless tools, a poor waveform can cause overheating, damage the equipment, or even cause complete malfunction. Some manufacturers will not offer a warranty on their product if used with modified or square wave inverters. Other potential problems are inverter noise in devices like compact fluorescent bulbs, radios, stereos, and televisions. For most people, the small difference in price makes it worthwhile to buy a pure sine-wave inverter in the first place so that they don't face limitations later if they want to use their inverter for another appliance.

Recommended models are:-

Outback Power GFX series

Morningstar SI-300 series

The size of your portable inverter depends on what appliances or tools you are planning to use and their power requirements, called the "load." You will need to know how many continuous watts your tools require to run, how many different tools you plan to run at the same time, and also how much of a surge, or power draw, they have when first starting up, as with some larger motors like power saws.
This information for each tool is usually found on what is called a "nameplate." The nameplate rating will give the information either in watts or in volts and amps. For general purposes, multiplying the volts times the amps gives you the number of watts (V x A = W). For determining power surge requirements, see the tool manufacturer's specifications, measure with an ammeter, or "guesstimate" it by multiplying the continuous watts times three (although the surge can sometimes be as much as seven times).

Home-Sized Inverters

The largest share of inverters being sold on the worldwide market today are for use in home energy systems. In the early days of the industry, inverters were built for remote, off-grid use where commercial power was unavailable. However, today most inverters in developed countries are being used for on-grid applications where grid-ties allow for clean, renewable energy to be produced and distributed into the larger public utility systems, displacing some of the energy previously supplied by burning coal and oil.

Off-grid and on-grid inverters serve two entirely different types of needs. On-grid inverters are subdivided into two further categories -- with and without battery backup . The type of inverter you will need is based on whether or not utility service is available at your location, and if available, how reliable that service is compared to your needs.

Off Grid

As primitive as the earliest inverters were, they provided the ultimate luxury and modern conveniences for living in remote locations. If your property is off-grid, it's likely that bringing in the utility even a short distance will cost a great deal more than setting up your own off-grid electrical system.
Off-grid inverters are much more sophisticated these days, with capabilities of coordinating battery maintenance and charging regimens, and turning on backup power automatically, making these systems easier to maintain, simple to use, and worry free. As with portable systems, while less expensive usage patterns. This assessment needs to be done carefully and with absolute honesty to yourself so that your entire system is sized correctly and will function without failure. The size inverter you need is based on what is called your "peak load" requirements -- all the AC loads that could be turned on at the same time.

On-Grid, without Backup

The grid-tied system without battery backup is the simplest and least expensive option for home energy systems. All that is required for this system are solar PV panels and an inverter, connected to your home's main switchboard, along with a disconnect switch and separate meter , depending on the local utility's requirements.

Grid Tie Inverters connect directly to the utility grid and do not require batteries. A battery-less system is much less complex (and less costly) than a system with batteries. The drawback is that a system without batteries cannot supply power to the home in the case of a power outage. For the safety of the workers working on the utility power lines, the grid-tied inverter will shut down until power has been restored. If frequent power outages are not an issue, then a utility grid-tied system can be an excellent, cost effective option.

On-Grid with Battery Backup

These inverters are intended to hook directly to the utility grid and can still allow a battery bank to provide power for a back up system. They are typically at least 2500 watts and can operate with 24 or 48 volt battery banks.

Pure sine wave inverters will generally meet or exceed the quality of electricity supplied from the power company. The peak voltage, and RMS voltage of these waveforms from inverters will generally match that of the grid or come very close. The quality of the sine wave output for pure sine wave inverters, ensure the proper operation of all types of AC loads.

Characteristics of Inverters

Here is a list of the important characteristics of inverters. These are the factors to consider when selecting an inverter.

Where is the inverter to be used ?

- Home
- Recreational vehicle
- Marine
- Portable
- Emergency backup

Electrical standards

- DC input voltage
- AC output voltage and frequency
- Power capacity (watts) (How much will it put out?)
- Continuous rating
- Limited duration ratings
- Surge rating (for starting motors/pumps)
- Expandability (modularity, stackability)

Power quality (waveform) Some inverters produce "cleaner" power than others.

- **Sine wave inverters**
  Ideal, smoothly alternating AC
  Equivalent (or superior) to grid power, relatively expensive

- **Modified sine wave inverters**
  Inferior waveform, choppy alternation
  Inexpensive
  Adequate for many homes with simple needs, but about 5% of loads malfunction
  May confuse digital timing devices in some appliances
  May overheat power converters in some appliances/computers
  May overheat surge protectors (don't use them) causes some devices to buzz (some fluorescent lights, ceiling fans, transformers)
  Reduces energy efficiency of motors and transformers by 10% or more, causes motors and transformers to run hotter
  Generally reduces the reliability of appliances

Internal protection

- Overload and surge protection
- Low voltage shutoff

Inductive load capability

- Some loads accept the AC wave with a slight time delay. These are call inductive loads. Motors are the most severely inductive loads.
- Starting large motors (well pump, washing machine, power tools, etc.)

Physical attributes - There are two ways that inverters are built:

Transformer type inverters

- Heavy, expensive
- High surge capacity
- Historically the most reliable
- Makes buzzing noise

High frequency switching type inverters

- Light weight, inexpensive
- Less reliable in cases of cheap consumer units
- No audible buzz

Efficiency

It is not possible to convert power without losing some of it (think of "friction"). Efficiency is the ratio of power out to power in, expressed as a percent. If the efficiency is 90%, that means 10% of the power is lost in the inverter. Lost power manifests as heat. Efficiency of an inverter varies with the load. Typically, it will be highest at about 2/3 of the inverter's capacity. This is called its "peak efficiency". The inverter requires some power just to run itself, so the efficiency of a large inverter may be low when running very small loads. In a typical home, there are many hours of the day when electrical load is very low. Under these conditions, an inverter's efficiency may be around 50% or far lower. The full story is told by a graph of efficiency vs. load, as published by the inverter manufacturer. This is called the "efficiency curve". Watch out. Some manufacturers cheat by drawing the curve only down to 100 watts or so, not down to zero!
Because the efficiency varies with load, don't assume that an inverter with 93% peak efficiency is better than one with 85% peak efficiency. The 85% efficient unit may be more efficient at low power levels, for example.

Automatic on/off

As stated above, an inverter takes some power just to run itself. This "idling" can be a substantial load on a small power system. Cheap portable inverters usually have a manual on/off switch. If you forget to turn the inverter off, you may surprised by a discharged battery bank after a few days. Most inverters made for home power systems have an automatic load-sensing system. The inverter puts out a brief pulse of power about every second (more or less). When you switch on an AC load, it senses the current draw and turns itself on. Manufacturers have various names for this feature, like "load demand", "sleep mode", "power saver", or "standby". This feature can make life a bit awkward because a tiny load may not trigger the inverter to turn on. For example, you start your washing machine and after the first cycle, it pauses with only the timer running. The timer may draw less than 10 watts. The inverter's turn-on "threshold" may be 10 or 15 watts. The inverter shuts off and doesn't come back on until it sees additional load from some other appliance. Some people solve this problem by leaving a small light on while running the washer.

Some system users cannot adapt to this situation. Therefore, inverters with automatic on/off also have an "always on" setting. That way, you can run your low- power night lights (they won't flash on/off) and your clocks and other tiny loads without losing continuity. A good system designer will then add the inverter's idle current into the load calculation (24 hours per day), and the cost of the power system will be correspondingly higher.

Battery charging features

Some inverters have a built-in battery charger that will recharge the battery bank whenever power is applied from an AC generator or from the utility grid (if the batteries are not already charged). This function is essential to most renewable energy systems because there are likely to be occasions when the energy supply (sun, wind) is insufficient. It also makes an inverter into a complete emergency backup system for on-grid power needs with batteries.

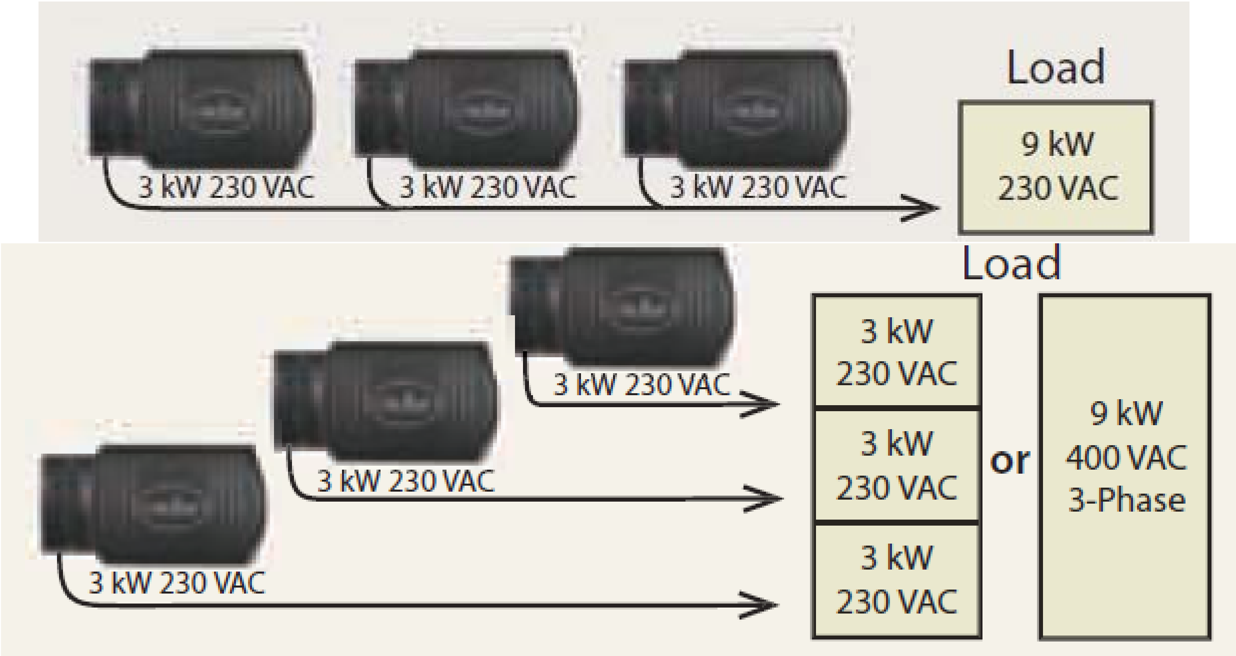
Here is a list of specifications that relate to battery charger function:

- Maximum charging rate (amps)
- Generator size and voltage requirements
- Charge control features, including accommodation of different battery types (flooded or sealed), temperature compensation, and other refinements

Be careful when sizing a generator to meet the requirements of an inverter/charger. Some inverters require that the generator be oversized. Be sure to get experienced advice on this, or you may be disappointed by the result.

Expansion options

- Some inverters can be "stacked" to expand their capacity



Laboratory Certification

- Inverters should be certified by an independent testing laboratory such as UL, ETL, CSA, etc., and stamped accordingly. There are different design and rating standards for various applications, such as use in buildings, vehicles, boats, etc. These also vary from one nation to another. An inverter used for a home power system must be appropriately rated for the system to pass an electrical inspection.

Phantom loads

- High tech consumers are stuck with gadgets that draw power all of the time that they are plugged in. These little demons are called "phantom loads" because their power draw is unexpected, unseen, and easily forgotten. Examples:- TV with remote control, any devices with an external wall-plug transformer or a built-in clock, plus smoke detectors, alarm systems, motion detector lights, fax machines, answering machines, and all cordless (rechargeable) appliances. Central heating systems have a transformer in their thermostat circuit that stays on all the time. How many phantom loads do you have?

There are several ways to cope with phantom loads.

- You can avoid them (easy for a small bach or other simple- living situation).
- You can minimize their presence and disconnect them when not needed, using external switches.
- You can work around them by modifying certain equipment to shut off completely.
- You can substitute devices that use DC power instead of AC.
- You can pay the additional cost for a large enough power system to handle the extra loads plus the inverter's idle current. Be very careful and honest when considering avoiding all phantom loads.

You cannot always anticipate future needs or human behaviour. All it takes is one phantom load to mess up your perfect plan.

<u>Quality: You get what you pay for</u>

A good inverter is reliable and able to handle a wide variety of loads without wasting lots of energy. It is well protected from surges from nearby lightning and static, and from surges that bounce back from motors under overload conditions. A good inverter is an industrial quality device that is proven and certified for safety, and can last for decades. A cheap inverter may soon end up in the junk pile, and can even be a fire hazard. Consider an inverter to be a foundation component. Buy a good one that allows for future expansion of your needs.

WIND POWER

If you are building a home in a remote location, a small wind energy system can help you avoid the high costs of extending utility power lines to your site.

How to determine if a Wind Turbine System is Practical for You

If you are a homeowner considering using wind turbines to power your home, there are a number of considerations. Fortunately, there are also a number of information sources to help you. The following will help you decide if a wind system is practical for you.

What are the benefits to homeowners from using wind turbines?

Although wind energy systems involve a significant initial investment, they can be competitive with conventional energy sources when you account for a lifetime of reduced or altogether avoided utility costs. The length of the payback period—the time before the savings resulting from your system equal the system cost—depends on the system you choose, the wind resource in your site, electric utility rates in your area, and how you use your wind system.

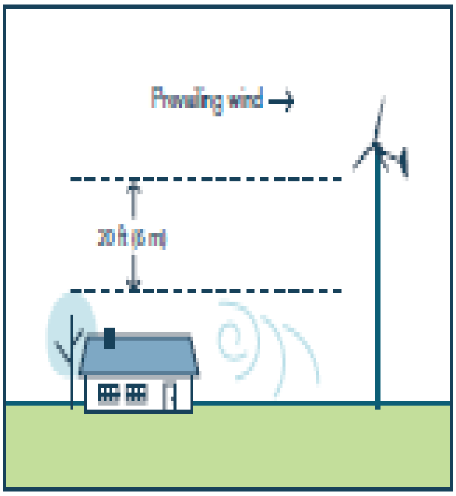
Is wind power practical for you?

Small wind energy systems can be used in connection with an electricity transmission and distribution system (called grid-connected systems), or in stand-alone applications that are not connected to the utility grid. A grid-connected wind turbine can reduce your consumption of utility-supplied electricity for lighting, appliances, and electric heat. If the turbine cannot deliver the amount of energy you need, the utility makes up the difference. When the wind system produces more electricity than the household requires, the excess can be sold to the utility. With the interconnections available today, switching takes place automatically. Stand-alone wind energy systems can be appropriate for homes, farms, or even entire communities that are far from the nearest utility lines.

Either type of system can be practical if the following conditions exist.

Conditions for stand-alone systems

- You live in an area with average annual wind speeds of at least 4.0 meters per second (9 miles per hour)
- A grid connection is not available or can only be made through an expensive extension. The cost of running a power line to a remote site to connect with the utility grid can be prohibitive, ranging from $15,000 to more than $50,000 per kilometre, depending on terrain.
- You have an interest in gaining energy independence from the utility
- You would like to reduce the environmental impact of electricity production
- You acknowledge the intermittent nature of wind power and have a strategy for using intermittent resources to meet your power needs



Conditions for grid-connected systems

- You live in an area with average annual wind speeds of at least 4.5 meters per second (10 miles per hour).
- Utility-supplied electricity is expensive in your area (about 12 to 18 cents per kilowatt-hour).
- The utility's requirements for connecting your system to its grid are not prohibitively expensive.
- Local building codes or covenants allow you to legally erect a wind turbine on your property.
- You are comfortable with long-term investments.
- Is your site right?

You will need site-specific data to determine the wind resource at your exact location. If you do not have on-site data and want to obtain a clearer, more predictable picture of your wind resource, you may wish to measure wind speeds at your location for a year. You can do this with a recording anemometer, which generally costs $500 to $1,500. The most accurate readings are taken at "hub height" (i.e., the elevation at the top of the wind turbine tower). This requires placing the anemometer high enough to avoid turbulence created by trees, buildings, and other obstructions. You can have varied wind resources within the same property. If you live in complex terrain, take care in selecting the installation site. If you site your wind turbine on the top of or on the windy side of a hill, for example, you will have more access to prevailing wind than in a gully or on the leeward (sheltered) side of a hill on the same property. Consider existing obstacles and plan for future obstructions, including trees and buildings, which could block the wind. Also realize the power in the wind is proportional to its speed (velocity) cubed (v^3). This means that the amount of power you get from your generator quadruples when the wind speed doubles.

In addition to the factors listed previously, you should also research

- potential legal and environmental obstacles
- obtain cost and performance information from manufacturers
- perform a complete economic analysis that accounts for a multitude of factors
- understand the basics of a small wind system
- review possibilities for combining your system with other energy sources, backups, and energy efficiency improvements.

You should establish an energy budget to help define the size of turbine that will be needed. Since energy efficiency is usually less expensive than energy production, making your house more energy efficient first will likely result in being able to spend less money since you may need a smaller wind turbine to meet your needs.

Potential Legal and Environmental Obstacles

Before you invest any time and money, research potential legal and environmental obstacles to installing a wind system.

- Some councils restrict the height of the structures permitted in residentially zoned areas, although variances are often obtainable
- Your neighbours might object to a wind machine that blocks their view, or they might be concerned about noise.
- Consider obstacles that might block the wind in the future (large planned developments or saplings, for example).
- If you plan to connect the wind generator to your local utility company's grid, find out its requirements for interconnections and buying electricity from small independent power producers.

The Economics of Wind Power for Home Use

A residential wind energy system can be a good long-term investment. However, because circumstances such as electricity rates and interest rates vary, you need to decide whether purchasing a wind system is a smart financial move for you.

Wind System Basics

All wind systems consist of a wind turbine, a tower, wiring, and the "balance of system" components: controllers, inverters, and/or batteries.

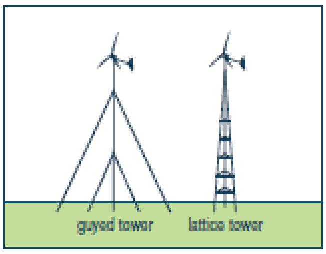
Wind Turbines

Home wind turbines consist of a rotor, a generator mounted on a frame, and (usually) a tail. Through the spinning blades, the rotor captures the kinetic energy of the wind and converts it into rotary motion to drive the generator. Rotors can have two or three blades, with three being more common. The best indication of how much energy a turbine will produce is the diameter of the rotor, which determines its "swept area," or the quantity of wind intercepted by the turbine. The frame is the strong central axis bar onto which the rotor, generator, and tail are attached. The tail keeps the turbine facing into the wind.

A 1.5-kilowatt (kW) wind turbine will meet the needs of a home requiring 300 kilowatt-hours (kWh) per month, for a location with a 6.26-meters-per-second (14-mile-per-hour) annual average wind speed. The manufacturer will provide you with the expected annual energy output of the turbine as a function of annual average wind speed. The manufacturer will also provide information on the maximum wind speed in which the turbine is designed to operate safely. Most turbines have automatic speed-governing systems to keep the rotor from spinning out of control in very high winds. This information, along with your local wind speed distribution and your energy budget, is sufficient to allow you to specify turbine size.

Towers

Because wind speeds increase with height in flat terrain, the turbine is mounted on a tower. Generally speaking, the higher the tower, the more power the wind system can produce. The tower also raises the turbine above the air turbulence that can exist close to the ground. A general rule of thumb is to install a wind turbine on a tower with the bottom of the rotor blades at least 9 meters (30 feet) above any obstacle that is within 90 meters (300 feet) of the tower.
Experiments have shown that relatively small investments in increased tower height can yield very high rates of return in power production. For instance, to raise a 10-kW generator from a 18-meter (60-foot) tower height to a 30-meter (100-foot) tower involves a 10% increase in overall system cost, but it can produce 25% more power.



There are two basic types of towers: self-supporting (free standing) and guyed. Most home wind power systems use a guyed tower. Guyed-lattice towers are the least expensive option. They consist of a simple, inexpensive framework of metal strips supported by guy cables and earth anchors.
However, because the guy radius must be one-half to three-quarters of the tower height, guyed-lattice towers require enough space to accommodate them. Guyed towers can be hinged at the base so that they can be lowered to the ground for maintenance, repairs, or during hazardous weather such as hurricanes. Aluminium towers are prone to cracking and should be avoided. Large wooden guyed poles or three pole systems are also commonly used for mounting the wind turbine.

Tips on How to Site a Small Wind Turbine for Your Location

- If tree growth at the site is not influenced by the prevailing wind (at least slightly visible flagging), and the wind is not a frequent nuisance, then the energy potential does not justify the investment.
- At most locations, wind energy is less consistent than PV, and usually peaks at different times. Wind is best used in a hybrid system with PV.
- The generator must be placed higher than all obstructions within 150meters in all directions, by at least 10 meters plus the blade radius.
- For a tower structure, budget 1 to 2 times the cost of the wind generator.

Tower height is crucial for two reasons:
- Adding tower height is the cheapest way to gain greater and more consistent energy yield. (
- Turbulence is greatly reduced with height. Turbulence is the equivalent of rocks on a highway. Sudden shifts in wind direction cause vibrations and stresses that greatly reduce reliability as well as energy output.

Micro Hydro Power

A hydro system is much more site-specific than a wind or solar electric system. A sufficient quantity of falling water must be available. The vertical distance the water falls is called ‘head’ and is usually measured in meters. The quantity of water is called ‘flow’ and is measured in liters per second (l/s). More head is usually better because the system uses less water and the equipment can be smaller. The turbine also runs at a higher speed. At very high heads, pipe pressure ratings and pipe joint integrity become problematic. Since power is the product of head and flow, more flow is required at lower head to generate the same power level. More flow is better, even if not all of it is used, since more water can remain in the stream.

Most hydro systems are limited in output capacity by stream conditions. That is, they cannot be expanded indefinitely like a wind or PV system. This means that the sizing procedure may be based on site conditions rather than power needs. The size and/or type of system components may vary greatly from site to site. System capacity may be dictated by specific circumstances (e.g., water dries up in the summer). If insufficient potential is available to generate the power necessary to operate the average load, you must use appliances that are more energy efficient and/or add other forms of generation equipment to the system. Hybrid wind/PV/hydro systems are very successful and the energy sources complement each other.

Despite the careful design needed to produce the best performance, a micro hydro system isn't complicated. The system is not difficult to operate and maintain. Its lifespan is measured in decades. Micro hydro power is almost always more cost-effective than any other form of renewable power.

Who should buy a micro hydro system?

A micro hydro is cost-effective for any off-grid site that has a suitable water resource, and even for some that are on-grid.

Homeowners without utility power have three options:-

- Purchasing a renewable energy system
- Extending the utility transmission line
- Buying a petrol or diesel generator.

Transmission line extension can be expensive because its cost depends on distance and terrain. Even the initial cost of a hydro system may be lower.

A petrol or diesel generator may be cheaper to purchase but is expensive to operate and maintain. The life-cycle cost of the hydro system is much lower than that of a generator.

Once the hydro system is paid for, there's no monthly electricity bill and minimal maintenance costs. Since utility electricity rates tend to rise, the value of the power increases, making your investment "inflation-proof."

RENEWABLE ENERGY SYSTEMS IN YOUR MOTORHOME OR BOAT

Solar and wind power systems are more frequently being used on Motor homes, caravans, launches and yachts to do everything from provide a main source of power without the use of a noisy generator to keeping the main battery bank from slowly discharging while the boat or motor homes not in use.

Solar panels on Motor homes and caravans are a great way to extend your independence from running your generator as often.
Solar and wind electric systems can both be used effectively to charge the large battery bank in a motor home or a boat. Due to the space limitations for both a solar panel array or a turbine that's capable of much more than 400 watts, you can't expect to be able to run all of the appliances you could run a normal home. Most notably it is not appropriate to run air conditioning nor electric heating systems off a wind or solar system. These devices simply consume too much power for even a moderately sized system to handle. However, solar and wind power have been used for years to effectively power lights, microwaves, televisions, radios, small water pumps among many other electronic devices you find in a motor home or a boat.

Many people use a very basic and small solar electric charging system to keep their battery bank topped off while leaving their motor home or boat unused for several months out of the year. By trickle charging their batteries during periods of non-use, they greatly extend their lifetime. Batteries, left alone, will discharge by themselves 5% or more per month. A simple, small, solar electric panel connected to the battery bank will prevent this discharge from occurring.

Difference Between a Typical Motor home or Boat Renewable Energy System and a Home System

In most ways a motor home or a marine wind or solar electric system is the same as an off-grid renewable energy system for a home. All of these systems share the basic components. A wind turbine or solar electric panels, charge controller, inverter, deep cycle battery bank, cabling, and AC / DC breakers and fuses. In most cases, the primary difference is that the solar panel array or wind turbine is smaller than what would be on a typical off-grid home. On a motor home or boat there is a limited amount of surface to mount a solar electric panel array. Because of vibrational noise, only the smallest of wind turbines can be used.

Similar to the higher quality inverters for off-grid home systems, motor home and marine inverters almost always include an AC charging system that will automatically charge up the battery bank when motor home or boat is connected to "shore" power.
Recently, some models of solar charge controllers have become available specifically for the mobile market that allow the solar panel array to principally charge deep cycle "house" battery bank and also trickle charge the separate 12-volt battery used to start the motor home's engine.

It is very common for people to interchange components that were originally marketed towards Motor home or Marine uses with off-grid applications, and vice-versa. The application that needs the most thought before using components designed for other markets is that of marine, because of the tougher environmental conditions.
Recommendations

As with off-grid home systems, we would not recommend that a customer try to run very large electrical loads like an air conditioning unit or an electric heating system off of a renewable energy system. These loads would likely drain the typical battery bank in a matter of minutes. To further reduce the load on their system, consider using a LPG refrigerator instead of a normal AC refrigerator, since they can be run with no electricity at all.

In addition to making sure that all of their components can resist the salty air, boat owners might consider using deep cycle, sealed lead acid batteries instead of the traditional deep cycle flooded lead acid batteries. With a lot of movement due to waves or the tipping of a boat normal flooded lead acid batteries can potentially spill a little bit of their sulphuric acid fluid through their caps, whereas a sealed battery can be turned upside down without spilling.

When choosing an inverter for motor home or boat, be sure to get one that has an AC battery charger incorporated, so that when you connect to shore power you can completely charge up your battery bank quickly if your renewable energy system was unable to do so. Remember also, to look for an inverter that has Neutral to Ground bonding to avoid any nasty shocks when connected to shore power.

The Morningstar SS-MPPT-15L and the SunSaver Duo SSD-25RM are MPPT charge controllers designed specifically for Motor home use. These controllers are up to 30% more efficient in charging your battery bank and well worth the extra money.

In a typical off grid renewable energy system, much care is taken to be sure that shadows from nearby buildings or vegetation don't fall on a solar panel array. In RV or Marine system you simply cannot plan whether or not the mast of your sailboat or the twig of a nearby tree is partially shading a solar array. For most types of solar electric panels, just a little bit of shadowing will greatly reduce the output of the entire solar panel array by 30-50% or more. Be very careful with shading.

Special adjustable solar panel mounts for RV can be used to optimize the position of the panels to take in the most sun as possible. It is most common that the solar panels on RVs are installed with aluminium mounting feet that raise the panels just an inch or so off of the roof of the RV. There are also special RV mounting systems which allow you to raise and angle up the solar panels so that you can optimize their orientation towards the sun. These racks or mounts are not usually designed to be in the upright position while the vehicle is in motion, so you need to remember to bring them down before going anywhere. Also, be aware that while these mounts tilt up they do not swivel to point north, so you will need to orient the entire RV to optimize the direction of the solar panels.
An alternative to tilting the solar panel(s), is to install an additional panel to make up for the loss in power production brought about by mounting panels flat on the roof of the motor home.

BALANCE OF SYSTEM COMPONENTS

As well as the major products described above, there are many more components required to make up the Balance of System in a Renewable Energy design.

Cabling, Solar PV mounting, DC and AC disconnects, Circuit Breakers, System enclosures (both AC and DC), BUS bars, PV Combiners, Battery Monitors and Shunts are all vital parts of your Renewable Energy System, and should be chosen carefully.

A Battery Monitor is essential in any system. Typically you will 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.

Simple 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 that report instantaneous information are less complex and less expensive and only give a general idea of what is happening in your system.

Cumulative type monitors, such as the Bogart TM-2525RV, Outback FN-DC, Magnum ME-BMK and the Schneider/Xantrex LinkLITE and TM500, usually include instantaneous information, but go much further by recording power production and usage over time. With this information (amp hours or watt hours) you can see how much power was generated yesterday or last month, and how much power was used.

Available information also includes:-
- Battery volts
- Battery amps
- Battery % full
- Days since batteries were last fully charged
- Days since batteries were equalized

What is Grid Connected Solar ?

Grid-Connected - No Batteries

Grid Connect Systems, often located in built-up areas, supply solar electricity through an inverter directly to the house, and to the electricity grid if the system is providing more energy than the house needs. When power is supplied to the mains grid, the home owner usually receives a credit or a payment for that electricity.

Any size grid connect solar power system will reduce your yearly power consumption and your power bill. Naturally the bigger the system, the bigger the benefit.

To make the most of solar power, the key is to implement simple energy efficiency measures. It is easy to conserve energy by using appropriate lighting and efficient appliances. Running high power appliances such as electric heaters, electric hot water systems and air conditioners etc. is really not economical.

Instead of considering a very large solar system, it is advisable to invest in energy efficient heaters, solar hot water and design features such as strategically placed vents or insulation to avoid heat entering the house in the first place. In summary - all your energy can be supplied by solar power and your budget and daily energy usage will determine the size of your solar power system.

What happens on cloudy days?

In a grid connected system you are still tied to the mains power supply, and any deficit will come from the mains grid.

Grid Connected with Batteries

With the addition of a small battery bank and a DC to AC power Inverter/Charger, a solar powered grid connected house can have electricity available during a mains power system failure.

While your solar panels are producing power, some of it is diverted via the Battery Charger to the batteries, keeping them ready for you to draw power from during a mains power failure. Depending on the size of battery bank and inverter/charger that you install, you will be able to keep part of your electrical loads running. Usually, vital lighting, TV, and Radio could be supported for several hours during a blackout. The solar panels will continue to put power into the batteries during sunshine hours, but you will still need to be aware that you can only use minimal appliances and lights at this time.

What is the difference between solar power and solar hot water?

Solar panels take light from the sun and make electricity. Solar Hot Water Systems take heat from the sun and heat water. It is easy to remember:

Heat from the sun heats the water. Light from the sun turns on the lights.