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Solar Panel Systems

Solar Photovoltaic Introduction

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Solar Panel Systems

Introduction

In this guide we will be taking a look at the ever-evolving world of Solar Photovoltaic, or PV for short and how the Do It Yourself movement is changing the upfront costs associated with PV. In essence, we will be examining how we have learned to take the sun's energy and convert that into electricity in a low cost manner.

The sun has an enormous amount of energy, evident by the sunburns we have all put ourselves through. Humans have learned to passively harness this energy for thousands of years, using the sun's rays to warm their homes or dry their food and clothing.

Not until the latter part of the 19th century, however, did we discover how to convert those powerful rays of sunlight into usable energy in the form of direct current (DC) electricity. This important breakthrough will be discussed, with the various types of solar cells that have been developed and the pros and cons of each.

The main components of a solar electric system will be identified and discussed, and, finally, we will discuss the steps towards constructing your own solar PV panel to harness the sun's full potential.

PV History

The roots of photovoltaic can be traced all the way back to 1839 when 19 year old physicist Alexandre Edmond Becquerel was experimenting with an electrolytic cell made up of two metal electrodes and stumbled upon the photovoltaic concept.

Forty years later, in 1873, Willoughby Smith discovered the photoconductivity of selenium, and in 1883 Charles Fritts, an American inventor, described the first solar cell derived from selenium wafers.

Even Nikola Tesla and Albert Einstein got into the concept of photovoltaic in the early years. Tesla received a US patent for the "method of utilizing, and apparatus for the utilization of, radiant energy" and Einstein received the Nobel Prize for a 1904 paper on the photoelectric effect.

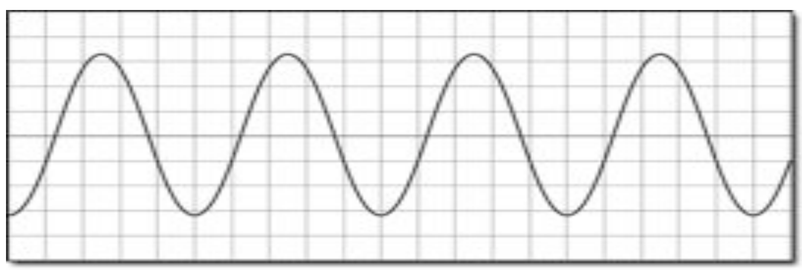
Then, in 1954 Bell Labs exhibited the first high-power silicon PV cell. Based upon the momentum of the photovoltaic sciences, the New York Times forecasted that solar cells will eventually lead to a source of "limitless energy of the sun".

This was done even though the cells back then were only about 5.5% efficient – compare that to the 20%+ efficient cells now! And the commercial age of photovoltaic has really just begun and we can expect some of the biggest technological breakthroughs yet to come.

The Science of Solar Electricity

Electricity Basics

Solar panels generate direct current (DC) electricity. Think of a garden hose that is simply turned on, it produces water in a steady stream. Most household electronics and the electrical power grid are designed to take alternating current (AC) power. Now imagine that the water coming out of the garden hose is being turned off and on so quickly that it has a "pulse" and the water comes out in waves. This is done because AC power travels over long distances much more efficiently.



AC power flows in waves as you see above, DC power flows in a straight line.

This means however, that the electricity coming out of the solar array must be converted to AC if it is going into your home. This is done with an inverter, which takes the DC power and makes AC power. The power is then ready to service your home, an electrical grid, or a device. Some devices (certain lights, batteries, special devices) use DC power and therefore do not need an inverter.

How Solar Power Panels Work

The most basic definition of how solar panels work is that the sun strikes a certain material, it excites electrons and creates a current and voltage that can be used to power devices. Now let's delve a little deeper.

<u>Silicon: Not Just for Cmoputer Chips</u>

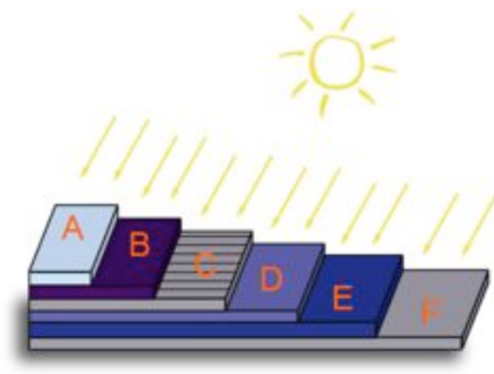
First, silicon is taken from the earth. Silicon is one of the earth's most abundant elements. It's found in sand and rocks of all types. You've probably heard of 'Silicon Valley', the hotbed of technology research and investment in California. It is so called because silicon is used in computer chips.

Silicon is a semi-conductor. Think of copper, a conductor, as in copper wires. Now think of rubber, an insulator, such as the coating on a copper wire. Silicon falls somewhere in between and is therefore called a semi-conductor. This property is exploited in computer chips and solar panels to handle tiny reactions that generate electrical currents.

<u>Just Add Boron and Phosphorous</u>

But silicon by itself is not enough to create power from the sun. The silicon is grown into a very thin crystal-like wafer using pressure and heat. It is then coated with two different materials: boron and phosphorous. Boron is coated on the back contact, phosphorous on the front contact, with a gap in between the two layers. Boron, when combined with silicon, is a positive material, but it wants to be neutral. The only way it can get neutral is to gain an electron, which has a negative charge.

Now enter phosphorous. Phosphorous and silicon is a negatively charged material, meaning it has extra electrons. But it wants to be neutral too! And how can it do that? By getting rid of electrons of course! And how will it get rid of them? That's where the good old sun comes in.



A cross section of a solar panel showing the various layers.

A. Tempered Glass Cover Plate: The cover plate is used to protect the cells from the elements.

B. Anti-reflective coating: This prevent the rays from being reflected OUT of the cell.

C. Contact Grid: The electricity generated by the silicon needs to be able to flow to the terminals. To help with this a grid of wire is placed on top of the silicon so that the electricity can flow through the low resistance wire instead of the silicon. A grid must be used so that most of the silicon is left exposed to the light.

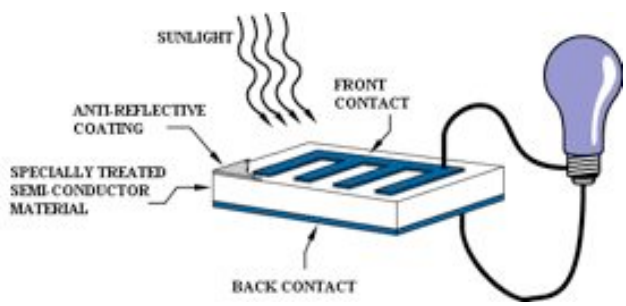
D. Silicon Layers: Silicon is a semiconductor material that is used to convert energy from the sun into electricity that can be used to power our homes. The silicon is the part of the solar cell that does the work. This silicon layer has a negative charge and is coated with phosphorous.

E. Same as the D layer, but this layer has a positive charge and is coated with boron.

F. Bottom Contact: This layer works the same as the contact grid that is placed above the silicon layers. It is used to help the electricity flow to the terminals.

Here Comes The Sun

When sunlight strikes the cell, it gets those electrons all excited. Just think of the electron as a kid in his mom's arms as they approach the park. He just can't wait to get away from mom and onto the swing set. The electrons leave the phosphorous and go toward the positive boron, creating an electrical pressure as they enter the gap. This pressure must be released, and is through the wiring in the cell. This creates the flow, or current, we talked about earlier.



The cells are coated with materials to ensure the sunlight is absorbed and not reflected. The silicon wafers are wired together and encased in tempered glass and aluminum to prevent weather damage. These are called panels, and are then wired together to form an array. And that is the basic building block reaction of a solar panel!

Types of Solar Cells

Solar cells are typically comprised of one of three solid types: monocrystalline, polycrystalline, and amorphous cells. While many different materials are used to make the solar cells, the most common element used for the monocrystalline and polycrystalline cells is silicon.

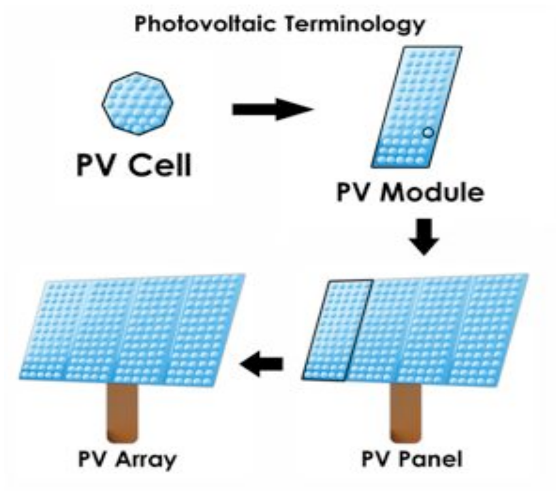
Silicon, while the second most abundant element on the Earth's crust, must be of the highest grade to be used in solar cell production. It must be cleaned of any impurities and superheated to form the ingots that are then thinly cut into the crystalline solar cells. Amorphous, or thin film, cells are comprised of many different elements: commonly cadmium, telluride or indium, among others. These cells are typically applied to a flexible substrate such as aluminum, certain plastics or even glass by evermore technically advanced methods.

Monocrystalline cells are the most efficient while polycrystalline cells are a close second. Amorphous cells, while considerably less efficient tend to cost only a fraction of what the crystalline cells do. The two types of crystalline cells comprise the panels that are typically used in residential installation.

Because they are so much more efficient than the amorphous cells, you do not need as much roof or ground space. However, due to amorphous panels' low costs they tend to be preferred for many commercial applications, since space is not an issue in many cases.

Solar Panels & Modules

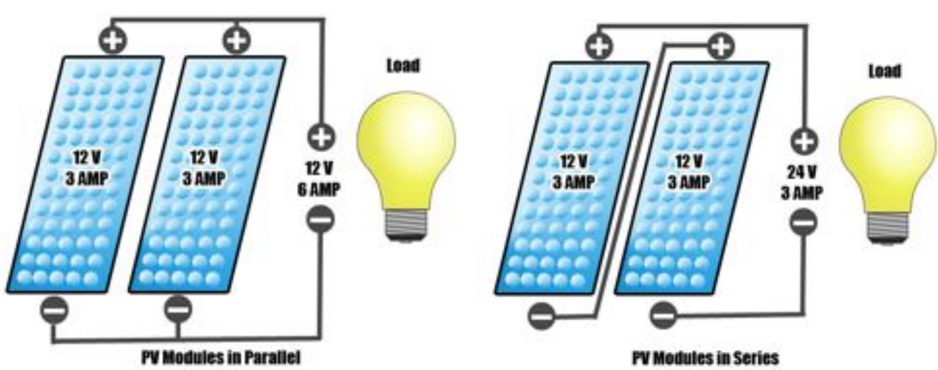
Photovoltaic (PV) cells are assembled together to create a solar module. The module is what you are used to seeing as a panel. It has anywhere from 2 to 200 cells assembled together, encased in tempered glass and aluminum to make them weather resistant.



The solar food chain

Tying Them Together

Like batteries, cells can be combined in series or in parallel to create larger and more specific voltages and amperages. For instance, four 1-volt/1-amp cells in series will combine for 4 volts, but the amperage will stay at 1 amp. By contrast, four 1-volt/1-amp cells in parallel will maintain 1 volt but have 4 amps of output. You can multiply the amperage by the wattage (in the example above 4 x 1) to get the watts generated.



Parallel wiring means that the if two cells are side by side the positive ends are connected to each other, and the negative ends are connected to each other. To connect cells in series, you connect the negative of one to the positive of another.

Sizes and Shapes

Modules can be made in a many sizes and shapes to fit their application. Panels come in standard rectangular, triangular, fold-able, and even rolls. This means they can be used in a wide variety of applications, from boats and recreational vehicles to electric cars and space stations.

The Solar Array

Modules are combined to create solar arrays. An array is a group of modules assembled together and designed to meet a certain electrical load. You've probably seen most arrays mounted on the rooftops of homes. These arrays are designed to generate a certain amount of electricity over the course of a year given the angle and installation.

Efficiencies

Generally solar modules convert about 10-15% of the energy that strikes them into electricity. This means that for every 100 units of energy that actually hit the panel, only 15 of them actually enter the home as electricity. This is the biggest area of research now, as scientists recognize that significant advancements in solar efficiency will lead to cheaper solar energy.

Calculating Volts, Amps & Watts

Solar cells output power can be measured in Volts and Amps. To compare this concept to water, the Voltage of a device can be related to the pressure of the water, while the Current (measured in Amps) can be compared to the amount of water flowing. This is an important concept to remember.

When you know both the Voltage and Current (or Amps) of a solar cell you can multiply them together to find its rating in Watts. Completed solar panels are rated in Watts, so it's important to understand this formula. Knowing just two parts of the formula, you can also derive the third component.

Often we need to determine how much power is used over time, so we multiply by hours. So if our 200 Watt panel produced full power for 3 hours, we would have 200W x 3 hours = 600 watt-hours, or 600-whrs. Often we are talking about thousands of watt-hours so use kilowatt-hours (kw-hrs) to measure energy. To do this we take 600w-hrs/1000= 0.6 kw-hrs. Your power bill measures your electrical consumption in kw-hrs.

Volts X Amps = Watts

For example, understanding the basic formula V (volts) x A (amps) = W (watts) allows us to derive the amps from a 100 Watt 18 Volt panel:

V x A = W or W/V=A

100w / 18v = 5.55 Amps that the panel will deliver

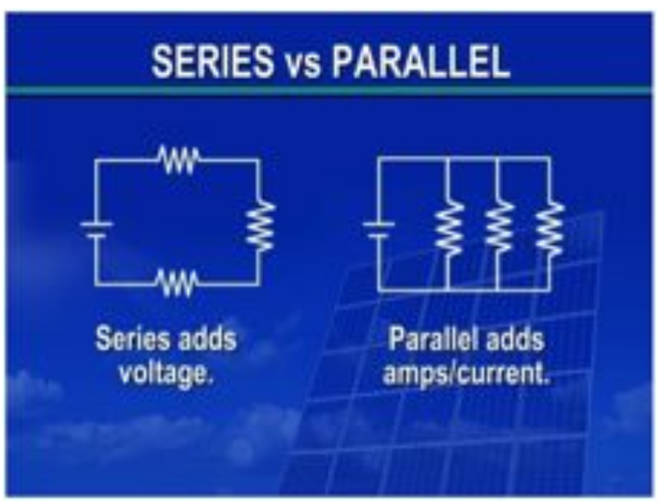
The best way to measure the output from the cells is to use a multimeter and touch the positive and negative leads to the positive and negative conductors on the solar cell under full sun. Once you know the Voltage and Amperage of your solar cells you can begin to wire them together to form the solar panel.

Connecting in Series or Parallel

The solar cells are wired together with conductors, commonly tab ribbon. This allows us to take the single solar cell and pair it with similar cells to create a solar panel with customizable power outputs.

There are two ways to connect the cells together. The first is in a "Series" connection, where the positive electrode from the cell is connected to the negative electrode of the next cell.

The second way is with a "Parallel" connection. This circuit takes the positive electrodes from the cells and connects it to the positive electrodes from the adjacent cell.



When you wire two cells together in Series you add the Voltage and the Current/Amps remains constant, while when you wire two cells together in Parallel you add the Current/Amps and the Voltage remains constant. This concept allows us to construct solar panels with customizable outputs.

Wired in "Series"

(Volts are added & Amps stay constant)

Wired in "Parallel"

(Amps are added, Volts stay constant)

Since most solar cells, regardless of size, will have an output of about 0.5 Volts, wiring the cells together in Series increases the Voltage a solar panel can achieve. And since the solar cells physical size determines the Current output (assuming the same type of cells are being used) we can create Parallel strings of cells to achieve the proper Current.

For example, if you have a 0.5 Volt X 3.5 Amp solar cell and you wire 20 of them in Series, this would give us about 10 Volts when exposed to the sun, while still outputting the original 3.5 Amps. On the other hand, if you take the same cells with 0.5 Volts and 3.5 Amps and wire 20 of them together in Parallel you would have a panel with 35 Amps but still just 0.5 Volts.

The same concept applies when wiring multiple panels together. Many larger solar inverters have a "voltage window," usually between about 150-450 Volts (depending on the inverter size and manufacturer).

In order to kick the inverter on we would have to wire enough solar panels together to raise the Voltage high enough for the inverter to operate properly.

You can also wire multiple solar panels together to achieve a higher Current/Amps, but take care not to raise the Current too high as it becomes dangerous and you may have a hard time finding fuses that can handle the higher Current levels.

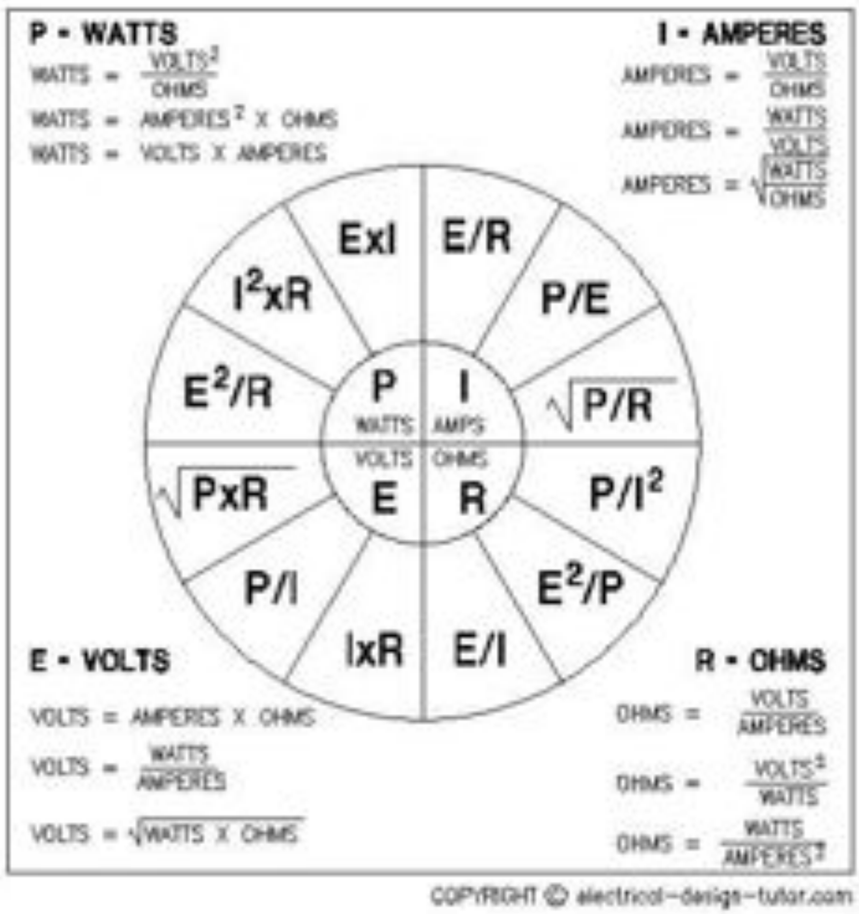
Voltage Drop

Every solar system will always start at the solar panel. This is where the energy starts, and from there it must enter some conductor to reach its destination. This conductor is typically an insulated copper wire. The amount of energy and the distance of the wire will determine what size wire to use.

In electrical circuits, Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference or voltage across the two points, and inversely proportional to the resistance between them. The mathematical equation that describes this relationship is:

$$I = \frac{V}{R}$$

"V" is the potential difference measured across the resistance in units of volts; "I" is the current through the resistance in units of amperes (amps) and R is the resistance of the conductor in units of ohms. A more thorough diagram to express the relationship between these units is shown below.



Typically you will want no more than 2% loss through your DC wire runs. There are several online calculators for determining this, or you may choose to do the math yourself using the table below.

Voltage Drop per 100 FT Run of Paired Wire

GAUGE (AWG)	.5 AMPS - Load Current	1 AMP - Load Current	2 AMPS - Load Current	4 AMPS - Load Current	10 AMPS - Load Current
10	0.10	0.20	0.40	0.80	2.00
11	0.13	0.25	0.50	1.01	2.52
12	0.16	0.32	0.64	1.27	3.18
13	0.20	0.40	0.80	1.60	4.00
14	0.25	0.50	1.01	2.02	5.04
15	0.32	0.64	1.27	2.54	6.35
16	0.40	0.80	1.60	3.20	8.00
17	0.50	1.01	2.02	4.03	10.08
18	0.64	1.27	2.54	5.08	12.71
19	0.80	1.60	3.20	6.40	16.01
20	1.01	2.02	4.03	8.07	20.17
21	1.27	2.54	5.08	10.17	25.42
22	1.60	3.20	6.40	12.81	32.02

For example; given a load current of 4 amps, and using 14 AWG wire, how much voltage drop can we expect at the load end for a 250 foot run of paired wire?

Using the chart, we match the row for 14 AWG and the column for 4 amps and determine that voltage drop per 100 feet is 2.02 Volts. By dividing the paired wire length by 100, we get the factor by which we need to multiply voltage drop per 100 feet to determine total voltage drop.

Therefore, 250 feet divided by 100 equals 2.5. Multiply 2.5 by 2.02 volts drop per 100 feet to get your total voltage drop. Thus the total voltage drop is 2.5 times 2.02, or 5.05 voltage drop for 250 feet. If your system voltage is 250 volts or more this may be acceptable loss. Note that the higher the voltage the lower the current, as they are inversely related.

If you have a long wire and have low system voltage you have 3 main choices. The first is to buy very thick wire, although the cost of copper these days may prohibit this. The second is to reduce the wire run by situating your solar array closer to your load. The third option is to increase the voltage by wiring more panels in series or by inverting the DC power to AC power at the site instead of the point of contact with the load. This may require putting the batteries closer to the array in an enclosure separate from your residence, but can result in some big savings since you will be running AC power at 120 or 240 volts instead of 12 volts.

$$\frac{350}{100} \times 1.27 = 4.45 \text{ Volts}$$

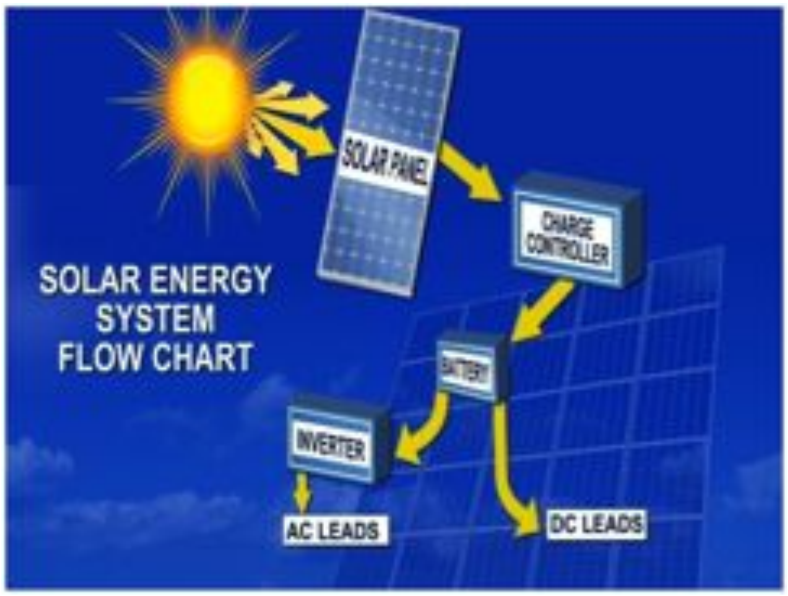
Solar Electric System Components

There are three main types of solar electric systems: off-grid, grid-tied, or grid-tied with battery backup. Off grid systems typically use batteries as their form of energy storage and have been around for many decades. These systems typically rely on a back-up power source like a generator for when the sun does not shine for prolonged periods.

Grid-tied systems have only gained popularity in recent years as utility, state, and federal incentives have made the solar system much more cost competitive with its dirty rivals: the fossil fuels. These grid-tied systems use the utility grid (the network of wires and cables that span every city and town in the US) to store their energy, sending excess energy into the grid during the day and pulling from it at night. A good resource to check to see what incentives are available in your locality is www.dsireusa.org.

There are numerous permitting and electrical codes that must be adhered to when connecting to the city grid and non-UL listed homemade solar panels absolutely can not be used in a grid-tied system.

In an off-grid application, the energy from the sun typically flows through these components:



Solar Panel:

As mentioned before there are different types of solar cells and methods of wiring them together to create the ideal Amps and Volts. When combining multiple solar panels together, you create a solar array that will create the power for a house or commercial application. This energy then must go through a series of components before finally being consumed.

Charge Controller:

From the solar panel the electrical current flows into a charge controller. This unit is in essence a regulator of energy. It is a customizable unit that regulates the flow of energy “to the batteries” and prevents energy being pulled “from the batteries” at nighttime or in cloudy weather. Depending on the size of the solar array you may spend anywhere from about $25 to over $800 USD for your charge controller(s).

Whenever batteries are present in a solar power system, a charge controller is needed. This is needed because, unlike other power sources that have an off and on switch, solar panels are pretty much 'on' as long as the sun is shining. This can be a problem if the batteries are at full capacity as overcharging them would ruin them. So the charge controller controls how much charge goes into the batteries and optimizes the energy they receive.

The charge controller can be programmed to stop flow from the batteries when they reach a certain depth of discharge (DOD). The DOD is typically no less than 50% of the battery’s capacity. The further you discharge a battery on a regular basis the shorter the life span of a battery will be.

Controllers are available in a variety of sizes and appearances.

A charge controller showing the voltage in a battery bank.

Charge controllers are also handy for measuring and displaying just how much charge the batteries have. More expensive versions can also measure the amperage coming in from the panels and the amperage going out to the home.

For full house off grid systems we'll often use a MPPT controller, which stands for Multi-Power Point Tracking controller. This is a technology that tracks the voltage and amperage flowing into your batteries and optimizes the power coming out of the solar panels for the batteries. Often times we will have a 24 volt solar panel, but a 12 volt solar battery, so the MPPT controller can alter the voltage automatically for the battery bank.

A 60 amp off grid charge controller

Most MPPT controllers also have a detailed display that will show you several critical pieces of information. The first vital piece of information is input amperage. This is what your panels are producing. Next it will show you the battery voltage, which will give you an idea of how ‘full’ your batteries are. This number is important for you to know since it will be the first to alert you if the batteries are low and you could either damage the batteries or lose power.

The controller won’t actually show a battery as ‘empty’. An ‘empty’ 12 volt battery actually has a voltage around 11 volts. ‘Full’ is about 14.5 volts. So you get used to this scale in your head and measure your battery state accordingly.

Battery:

The batteries are a crucial component of your off-grid system. This is what will be powering your appliances when the sun goes down or behind clouds. Most batteries now are lead-acid batteries, although as more funding is being put into the R&D of batteries the chemistry is constantly evolving and becoming more efficient. For solar applications you will want to use deep cycle batteries. Wired together, they form a battery bank.

Batteries are also available in unsealed and sealed types. The unsealed types are much more common due to their lower cost. However, they do require ongoing maintenance to keep their electrolyte levels above the plates inside the battery. The sealed batteries come at a premium, but do not require the maintenance, since the electrolyte is usually in a gel substance.

For either battery you will want to keep them away from any potential heat or fire sources. A shed or a well vented room in your home will work best. Try to avoid temperature extremes for your battery bank, as this will affect the performance negatively.

These may look very similar to car batteries, but they are only similar in appearance and greatly differ in their requirements. Car batteries are meant to be fully discharged and then rapidly recharged.

Solar deep cycle batteries are slowly charged throughout the day and then discharged slowly at night. Their energy input will vary throughout the day and the discharge will be sporadic at night, too.

A car battery used for a solar application would not be expected to last even one year, while a well maintained deep-cycle battery can be expected to last 6 years or more, depending on the depth of discharge level you have set and how often you keep the electrolyte levels maintained.

Batteries require by far the most maintenance of any of the solar components. Battery terminals should be cleaned and tightened once a year and a battery fluids should be topped off several times a year. You can test your batteries with a 'toaster tester' which has a heated coil similar to a toaster, that loads the battery and then monitors how it recovers after the load is removed.

This system is wired in a combination to create a capacity that meets the home's needs.

Most residential systems require large battery arrays to handle the load of a home's electrical system. The picture above shows a system that is wired to create a 24V, 600 amp-hr system out of 6V, 150 amp hour batteries. So the batteries are wired in series (the columns), so 6V x 4 = 24V, and then in parallel (the top and bottom and row) so that each column will add amperage, 150 amp-hours x 4 =600 amp hours.

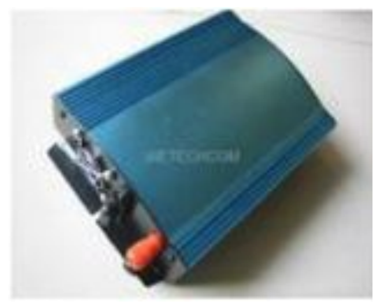
When dealing with batteries and more sophisticated charge controllers, you will often hear about 'bulk', 'absorption', and 'float' charging. Bulk charging is basically anytime the battery is less than 80% full and the charger will often just provide constant amperage to fill the battery as quickly as possible. The absorption charge is sort of a 'topping off' of a very nearly full battery and is used to fill the last 20% of a battery. The float charge basically holds the charge steady and is used to get the batteries to hold charge for longer. Many more sophisticated off grid systems will let you play with the timing and voltage of all these numbers, but you should consult the manufacturer for your system.

Inverter:

If you are using just direct current (DC) loads (appliances) you will not need an inverter and can just power the loads from the battery, assuming the voltages match up. However, the cost and availability of DC appliances remains an impediment to the solely DC home.

Alternating current (AC) appliances dominate the home landscape and require an inverter to change the DC current from the solar array to AC current for your refrigerator, TV, lights, etc. You should expect to spend around $0.50/watt or more depending on the size of the inverter needed. Typically, all but the largest residential solar systems will work fine on one inverter.

Inverters, like the charge controllers, will vary in shape and size depending upon the inverter's output rating and manufacturer.



You may be able to save some money on larger systems by purchasing an inverter that has a charge controller inside its circuitry. Check the spec sheets to determine this. Many of the larger manufacturers of inverters have solar string sizing programs available for free on their website, so you may want to reference this to determine what size inverter to use.

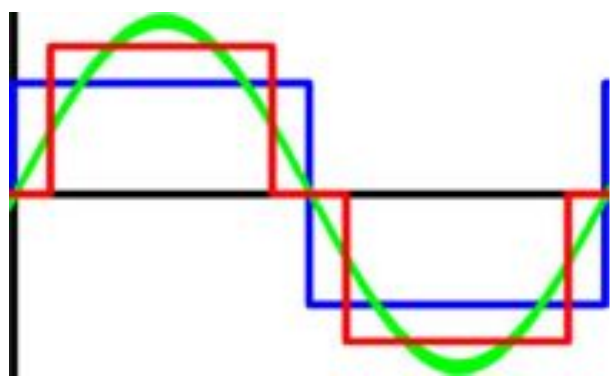
The inverter's input voltage window is the main determination to determine how many panels you can wire together in a series string, which is why they are often called string inverters.

You can get by with an inverter that is rated below the name plate rating of the array. For example, a solar array with a name plate rating of 3,300 watts (3.3 kilowatts) will work just fine with a 3,000 watt inverter, since you will typically lose up to 20% of the output from the panels from many factors. Among them, voltage losses in the wires, panel mismatch, dirt or pollen on the panels and the DC to AC inversion.

Off grid inverters are different. Instead of being rated for the array they are attached to, they are rated for the maximum output they are rated for. So a 4000 watt off grid inverter will be rated to handle 4000 watts of electronics running at once. All inverters have a ‘surge load’ as well that accounts for the higher temporary load a large electrical device will draw. For example, your dryer might use 300 watts under normal conditions, but when it starts it might need 600 watts to get the drum turning.

In an off grid system the inverter is really the brains of the whole operation. It monitors the battery voltage and can turn on a generator if the batteries are low. It might also cut the power to the house if the battery voltage was low (known as the Low Battery Cut Off). It will also ‘equalize’ the batteries as needed, which is a way of maintaining the batteries. Batteries will often build up mineralization on the plates and start holding uneven and inconsistent charge. The equalization uses a pulsing electrical charge to knock off this mineralization and equalize the charge between all the batteries. This should be done 5-6 times per year for optimal battery performance.

Inverters are often rated as to what kind of 'wave' they put out. Remember, inverters are putting the wave into the power, to make flat direct current (DC) power into wavy alternating current (AC) power. Inverters do this in many different ways. Some of them just simply step the charge as in the blue line in the drawing below. These inverters are pretty rare now and aren't really recommended for anything other than lighting.



Other inverters use a 'modified sine wave' to replicate the wave affect, as in the red line. These inverters are good for simple electronics and charging systems like hand tools, lighting, and cheap electronics. For home type systems where you are going to use stereo equipment, pumps, computers and appliances, generally you want a pure sine wave inverter like the green line above. This will protect your electronics from damage and wear, and give you maximum efficiency.

Disconnect Switches:

Disconnect switches are often times built into the inverters, but many municipalities require a separate disconnect switch for either the DC side or the AC side, or both. If you are planning on getting your system inspected by a licensed inspector or are going to connect your system to the grid check with your local laws to determine which disconnects you will need to install.

The disconnects will allow you to shut certain parts of the system off for maintenance and adding in components.

The National Electrical Code (NEC) book has set laws on mounting the equipment, such as how high off the ground, distance from batteries and other components, etc. Disconnect switches, depending on how many strings of panels you are creating may need to have an integrated fuse. These disconnects can be purchased at a local electrical supply or hardware store.

Putting it all together:

If you are constructing a small array, you may get away with just one battery, a small charge controller and a low wattage inverter, like the kind you can plug into your car adaptor. You can plug many AC electronics and appliances directly into the inverter, so long as the inverter is rated to handle the load requirements. For larger systems, you should opt to run the inverter AC wires directly into your homes breaker panel with breaker slots allotted for the inverter. A master electrician's services should be sought for this step.

To make sure your breaker panel can handle the backfed current take the busbar rating found on the inside cover, multiply it by 1.2 and then subtract your main breaker size. The max continuous output current of the inverter multiplied by 1.25 (depending on which NEC Code year you reference) must be below this number. For example, a 200 A breaker panel (standard in most new construction) with a 200 A main breaker will allow for 40 A to be backfed (200 x 1.2 – 200 = 40 A).

You can typically fit up to about 7000 watts on a 200 A breaker panel since the max continuous output of a 7,000 watt inverter is usually close to 32 A. The max continuous output of the inverter is found in the spec sheet or by contacting the manufacturer. Reference the National Electrical Code (NEC) book for the latest requirements when sizing an electrical array.

Remember that homemade solar panels should never be hooked up to a grid-tied system. And always check your local laws and permitting requirements when working with electricity.

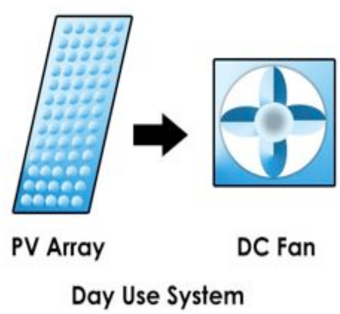
There are inverters out there that have grid-tied/battery backup capabilities, but you may need two inverters for this option. Having a crucial load subpanel is a good option for when the power goes down and you are drawing from the batteries. This isolates some of your electric loads on a separate breaker panel so that you won't pull down the battery's storage too fast by running unnecessary loads.

Different Solar Power Systems

There are several types of solar power systems that are used in homes. Let's cover the most common.

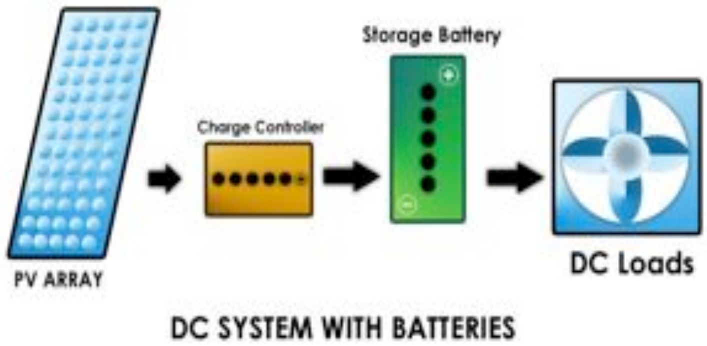
Solar Direct (or Day-Use Solar)

These systems are intended to be used only when the sun shines. There are no storage batteries, so as soon as the sun goes away, the power stops. These systems are great for certain water pumping applications, venting fans, and certain electronics. Rare in application, they are very affordable and easy to install.



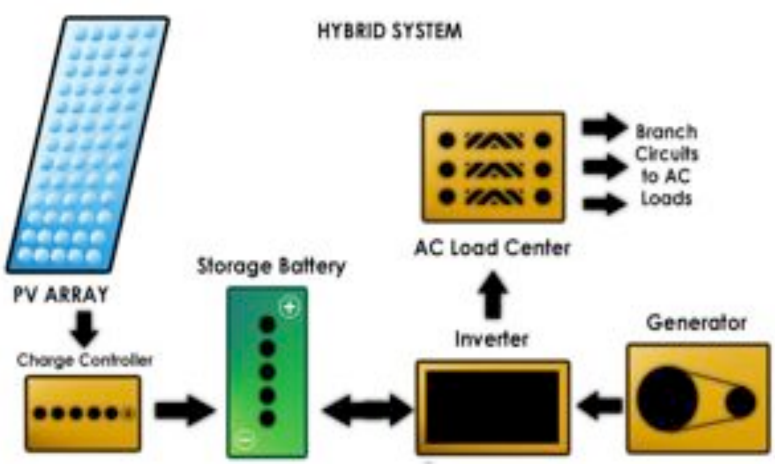
DC System with Batteries

These systems are great for small electronics that need to run day or night. Often times you'll see these systems employed on highway sign lights, gate openers, and communication boxes. Simple and affordable these systems have a wide variety of uses and are perfect for remote locations that require low voltage.



Hybrid Solar-Generator Systems

For off-grid and back-up power applications, most folks turn to a hybrid system. The hybrid system usually consists of a PV array, a charge controller, a battery bank, an inverter, and sometimes a tertiary power source such as a wind turbine or a gas generator. These systems are fairly complex and require a high level of expertise to design and install. With the popularity of off-grid living, however, there are more and more packaged systems for people to choose from. These systems will provide power if the grid shuts down and can still sell power back to a grid if desired.

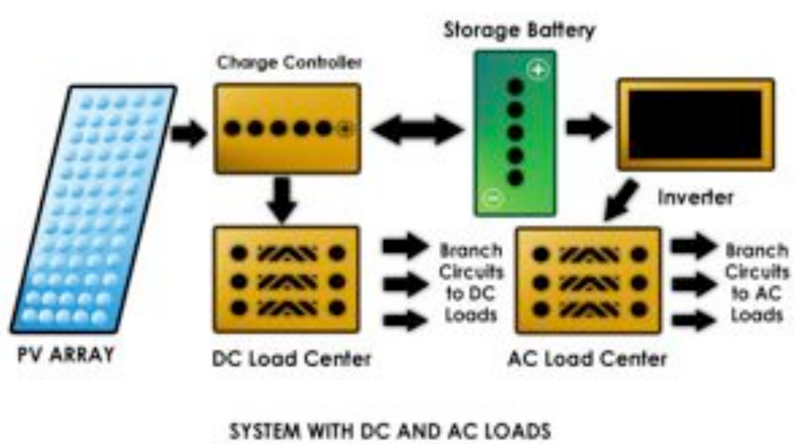


Hybrid system with **solar and generator backup**

The biggest disadvantage of these systems is the cost and complexity. The battery bank requires regular maintenance and must be replaced long before the panels are done generating. They are also fairly expensive. These costs, however, are often a better alternative to the cost and hassle of bringing in grid power to remote locations.

Off-Grid Solar Dependent Systems

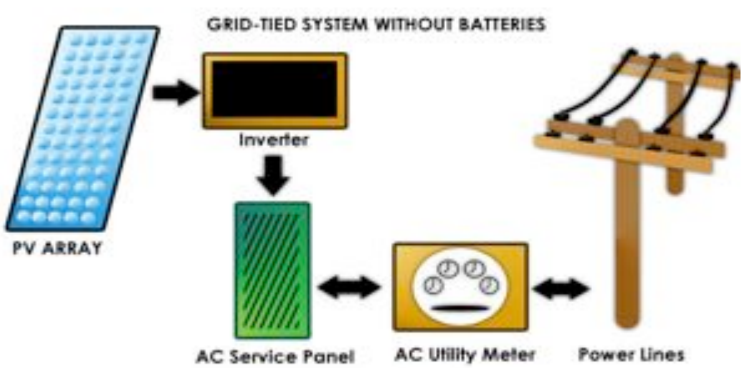
For cheap power in remote locations, often these systems are the only choice. They generally consist of a small battery bank, a charge controller, and a solar array. People with these systems choose to use all DC appliances so as to avoid the cost and inefficiency of inverters. These systems have the advantage of lower initial cost. The batteries are still an issue for maintenance cost. And there is no backup power if weather doesn't allow the panels to charge the batteries.



A typical off-grid solar power system

Grid-Tied Solar Systems

This is the easiest and most popular way to get started in PV power. These systems simply tie into your existing home power system and the utility grid. If your array generates more energy than you use, the energy is sold back to the power grid and creates a credit for you. The advantages of these systems are the relative simplicity and lower initial cost. A system like this typically requires a few panels, some wiring boxes and disconnects, and an inverter. The inverter converts the electricity from your panels to power that your home and the grid can use.



A typical grid tied system

This system also requires an interconnection agreement with the local utility. This outlines just how the connection to the grid should be made and what the inspection schedule is. It is generally advisable to get your power company involved early on for a grid-tied system. Since there are often incentives and rebates in place from the state and the utility, it's well worth the call.

For Grid-Tied systems without battery backups, it is important to note that when you lose power from the grid, you won't be able to use the power from your solar array. This is a safety feature built into the inverters so that if you have a utility lineman working on the power lines in your front yard they can be confident there is no current in the lines. If your array were in the backyard feeding the grid and he was working in the front he would run the chance of having a bad electric shock.

Advantages of the Grid-Tied System

- **Initial Cost**: The upfront cost of purchasing a system that would provide for a home's entire electrical needs can be very high. With variable climate and weather conditions across the globe, the use of off-grid systems requires batteries. Off-grid systems generally require a secondary power source, such as a gas generator, to provide backup power which adds significant cost to the system. Grid tied systems are much cheaper than off grid
- **Operating Cost**: The maintenance cost of grid-tied systems is very low. Solar panels routinely have 20-25 year warranties and some of the panels created in the 1950's as part of NASA's space program are still operational. Batteries associated with off-grid systems require regular maintenance and have a much shorter life than the panels. Backup generators also require significant maintenance and access to a cheap and reliable fuel source.
- **Flexibility**: Having an alternative energy source AND a utility source means you can design your system to meet whatever needs you have now and still have the flexibility to increase the system size later. It also allows you to change your system parameters to meet your different needs in the future.

More Explanation of Grid-Tied Solar Power Systems

Utility connected systems generate electricity from the sun, supply the house with its needed electrical needs, and then push any excess electricity onto the utility grid. Thanks to the Public Utility Regulatory Act of 1978 (PURPA), public utilities are now required to purchase this surplus electricity from small producers, such as you and your house. This allows for net-metering, which means that utility must pay you for the electricity you put back into the grid. This generally causes your electric meter to run backwards and creates a credit on your power bill. However, the utility does not necessarily have to pay you the same rate that you pay them for their electricity. This means there is often a 'gap' in the utility rates.

There are generally two types of grid-tied solar power systems:

- Systems WITH Battery Back-up
- Systems WITHOUT Battery Back-up.

<u>Utility Connected Systems WITH Battery Back-up</u>

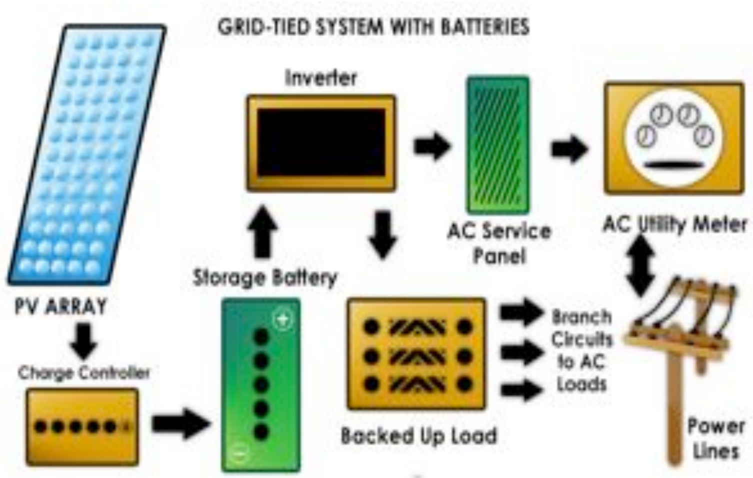
These systems are very useful in areas with frequent power failures. Provided there is ample sunshine, these systems give the customer more autonomy, while still providing a backup system in the utility grid.

A small percentage of homeowners opt for a grid-tied solar system with battery backup. This is more common in places with an unreliable utility connection like very remote areas or places with extreme weather conditions. You could pay up to 50% more on the total cost of an installed system by adding battery backup.

Advantages of these systems include:

- With proper system design, they provide continuous power to the customer regardless of utility availability or weather conditions.
- These systems make it easier to manage your power consumption, production, and storage.
- Depending on the utility company's policy, the cost of the batteries can sometimes make

up for the rate 'gap', meaning it is worthwhile to store the excess electricity you produce as opposed to selling it back to the utility.



Disadvantages of the battery back-up systems:

- Increased system complexity, more components to install.
- Increased cost of the system
- Increased maintenance of the system
- Decreased efficiency of the overall system
- Environmental issues: The manufacturing and disposal of batteries involves chemicals and metals that most eco-minded consumers would rather avoid.

<u>Utility Connected Systems WITHOUT Battery Back-up</u>

These systems are the most popular for their relative simplicity.

Advantages of these systems include:

- Cost effectiveness: when combined with net-metering systems owners can see payback times from 5-10 years.

- Simplicity of design and installation
- Higher overall system efficiency

Disadvantages of the systems without battery backup:

- Does not necessarily provide backup power in the case of grid failure
- Does not allow for power management

Solar Tracking Systems

Solar tracking systems are used to continually orient photovoltaic panels towards the sun and can help maximize your investment in your PV system. They are beneficial as the sun's position in the sky will change gradually over the course of a day and over the seasons throughout the year.

Single vs. Dual Axis

You will hear a tracker referred to as single or dual axis. Single axis trackers will track the sun across the sky from morning until night, but they will not automatically change the tilt as the sun's angle changes in the sky over seasons. Double axis trackers will track the sun across the sky over the day and over the seasons, giving you maximum efficiency.

Advantages of Trackers

Advantages to using a tracker system like this will depend mainly on its placement in determining how well it will increase the effectiveness of the panels. They can be used most effectively in areas with low horizons and locations that are shade free from dawn to dusk each day.

A duel axis tracking system, note the lack of shading and low horizons.

Throughout the year the tracking array will be able to utilize the wide open access to gain every available electron from the sun. This way, energy production is at an optimum and energy output is increased year round. This is especially significant throughout the summer months with its long days of sunlight available to capture and when, at many Northern latitudes, the sun rises in the northeast and sets in the northwest, no energy will be lost. For those with limited space this means that a smaller array only needs to be installed, a huge advantage for those smaller sites with only a small area to place equipment; they will be able to produce maximum energy output but only need to utilize one of the smaller solar home systems. Trackers can add anywhere from 20-50% in solar production from a solar array, depending on the installation.

Some Disadvantages

Solar tracking systems do not come without their disadvantages though. The standalone PV home kit system is a very reliable and uncomplicated source of energy production; the panels don't move and require little maintenance. By adding a solar tracking system to your solar panels, you are adding moving parts and gears which will require regular maintenance of your solar system and repair or replacement of broken parts. If your electronically controlled tracker stops working and you don't have a manual control, an option you can choose at the time of purchase, you can manually position your array to solar south to ensure that you will continue to capture as much solar energy as possible. Secure the array into place with ropes or straps found on the four corners of the rack and tie onto the pole or in the concrete pad.

Another possible disadvantage to be aware of when purchasing a tracking solar power system, is in the way your local utility's PV Rebate Program may be set up. Many are based on the size of the PV array in your home kit and not on your PV array's production, which could mean less of a financial benefit to you. If you have a small array, such as a 3 Watt capacity, you may get less overall cost benefit than someone else with a larger array of a 4-5 Watt size capacity, even if your energy production works out higher than the person using a bigger array, due to increased sun exposure in your area. The upfront cost of purchasing a home kit with a smaller size array is less but you may receive a smaller rebate check. Many areas though, are now starting to make the move from the rated wattage system of photovoltaic home systems to the energy production based incentive program.

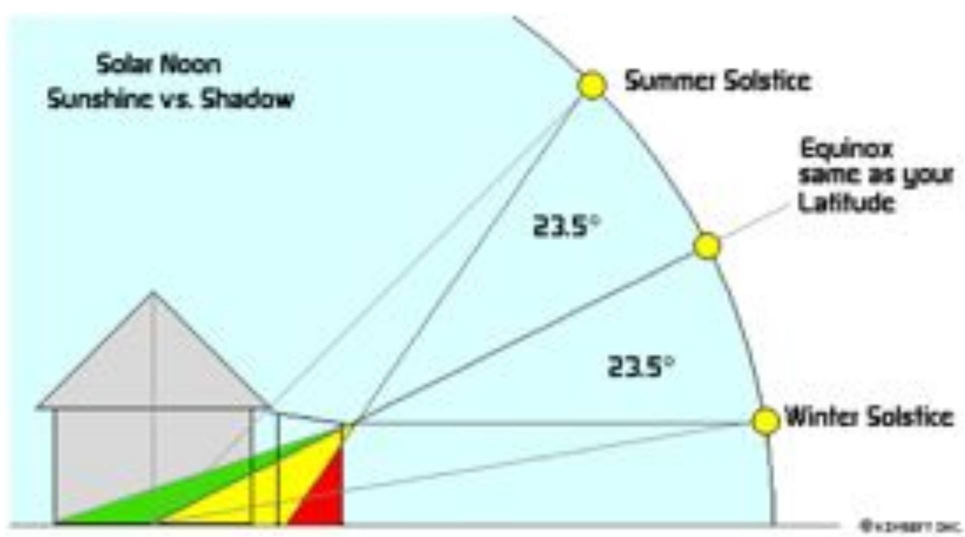
For more information about parts or pre-assembled solar kits, check out our Power4Patriots shop at http://www.power4patriots.com/shop.

Site Determination

The biggest factor when determining the location is access to the sun. It is very important that your panels be located where they will get at least 6 hours of unobstructed sun per day. This 'solar window' is typically from 9am to 6pm, but may adjust to earlier or later in the day depending on the orientation of the panels.

The optimal pitch for the panels is equal to your latitude, although in many locations with cloudy winters, it may be optimal to subtract about 15 degrees from your latitude for optimal pitch. A solar pathfinder or Solmetric Sun Eyes are two popular options for determining the site's sun potential. They are useful tools that will show what shade issues you will have with a particular spot at all times of the year.

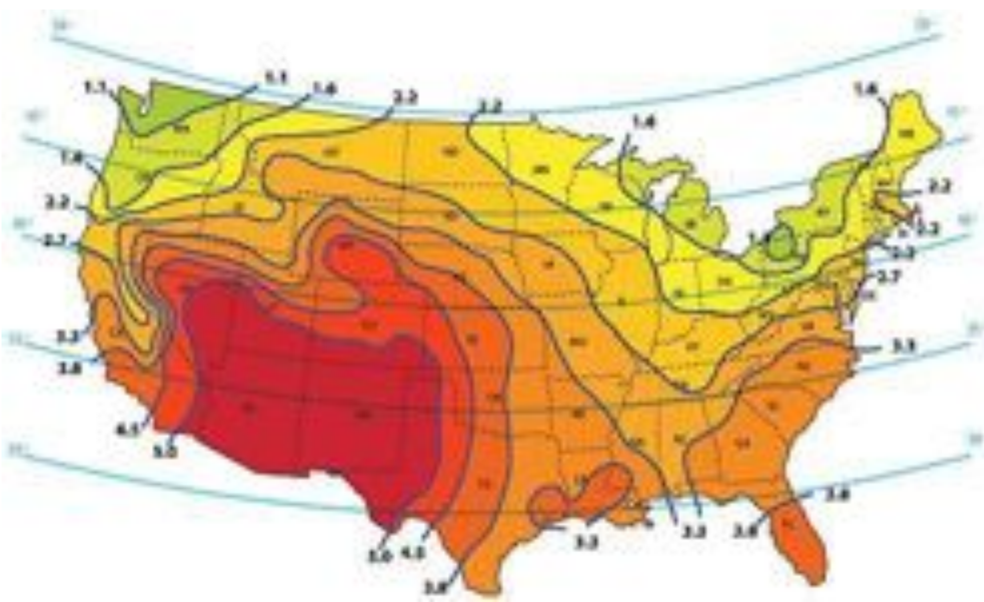
Shade is to be avoided at all costs since the cells and panels are mainly wired in series, and shading even one cell of a panel can wipe out a portion of the entire array.



Regional Weather and Sun Exposure

US Sun Exposure

Do you live in a reasonably sunny area? About 30% of the US is what solar experts would call 'moderate' for exposure to the sun. This includes the Great Lakes Region, the Northeast, and the upper Northwest. These areas, while not ideal, do have pretty good exposure to the sun's rays during the late spring, summer and early fall. And the panel technology is getting better and better at producing energy on cloudy and semi-cloudy days.



(*Courtesy NREL)* ***Solar radiation information for the US, with permission from NREL. The darker the color the more sunshine.***

Much of the country could be called 'good' for solar power. These areas include the Midwest , Northern Rockies, and the Southeast.

The remaining area can be called great for photovoltaics. These areas include California, Texas, Hawaii, the desert Southwest, and the Lower Rocky Mountain states. These areas have relatively few cloudy days and the southern latitudes mean the sun is higher in the sky and therefore more energy reaches the ground.

The number on the drawing above are what we call ‘sun-hours’. This number is what we would normally use in place of a hours of sunshine number. We don’t use hours of actual sunshine since this wouldn’t account for latitude, seasonal shifts, weather and climate considerations. So the solar authorities assign this sun-hours number to every place on the planet. We’ll use this number more when we try to figure out just how much power a system will produce.

<u>*Canada Sun Exposure*</u>

Certain parts of Canada are pretty good candidates for solar. Obviously because of the Northern latitudes and weather patterns, most of the country is not so great. But areas of Southern Alberta, Saskatchewan, Ontario, and Quebec have decent exposure.

Solar data for Canada, color scale does not match US solar data map. The darker the yellow, the better the solar exposure.

Figuring out Where to Put Your Solar Power System

The basic rules of placing a solar power system are pretty easy. We need:

- **Good southern exposure.** We want a space that's going to get tons of sunlight all year round. Getting good morning light and evening light is not nearly as important as getting good midday sun exposure, when the most energy is going to be hitting the ground.
- **Angle at or near latitude.** The angle of the panels should be as close to your latitude as possible. The sun is directly overhead at the equinox in March and September, which means that the sun is nearest that angle for the greatest part of the year. Having the panels at that angle will maximize your system's efficiency.
- **Minimal shading.** Even small objects like roof vents can affect our panel's performance significantly. And don't forget that trees grow, and your panels will be around for 30 years or more.
- **Access without nuisance.** This means we can get to the panels (they are not on top of a 50' pole) but they're also not in the way (where the kids will be bouncing soccer balls off them).
- **Close to consumption.** As we talked about earlier, the panels produce DC power which tends to lose voltage over distances. The closer the panels are to the main area of consumption (like your main AC panel and power meter) the more power you'll get to actually consume.

See our section toward the end of the book on solar tracking systems to see if they are right for your project.

Now let's discuss the advantages and disadvantages of placing your panels in three places: the roof of your home; on an out-building; on the ground.

On The Roof of Your Home or Business

This is probably the most obvious place.

Advantages:

- Panels on the roof are usually out of the way and sometimes less visible
- It usually provides a large, stable, and even surface for the panels to rest on
- There are usually less obstructions and trees in the roof area that could shade the panels
- Roof installation systems (the brackets and bolting) are pretty simple
- The panels will be probably be close to the electric meter and the primary consumption areas of electricity

A roof mounted system in Canada.

Disadvantages:

- If the roof does not have a south-facing slope the installation can get complicated
- The roof angle may not be optimal for the array.
- Roof work can be dangerous
- The panels may be hard to access for snow-removal or occasional cleanings
- The panels usually cannot be moved or adjusted for the sun angle

The National Renewable Energy Laboratories (NREL) has developed a very useful online resource to determine the potential output of your array. The program is called PVWatts and is free to use online. It can be found online at: http://www.nrel.gov/rredc/pvwatts/. Simply input your array size in kilowatts, the orientation and angle of your panel and your zip code and the program will give you your estimated kilowatt hour (kWh) output for each month of the year.

If you cannot mount the panel to your roof, another consideration for site selection is to keep the array as close to your home as reasonably possible, since long wire runs will have higher power losses and will require thicker wires, increasing the cost of your system and requiring longer trenches.

On An Out-Building

This could be a storage shed, garage, barn, or even a deck on the main house.

Advantages:

- The panels will probably be out of the way maybe less visible
- The panels and related components (inverter, disconnects, batteries if needed) can all be stored together and usually out of sight.
- These structures are usually closer to the ground and easier for installation, cleaning and snow removal

This shed holds the panels, the inverter, and all related electronics, keeping them tucked away.

Disadvantages:

- These installations are usually fixed and therefore the angle cannot be adjusted
- Roof angle may not be optimal
- These buildings may be far away from the house, where the most of the consumption takes place. In general, you want the panels close to the consumption to avoid losing energy while transferring it to other locations
- Installing the units on a deck can make them very visible and prone to damage from human error

On The Ground

There are several options for putting your panels right on the ground.

Advantages:

- Ground mounted systems are easy to install and clean
- Tracking systems are ideal for ground installation. These systems actually move with the sun using a powerless system. This increases the amount of energy collected significantly
- They are easier to adjust for manual adjusting systems

A ground mounted system, also called a 'pole mount' (running child not included).

Disadvantages:

- These systems can be more prone to shading concerns
- The array is more visible and more in the way
- They may require more hardware to get the units to the proper angle

They may be further from the house, increasing installation cost and decreasing efficiency

Physical Size Considerations – How Much Room Do I Need

Many people wonder how much space systems take up. A good rule of thumb is to remember that the panels will take about 1/10th of their space in square footage. So if you determine that a 5kw system will suffice for you needs:

5kw x 1000W/kw = 5,000 Watts

5,000 watts x 0.1 sq. ft/watt = 500 sq. ft.

So you would need about 500 sq. ft for the panels in the example above. The inverter and disconnects will take up about a 3'x3' area on a wall.

If you have an off-grid system or a system with batteries, you can expect to need the area of a medium sized closet, approximately 6'x6', to house everything.

We will determine how many kilowatts you need in a later chapter.

Backup Generators

Many people might decide that a full house system is just too complicated or expensive to do, and would rather just have emergency backup. This can be done pretty easily with some small kits currently on the market. These kits range in complexity from assembling panels and connected components, to simply plug and play the panels and appliances. The size of the kit largely depends on how much you want to run during an emergency.

To figure out what you need, try to figure out the bare minimum of what you'll need in an emergency. For most people, a few small electric lights, a radio or TV, and a fan would be enough to survive for weeks. For these folks a simple 10 to 20 watt kit will be plenty and would cost less than $400. For others that want to plug in their refrigerator and save the food, they would need a 130 watt solar panel with a 1800 watt inverter, that would cost around $1500.

For more information about backup generators, check out our Power4Patriots shop at http://www.power4patriots.com/shop.

Manufactured vs. DIY Solar Panels

Some people wonder if they should build their own solar panels or buy manufactured panels. The choice really comes down to how much work you want to do. Making your own solar panels is labor intensive, but can save you about 50 to 70% off the retail cost of panels. This can add up to thousands of dollars on a big system. Of course you have to factor in just how much time you have to invest, and the quality of the panels you are going to make. If you can solder well, or are willing to learn, and have the patience and diligence to do a quality job, making your own solar panels can be enormously rewarding. If you're not the type of person that enjoys working with your hands or working with small electronic connections, then consider spending the money on manufactured panels.

Incentive and Rebates – Is There Help For Us?

Uncle Sam is continuing to make it easier for homeowners to include solar energy as a viable, and affordable, means of powering their homes. Not to be outdone, the majority of states are also devising ways to encourage their residents to "switch on" to renewable energy, many times through electric companies. Renewable energy includes leveraging the power of the sun. Here are some examples of how both forms of government are attempting to do so. Be sure to check out DSIREUSA.org for more information on all incentives as they can be complicated and are constantly changing.

Federal Tax Credits

With the adoption of the Energy Policy Act of 2005 and the subsequent Energy Improvement and Extension Act of 2008, Americans are now eligible for a 30% rebate through the Federal Government toward a residential solar power system. This applies to off grid systems as well. In addition, there is now no limit to the amount that can be claimed toward the cost of a photovoltaic system. In the past, the amount was restricted to $2,000. The rebate currently covers both the cost of the materials and the labor. For example, a PV system with a cost of $25,000 would be eligible for a $7,500 credit. A credit, unlike a deduction, is applied directly to the taxes owed, so would therefore reduce your total taxes owed to the IRS by $7,500.

Along with their normal tax forms, residents would use IRS Form 5695 to earn their rebate. Something to keep in mind however is how this relates to other incentive programs. Talk to your accountant on how to treat this credit, plus any other rebates and incentives you might be receiving. Generally the 30% credit is taken on the cost of a system AFTER other rebates.

Municipal Financing

Another attempt at making solar power attainable for the everyday homeowner is a program that allows the cost of the PV to be covered by municipal tax funds over an extended period of time. In most cases, this payment plan lasts for twenty years. If the home is sold before that period is up, the solar power system, and whatever tax liability remains, go to the new owner of the home. The program is usually funded by municipal bonds. Many cities in California have incorporated this program, as well as some cities in Colorado, Maryland, and Louisiana.

Net Metering

Many energy companies are implementing programs that enable residents with a photovoltaic system to "sell" the extra electricity they obtain back to their energy companies. If the customer's system generates more than they consume the specially built meter simply spins backwards. All utilities in the US are required to purchase back consumer-produced power, but the rates at which they do so varies widely. Also, if you want to be entirely off grid, there won't be a grid to sell power back to!

Renewable Energy Credits (REC)

Producing renewable energy is a seen as a good thing of course, and installing a system can create a credit which traditional utilities and state governments want to buy. This usually takes form as a check written directly to the homeowner for a percentage of the system. In Colorado for example, Xcel Energy will pay $1.50 per watt in REC's when you install a system and connect it to their grid. Some manufacturers, such as Sharp, will even deduct this amount off the price of the system and then pursue the credit from the utility. This makes it easier for the customer to afford the system since they won't have to wait for the utility rebate, which can take a few months.

Feed-in Tariffs (FIT)

As an extension to the process of buying back energy, the state of California and the city of Gainesville, Florida have begun enacting feed-in tariffs (FiT). FiT's are designed to pay for the installation of a solar power system plus a small profit. Overall, the tariffs range from 8 to 81 cents per kilowatt-hour, which means you would get paid that amount for the energy you produce. This amount is often 3 to 4 times the amount the utility charges customers. This encourages both production of renewable energy and conservation of existing energy since every penny a producer saves off consumption will go straight to their pocket in production. However, sometimes residents earning the tariff cannot participate in other state incentive programs.

Bank Financing

It's definitely worth a call to your bank to see if they offer financing with solar power systems. Many banks look at it the same way as any home-improvement loan, and many people use a home equity line of credit for the purchase. Some banks are even offering reduced rates for loans because they realize that the loan will actually help you pay your bills every month since you'll have reduced utility payments. If your bank is wary, remind them that the panels aren't going to walk off, like a boat or RV can, and that with the coming solar revolution they could be making many more loans in the future for these systems.

Solar System Economics and Sizing – OK, How Much is This Going to Cost Me?

Typical System Costs

So, you've got a basic understanding of system layout and terminology, let’s get down to the nitty-gritty and talk about system cost. We'll tackle the grid-tie system first since it is the most common.

Grid-Tie System Costs

It's difficult to estimate exactly what you are going to pay for a system. Prices and installation costs vary widely based on local competition, hardware availability and the difficulty of installation. OK? Next subject.

But wait!!! That doesn't help at all does it? There are some basic rules of thumb we can use to estimate system cost. Solar panels have been coming down in price recently as worldwide production has increased.

An easy number to remember is **$3-4/watt for an installed grid tie system**. That means that if you decide you want a 2,000 watt system you can expect to pay between $6,000-$18,000 before incentives. So what goes into that number? Generally equipment runs about $2-$3 per watt for panels, mounting, wiring, inverter and various fasteners. Panels themselves are running about $1.50/watt.

The remaining $1-$2 per watt covers the labor, licensing, insurance, equipment, overhead (office, phones, and trucks), and profit for the installing contractor. Sound like a lot? These folks earn it. Unlike some trades where cheap, unskilled labor can knock out a job in a few hours, solar can be complicated and roof work is dangerous.

Off-Grid System Costs

Off-grid systems are much more complicated (complicated = expensive if you haven't picked up on that already). Off-grid system can run anywhere from 50-100% more than grid-tie systems. So a budgetary number is around **$7-8/watt for an off-grid system and much less if you build your own panels**. Building your own solar panels can save you 50% off the cost of solar panels.

Why is an off grid system so much more? One word: batteries. Batteries add a tremendous amount of expense and complexity. One deep-cycle battery for off-grid use can run $300, and often times a system requires *16 batteries.* We're talking about $5,000 for batteries. Then there's the charge controller, the copper wiring for all the batteries, and most systems need some kind of enclosure.

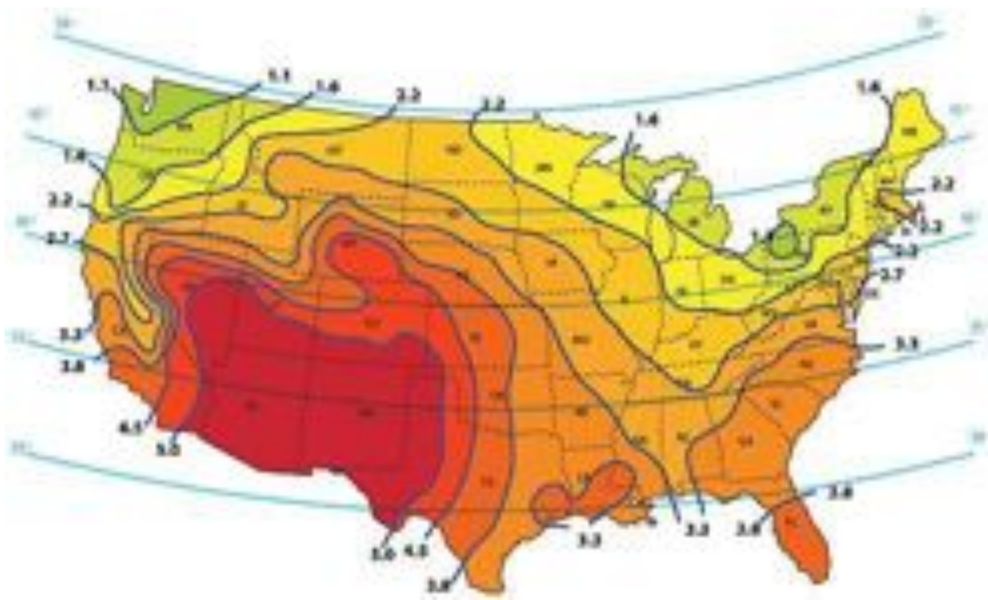
Still, most people who are considering an off-grid system don't have a lot of choices when it comes to power sources, so spending $8/watt or spending evenings by a candle is an easy choice.

Estimating How Much Power a System Will Produce

Often people will wonder how much power a given system will produce. Let's use an example. Let's say that you had about 1000 square feet of usable space on your roof, and you wanted to fill every last foot with solar to reduce the power bill as much as possible.

1000 sq. ft., x 10 watts/square ft = 10,000 watts

So you could conceivably install 10,000 watts on your roof, but how much power will that actually produce. Well, 10,000 watts means that the panels, in ideal conditions will produce 10,000 watts per hour. Now remember that we have to use the ‘sun hour’ number for our area. This is easily found on this map:



So we use the number that corresponds to our area, let’s use 4.5 for Colorado. So on a typical day, our panels will generate:

10,000Watts x 4.5 hours = 45,000 watt-hours or 45 kilowatt-hours per day

But we have to account for efficiency adjustments since our wiring, inverter, and related equipment will actually not convert every bit of sunlight into power. So we would knock off about 30% for inefficiencies in the system, so our system will produce:

45 kw-hrs x .70 = 31.50 kw-hrs per day, or

30 x 31.50 kw-hrs = 945 kw-hrs per month

This will give us a nice number to compare to our power bill.

Installing Your System

Invariably people who are handy and familiar with home improvement projects ask 'Can I install my own solar power system?'. The answer is 'Maybe'. A lot of it depends of course on you. The solar manufacturers have recognized the need for simplicity in these systems. With the groundswell of both DIY homeownership and clean energy, many of them are making kits that homeowners can install. Some are completely self-contained prepackaged systems designed for the average homeowner. Let's talk about the literal and figurative tools you'll need to install a system yourself.

Permitting and Inspection

Check with your local building department to see if they even allow homeowners installed systems. IF they do, be sure to get a clear idea of what the inspector wants to see and what stages of the installation need to be signed off. The local utility will also want to inspect it to make sure that you know what they require.

Familiarity with Electricity

While you don't need to be a NASA engineer to figure out these prepackaged systems, basic electrical knowledge is a must. If you can use a volt/ammeter, understand basic grounding techniques, and can use electrical terminology, you're probably a great candidate. Ability to run wiring efficiently and troubleshoot electrical circuits is a huge plus. We always, ALWAYS suggest that you talk to a master electrician before and after every installation so that you can be sure that you have installed your system correctly and in a manner that will maximize energy efficiency.

Roof Type and Composition

The trickiest part of it all can be the actual roof attachment. Generally for asphalt shingle roofs the homeowners must attach the panel mounts directly to the rafters. If you live in a gabled home with an accessible attic, this might not be a big deal. If you live in a home with a complicated roof line this can be a huge deal. Checking this out ahead of time and gaging the complexity of the roof mount will save you a lot of time and headache later.

A Quickmount system with colored flashing. An attachment bolt is fed through the hole and into a rafter.

Basic Carpentry Skills

Much of the actual installation of a system involves basic carpentry layout and nuts and bolts assembly. The racking systems come with instructions and are generally no harder than assembling that entertainment center your spouse bought at Target. Layout will include making a simple drawing, snapping a chalk line, and basic measurements.

Pole and Ground Mounted Systems

Most ground mounted system will require you to drill and place one or several concrete caissons. This has gotten much easier in recent years with the availability of Quikcrete and

Sonotubes. For any installation required more than a ½ cubic yard of concrete, we recommend just purchasing it from a ready mix company that will deliver it to your site. Your back and your sanity will thank you.

Tools for Installing a System

So, now its down to the fun part. You've designed a system, built the panels or purchased a kit, and now it's ready to be put up. Now what? Some of you may want to leave this part to a professional. But, since we're all about empowering people with do it yourself knowledge, we'll cover the basics and offer suggestions for finding more details for your specific situation. In this example remember we're talking about a 2000 Watt, roof-mounted, grid-tied system, one of the most popular.

Safety Equipment

As always safety comes first. For starters makes sure you have a really good, solid ladder. Make sure it doesn't have broken or loose rungs and it should extend at least 3 feet PAST the top of your roof when leaned against it at a safe angle. Don't scrimp here, you'll be going up and down that thing a lot and most accidents occur falling off ladders, not falling off roofs. Technically you are supposed to have a rope and harness system at all times as well. These systems can attach to ridges and will save your life if used properly. Many equipment rental stores will rent large ladders and harnesses.

As always a good set of gloves, safety glasses, and work boots are indispensable. That roof surface can be more slippery than you think, especially in cold weather. For 10:12 roofs and above you may want to install a temporary walkway system with 2 x 4's running perpendicular to the slope. This will take some extra time but can actually speed up the actual installation process. If you've got the budget, or the fear of hospital bills, a boom lift (sometimes called a JLG or a cherry picker) can lift you into hard to reach places safely and quickly. These too can be rented easily.

This is a good example of a roof where you could use a mechanical boom lift. The roof is steep, there is little room to work, and plenty of room on the ground for the machine.

Hand Tools

If you are buying a prepackaged kit, your tool requirements are pretty basic. The kits these days come connectors, often multi-contact type, that are very simple to connect. There are many projects though that bits and pieces of wire that must be cut to fit, so a standard electrician's list of pliers (small and heavy duty), wire strippers, utility knife, and diagonal cutters will be helpful. You'll also need a small torpedo level, multimeter voltage/amperage tester, chalk line, and a set of sockets for assembling rail hardware. If you are building your own system from scratch you'll need heavy duty cutters for large gauge wire and crimpers for attaching connectors, check with your local equipment rental shop for these (they are very expensive!).

This tool set by Klein would come in very handy on a project like this.

Power Tools

For 90% of solar installations all you'll need is a power drill. Depending on your roof anchoring system and your roof makeup you may want an impact drill, but usually not. For standard residential roofs with asphalt shingles and wood rafters, a simple battery pack drill will do just fine. You'll want a nice long bit (refer to your roof anchor instructions for bit sizing) and some socket inserts to tighten rail hardware.

Doing An Installation Plan

Ok, we've got solar panels, we've got tools, now we're ready to start putting them up! Well, hold on there partner, the better we plan this out the smoother the install will be. So let's take a minute and a piece of paper to figure out how we're going to do this.

Simple Roof Diagram

Most building departments will require a sketch of where your panels are going anyway, so this is not a wasted effort. If you can do a scale drawing your install will go that much faster. Make a basic sketch of the roof area in question. Then do some reconnaissance and figure out where the rafters are and their spacing. The roof mounts, which will hold the rails, will attach to rafters. Mark the rafter locations on your drawing.

Panel Strings

Solar power systems are laid out in strings to achieve certain voltages and amperages required by the inverter. So if you have 10 panels, you may have two strings of five panels. The panels will be wired in series (positive to negative) generally in that string, to get the voltage up to a level acceptable to the inverter. Refer to your inverter specifications or your kit drawings to make sure you get this right, its critical. You'll want one string in a row, with the next row/string adjacent to it since that one will likely be wired in parallel (positive to positive). Layout the strings and rows on your drawing and make sure its all going to work. Your local building code will probably tell you what the spacing on supports should be.

In this picture, each row is its own string. So the panels in that row are wired together in series. Then each row is wired together in parallel. This is how most systems are wired, yours may be different.

Equipment Check

Ok you have a drawing of the system, now check with your equipment again to make sure you've got everything. Nothing like getting everything on the roof only to find out you're missing some mounts. Also, if you're getting permits, its worth a call to the building department to see what stages they want to inspect the system at. Some just want to see the final install, other want to see the roof penetrations, which means you will have to call them before you actually put the panels up.

Roof Specifications

One final note before we get to the actual install. Certain roof materials have requirements for sealing up penetrations and temperature during roof work. If its too cold your roof materials may crack or chip. If you can take a sample of your roof material to a local supply house and have them tell you about minimum temperature requirements and sealants. This ensure that you are not damaging your roof and shortening its life.

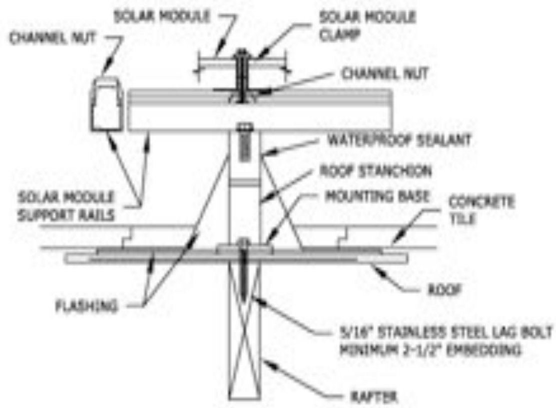
Roof Mounted Array Installation

Okay, you are ready to install your system. As we noted before, there are so many types of systems today with all sorts of mounting and panel systems, its really hard to build an instruction manual for all systems. But what we'll try to do is instruct you on building a TYPICAL system, just keep in mind that your system may be, and probably will be, slightly different.

Roof Attachment

Start with your roof installation plan drawing, and mark out the rafters that you will attaching to. A chalk line is handy laying out straight lines on an uneven surface.

Now, again using your diagram you made earlier, drill holes for your lag bolts into the roof rafters. Your standoff, sometimes called a stanchion like in the picture below, will often have an 'L' type mount. There is also the flashing type standoff mount that protects your roof penetration better. For a great demonstration on this, check out QuickMountPV.com, which has a great video demonstration of this method. After the standoffs are mounted to the roof, the panel rails are then mounted to the standoffs. This generally done with channel nuts and bolts. See the diagram below for a typical installation cross section.



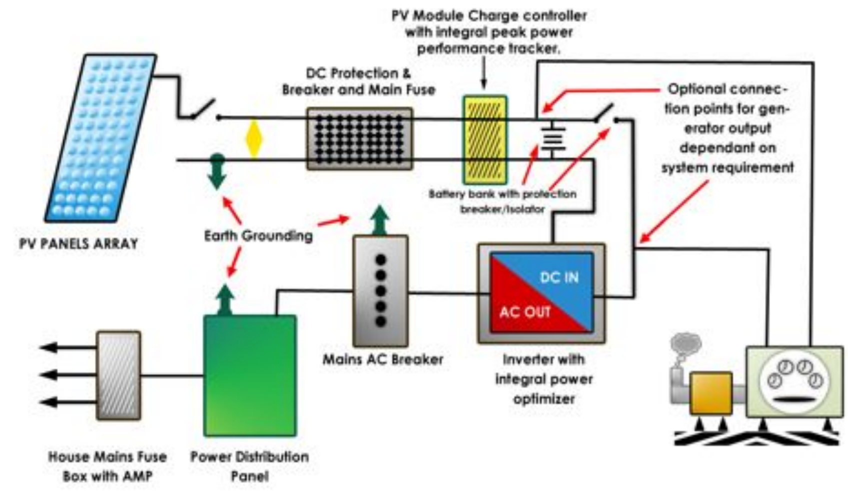
PENETRATION DETAIL

FRONT ELEVATION

So you think you are up to the task? The details of solar installation is beyond the scope of this book. But there are plenty of other resources out there. Many websites have videos and books that will help you with the nitty gritty details of solar installations. Get as much information as you can. There are also tons of hands-on training sessions held around the country for novices and experts alike. And who knows, after you get your system done you may have found a new career. Check out our training options on SolarSphereOnline.com.

Connecting Your Solar Power System

Keep in mind that all outdoor wire connections should be one in a junction box. Also, no wire (insulated or not) should be visible in the exterior of the system. All of the outdoor wiring and most wiring indoors should be inside conduit.



LINE DIAGRAM OF BASIC SYSTEM OF PV OFF-GRID SUPPLY

Connecting your system should be done according to the line drawing from your solar power kit provider, or according to the instructions on the charge controller and inverter. It is difficult to provide one set of instructions for wiring a solar power system because there are so many different types and each one is going to be a little different. Here are some general ideas to keep in mind.

The first priority is always safety of course. And this means that the safest thing to do to connect your power sources last. So if you have solar panels and batteries, the final connection to these components would be done last. So you can start in the middle of your system, and connect the inverter, disconnects, and charge controller first. Then the connection to the batteries can be made, with the battery disconnect open. Finally you can connect your solar panels to the charge controller.

While installing solar panels on a roof or any other structure its important to remember that if there is sunshine, even a small amount, on the panel, there will be power flowing through that panel. Many installers use blankets, burlap sacks, or black plastic and cover the panels so the there is no voltage while they are working on the system.

This is a good time to remind you to use a master electrician to help you. A good, experienced master electrician will be invaluable during this process, even if they don't have specific experience with solar. The amount of time they save you trouble shooting your system, giving you tricks of the trade, and access to tools will be well worth their hourly rate. The majority of installing a solar system is just hard labor that most anybody can do. Use the electrician early on the job, and at the very end to help make the job run smoothly.

Testing Your System

Invariably on larger systems there will be minor issues in the beginning and you wont be getting the juice you need. Assuming you followed the line drawing, the problem 95% of the time is just a bad connection in the system. Checking connection with a simple multimeter will help you determine problem areas. Also, the meters on inverters and charge controllers can be very telling with what is going on with your system. If your system has no voltage, that means there is a disconnect or short somewhere in the circuit. If there is no amperage flowing, usually you have something connected incorrectly.

Every system experiences a settling in period, where the system will have some minor issues and will not perform as expected. This is perfectly normal. Give your system at least a week, and sometimes more like a month or two, to fully charge the batteries, establish a cycle, and settle in.