SOLAR POWER SOLUTIONS

· THE DIY GUIDE TO CATCH THE SUN ·

FROM GRID-TIE TO OFF-GRID SOLAR PANEL SYSTEMS, EVERYTHING YOU NEED TO KNOW TO DESIGN AND INSTALL YOUR OWN PHOTOVOLTAIC SYSTEM AT HOME AND BEYOND

ENERGY NEST


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POWER
· THE DIY GU

Solar Power Solutions
The DIY Guide to Catch the Sun

From Grid-Tie to Off-Grid Solar Panel Systems, Everything You Need to Know to Design and Install Your Photovoltaic System at Home and Beyond

Energy Nest

KNOWLEDGE IS LIFE

RED LOTUS

PUBLISHING

Disclaimer

The steps outlined in this book are based on the author's personal experience in the solar industry in the last decade. Therefore it is advised to take note of all the safety standards mentioned in this book and the safety standards in the reader's country. This book is meant for educational purposes only and helps you to learn how a solar PV rooftop system is designed and implemented. Please note that improper use of the equipment and/or procedure/s can lead to lethal damage. Thus, it is advised to take all preventive and precautionary measures to safeguard your life from all possible threats. This book is for educational purposes only, and we encourage you to seek professional advice as per specific circumstances and requirements before implementing or acting upon any information contained in this book. Further, we make no claims, promises, or guarantees about the accuracy, completeness, or adequacy of the content of this book, and disclaim liability for errors and omissions. Any action that the readers may take upon the information contained in this book shall be entirely at the readers' own risk. We shall not be liable for any damages or losses in connection with the use of this book. Each country has a different set of electrical standards and compliances' which are meant to be followed before installing solar on the rooftop. Different states have different procedures for the installation of solar. Without the approval of the state authorities, installing a solar plant is illegal. Hence, it is advised that after the designing of the plant on paper/ software based on this book, the reader shall take permission from the local authorities. Popularly known as permit package, the reader is advised to make a permit plan based on the designs in this book and submit and verify this plan with the authorities before installing solar.

Table of Contents

Introduction

Every hour the Earth is hit with more energy from the sun than the entire world consumes in a year. In the last two decades the contribution of solar energy to the world's total energy supply has grown significantly. Solar Panel Systems for homes are increasing in popularity and decreasing in price.

With the new technologies and a bit of ingenuity solar is cheap, easy, and versatile. It can power up your home, your van, your boat, your garden, your shed, for no running costs at all!

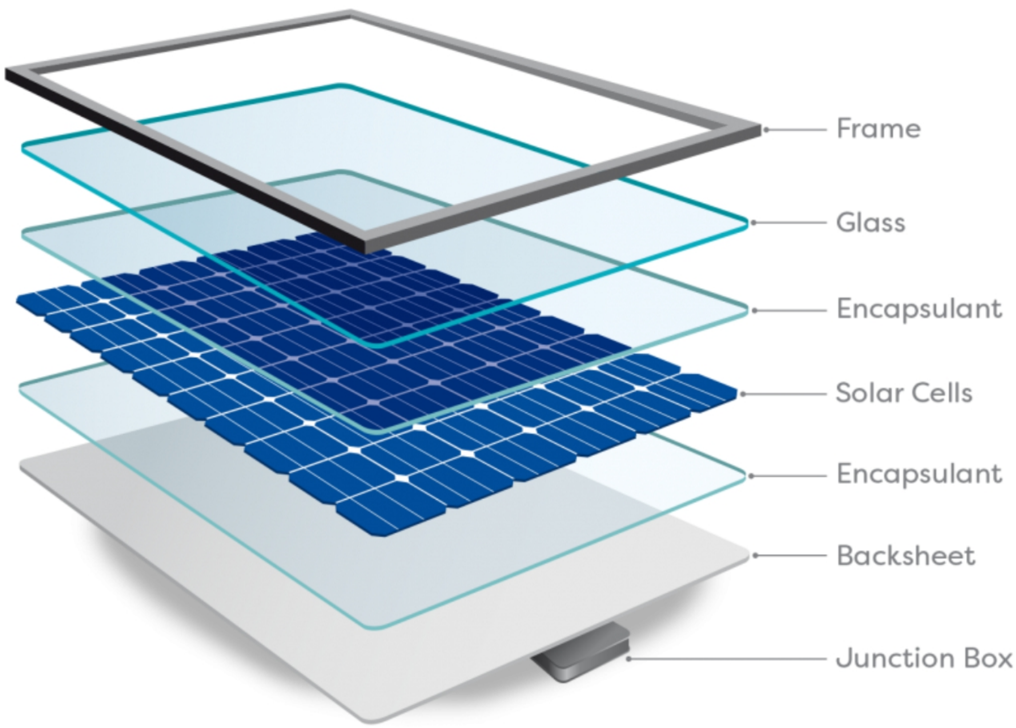
Many homeowners are discovering the advantages of Solar Power and you may have even seen quite a few systems being installed in your own neighborhood. If you're solar curious and want to learn more it can all seem a bit overwhelming.

Moreover, solar power is the most efficient way to power up a mobile home, such as an RV or a boat, without relying on shore power. Isn't it wonderful to think that we have the freedom to travel in the most remote places on earth and rely on the energy that is raining down on us in the form of photons?

You're probably wondering: How much does it cost to install a solar system, and how much money will I really save on my electricity bill?

This book offers you a complete overview of solar energy so you can have a strong foundation of knowledge and make the best possible educated decisions regarding solar power for your home or your mobile home.

First things first, what is a solar panel? A solar panel (or photovoltaic panel) is a panel made of solar cells. Solar cells are the essential component by which light is converted into electrical energy and they are usually made of crystalline silicon.



Each solar panel usually contains from 32 up to 96 solar cells. Depending on the way solar cells are made, solar panels are categorized as polycrystalline, monocrystalline or thin film. The first two categories, which are the most common types of solar panels, are made of crystalline solar cells. The third category (thin film) is made of amorphous silicon. Apart from the typical framed solar panel, there are also other types of products that can be used in residential applications.

Frameless solar panels have been on the market for more than a decade. Also, solar shingles and solar tiles popularized by the tesla solar roof are two types of products that are becoming more popular among residential applications because they combine the technology of solar panels with aesthetic integration to the house.

Solar cells produce electricity by converting the tremendous solar energy that the earth receives every day in the form of sunlight and more specifically in the form of photons. Most typical commercial solar solutions convert sunlight to electrical energy at an average efficiency of 3 – 17% If we could “break” the sunlight into the smallest possible pieces, we would get photons. So, photons practically are the smallest possible energy packages of sunlight.

First of all, the top layer of solar cells have an anti-reflective coating which helps them collect as much light as possible. Right below, there is a main layer of a solar cell which is basically a sandwich of two silicon layers. These two layers are specially treated, so that the upper layer has a surplus of electrons while the bottom layer has a shortage of electrons. What is needed for the extra electrons to move from the upper to the bottom layer is a little bit of extra energy! And that energy is provided by the photons, when the sunlight hits the solar cells! When the solar panels are exposed to the light, electric current is generated! The more sunlight hits the solar panel, the more the electricity is produced.

Solar panels definitely do not generate electricity during the night, but you can store excess energy collected during the daytime in a large battery.

Generally, residential solar systems are separated into 2 main categories: off-grid and on-grid. In the case of an off-grid system, the electricity generated by the solar system will be used to cover 100% of the electrical usage of a home since the house is not connected to the electrical grid at all. This can be accomplished by using large batteries that will store any extra electricity produced during the day. The main disadvantage of an off-grid system is its cost, since the use of batteries increases the cost about 20-30% compared to an on-grid system.

Many jurisdictions do not allow you to operate your residence off grid, so you'll have to check. In a on-grid system, the house where the solar panels are installed is connected to the main power grid. Electricity generated by the solar panels can either cover the electrical needs of the house or when you produce more electricity than needed, it is sent to the power grid. This leads us to net metering.

With net metering, your monthly electricity bill is calculated both ways, based on the net of your overall energy consumption and the monthly output from your solar panels. If you are producing more energy than you're using the utility company will actually pay you!

Equipment makes up the majority of the cost but permits and labor are also factored in. You can deduct for the current federal solar tax credit, and there are also many other localized incentives offered by your state or your utility company. These prices of course vary depending on the brand of solar panels, the size of your installation, your installer, and also on your state, but this is just to give you a rough idea of what to expect.

Keep in mind the cost of solar has been steadily decreasing over time. The best way to get a good price on solar it to compare quotes from many different installers or just do it yourself with the help of this book.

As there are practically no moving parts in a solar installation, minimal maintenance is required. However routine maintenance is needed in order to ensure that the system is performing properly. Solar panels require routine inspection for signs of damage, build-up of dirt or shade encroachment. Although solar panels are usually designed and installed in order to be cleaned by rainfall, they should be cleaned manually if there is a build-up of dust or any other obscuring material.
Periodically, system mounting structures must be checked for corrosion in order to ensure that the photovoltaic system is safely secured.

Solar power is a true renewable energy source, it reduces your electricity bill and provides insurance against rising power prices, it has low maintenance cost and even if the initial investment cost might be high you can profit from financial incentives from the government.

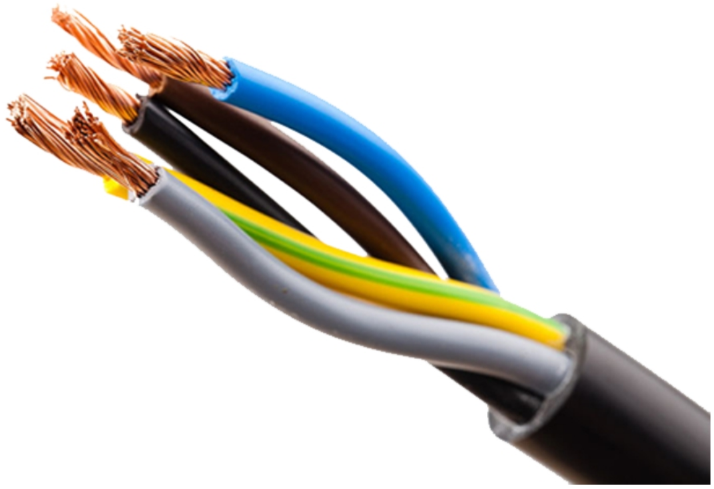
Solar panels operate quietly, with no moving parts and emit zero pollution, absorbing the unlimited energy source that gently rains down on us.
Take the first step towards energy independence and a greener future and keep reading to learn how to profit from this amazing gift Nature bestowed upon us!

1. The basics of electricity for complete beginners

Before starting out building your own solar system, you must have a general background of how an electrical system works. It doesn't mean that you need a degree in engineering, but a basic knowledge of the electrical units and formulae is a prerequisite for building your system and to be able to identify and solve any problems that you might have.

Don't worry! It is just basic high-school level physics and if it has been a while since you've graduated or you never did pay much attention, this short chapter will just refresh your memory and give you the basis to understand how electrical circuits work and which equipment and tools you will need and why.

If you are already familiar with the concepts, please feel free to skip and jump right into the second chapter about the components of a solar power system. I do encourage you to take a look at the list of recommended equipment and tools, even if you are an expert electrician, as a checklist before starting your project.

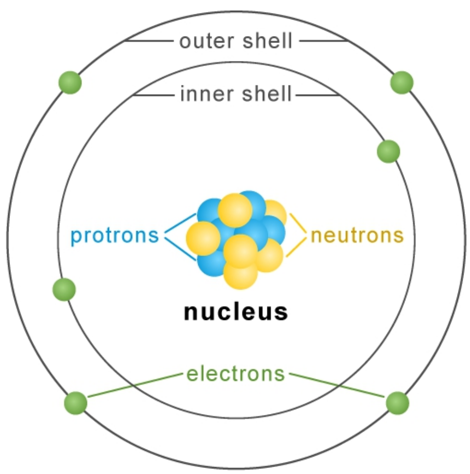
 Moreover, you might find the section on calculating your load quite useful: it is after all the first step to determine the size and efficiency of your solar system. Determining your electrical output is a prerequisite for any solar power system project: only after you have determined your needs, will you be able to decide if you want to go completely off grid, partially off-grid, or grid-tied, and subsequently sizing your system. But more on that later, now, let’s start with the basics!

1.1 How does electricity work?

If you have decided to embark on the amazing journey of being energy independent and build your own solar power system, then you will need at least the basic theoretical knowledge of how electricity works.
Take a bit of time to refresh your high-school knowledge and you will understand way more easily even the most complex electrical circuits.

Let’s start at the most elemental level!
Everything, including you, is made from atoms. All the materials we use are made from atoms.
The materials are just different because the construction of their atoms is slightly different.

The atoms are made from three particles, two of which are found inside the nucleus and the third particle sits outside this.



At the center of the atom, we have the nucleus. Inside the nucleus, we have the neutrons, which have no charge, and we also have the protons, which are positively charged. The neutrons and the protons are much heavier than the electrons so these will stay within the nucleus.

Surrounding the nucleus are different layers of orbital shells. These are like flight paths for the electrons. The electrons flow along these flight paths much like a satellite orbits our plant, except that the electrons travel at almost the speed of light. The electrons are negatively charged and they are attracted to the positive charge of the protons.

The electrons orbit around the nucleus in these orbital shells and there are a set numbers of how many electrons can be in any one orbital shell.

The number of protons, neutrons, and electrons an atom has tells us which material it is. Atoms hold on to their electrons very tightly, but some materials will hold on to them more tightly than others.

The outer-most shell is known as the valence shell, and in this shell, some materials have loosely bound electrons which can flow to other atoms.

Atoms which can pass electrons are called conductors and most metals are **conductors** .

On the other hand, atoms which do not have free electrons and so they can't pass electrons between other atoms are known as **insulators** . And these are things like glass and rubber.

Now, we can combine these materials to safely use electricity by having the conductor in the center, which allows electrons to move, but surround this with an insulator to restrict where they can flow to, i.e., not lead to us, which keeps us safe.

If we look inside a slice of copper cable at the free electrons surrounding the nucleus of the copper atom, you'll see that the free electrons are able to move to other atoms, but this happens randomly in any direction. If we then connect this slice of copper cable to a closed circuit with a power source, such as a battery, then the voltage will force the electrons to move and these will then all flow in the same direction to try and get back to the other terminal of the battery.

When I say circuit, this just means the root which electrons could flow along between the two terminals, the positive and the negative, of a power source. So, we can add things into their path, like light bulbs, and this means that the electrons will have to pass through this in order to get to the other terminal: let there be light!

The circuit can either be open or closed. In a closed circuit, that means the electrons can flow around. And in an open circuit, this means that the electrons are not able to flow.

Voltage is a pushing force of electrons within a circuit. It's like pressure in a water pipe. The more pressure you have, the more water can flow. The more voltage you have, the more electrons can flow. But what does a volt mean? Well, a volt is a joule per coulomb. And a joule is a measurement of energy or work and a coulomb is a group of flowing electrons.

For example, a nine-volt battery can provide nine joules of energy in the form of work or heat per group of electrons that flow from one side of the battery to the other. In this case, the current of electrons flow from one side of the battery through the LED light bulb, which produces light, and then the electrons flow to the other side of the battery, therefore, nine joules of light and heat is produced by the light bulb.

Current is the flow of electrons. We can measure the flow of electrons just like you can measure the flow of water through a pipe. To measure the flow of electrons, we use the unit of **amp** . One amp means one coulomb per second and one coulomb is a group of electrons. The group is incredibly large and is approximately six billion, 242 million, billion electrons, and that has to pass in one second for it to equal one amp. That's why electrons are grouped together and just called amps, to make it easier for engineers.

Resistance is a restriction to the flow of electrons in a circuit. The wire which carries the electrons will naturally have some resistance. The longer the wire, the greater the resistance. The thicker the wire, the lower the resistance. Resistance to the flow of electrons is different for each material. And the temperature of the material can also change resistance to the flow of electrons. Electrical circuits use specially designed components known as resistors to purposely restrict the flow of electrons. This is either to protect other components from too many electrons flowing through it or it can also be used to create light and heat, such as in an incandescent light bulb.
Resistance occurs when electrons collide with atoms. The amount of collisions is different from one material to another. Copper has very low collision rate, but other materials such as iron will have much more collisions. When collisions occur, the atoms generate heat and at a certain temperature, the material will then start to produce light as well as heat, which is how the incandescent lamps work.

When a wire is wrapped in a coil, it will generate a **magnetic field** as the current passes through it. The cable will naturally create electromagnetic field by itself. It's just intensified by the coil.
By wrapping it in a coil, the magnetic field becomes so strong that the magnetic field starts to actually affect the electrons within the wire. We can increase the strength of the magnetic field simply by wrapping the coils around an iron core. We can also increase the number of turns within the coils and we can increase the amount of current passing through the circuit. And this is how electromagnets work and it's also the base of how induction motors work.

When a magnetic field passes across the coil of wire, it will induce a voltage in that wire caused by an induced electromotive force, which is pushing electrons in a certain direction. If the wire is connected in a circuit, then this electromotive force will cause a current to flow. This is the basis of how AC generators work and the electricity at your wall sockets within your home is produced in a very similar way, more on that in the next chapter.

If we have one coil to generate electricity and we can place two other coils in very close proximity to each other but not touching, this will create a **transformer** . The transformer will induce a voltage from the first of the primary coil over into the secondary coil. And this will force electrons to flow if the coil in the secondary side has a closed circuit.
Now what's important about the transformer is that we can increase or decrease the voltage between the primary and the secondary coils simply by changing the number of coils on either side

Finally, to cover all the basics, a **capacitor** forces positive and negative charges to separate across two plates when it is connected to a power supply. This causes a build-up or store of electrons within an electric field. When the power supply is cut or interrupted, these charges will then be released, flow up, and meet again. This provides a power source but only for a few seconds until the charges have paired back up again. It's slightly similar to a battery, but capacitors are very common and they're in almost every single circuit board.

1.3 Electrical units

When you get your home energy bill, it lists the usage in kilowatt hours. But when you go to the store, you'll see 12-watt light bulbs, 9-volt batteries and vacuum cleaners with 15-amps of sucking power: what do these numbers even mean?

Why do we have so many different units to measure something that seems as straightforward as electricity? Surprisingly, the answer isn't “Just so appliance companies and physics professors can confuse you”; it's because several important things have to happen in an electrical circuit for electricity to flow as we have seen in the previous chapter.

1.3.1 Volts, amps, and watts

Voltage is what pushes the free electrons around a circuit. Without voltage, the free electrons will move around between atoms but they move around randomly, so they aren't much use to us. It's only when we apply a voltage to a circuit that the free electrons will all move in the same direction, causing current.

It's easy to imagine voltage like pressure in a water pipe. If we have a water tank completely filled with water, then the mass of all that water is going to cause a huge amount of pressure at the end of the pipe. If we have a water tank that's only partly filled, then there will be much less pressure in the pipe. If we open the valve to let the water flow, then more water will flow at a faster rate from the high-pressure tank compared to the low-pressure tank. The same with electricity; the more voltage we have, then the more current can flow.

Voltage can exist without current. For example, we can measure the pressure in the pipe with the valve shut with no water flowing, and from this, we can tell that the pipe is pressurized. What we're really measuring is the pressure difference between what's inside the pipe compared to the pressure outside.

The same thing if we have a battery connected to a circuit with an open switch. The voltage is still present, we can measure that, and as soon as the switch closes, it's going to push the free electrons around the circuit. We sometimes hear voltage referred to as potential difference. This really means how much work can potentially be done by a circuit.

Coming back to our water analogy, if we have two lakes at the same level, then there is no potential to do work because the water isn't flowing, but if we raise one lake higher than the other, then the higher lake now has the potential to flow down to the second one, and if we give it a path, then it will flow. If we place a turbine in its path, then we can use its energy to power a light or even an entire town.

Back to the electrical circuit, let’s imagine a battery with a potential difference of 1.5 volts between its negative and positive terminal. If we connect a piece of wire to both terminals of a battery, then the pressure of the battery will force electrons to flow all in the same direction, along the same path. We can then place electrical components in the path of these electrons to do work for us. For example, if we place a lamp into the circuit, then this will light up as the electrons flow through it. If we then added another battery to the circuit in series, then the electrons will effectively be boosted by my second battery because they can only flow along this path, and there is more energy being added. This will combine the voltages so we get 3 volts. More volts equals more pressure, which means more pushing force. That will mean more electrons will flow and the lamp will glow brighter.

However, if we were to move the battery and connect it in parallel, then the path of the electron splits. Some will flow to the first battery and some will flow to the second battery, therefore, the batteries will both provide the same amount of energy, so the voltage isn't combined, the voltage isn't boosted, and we only get 1.5 volts. So, the workload is split by the batteries and the lamp will be powered for longer, but it will be dimmer.

We measure the potential difference of voltage with the units of volts, and we use the symbol of a capital V to show this. If you look on your electrical appliances, you will see a number next to a capital V, indicating how many volts the product is designed for.

The term volt comes from an Italian physicist named Alessandro Volta, who invented the voltaic pile, which was the first electrical battery that could provide an electrical current in a steady rate in a circuit. Voltage and volts are different. Remember, voltage is the pressure and volts is just the units we use to measure it in. The same as we know the pipe has pressure but we use units to measure this pressure, such as bar, PSI, kPa, et cetera.

We can measure volts with a voltmeter. This can be separate or part of a multimeter. If you don't have a multimeter yet, I highly encourage you to have one in your tool kit.

To measure voltage, we have to connect to the circuit in parallel across the two points we would like to know the voltage, or potential difference, for. So, for a single battery in a circuit, then we measure 1.5 volts across the battery and we also measure 1.5 volts across the lamp. The battery is providing 1.5 volts to the lamp, and the lamp uses 1.5 volts to produce light and heat. In a two-lamp series circuit, we measure 1.5 volts across the battery, 1.5 volts across the two lamps combined, but 0.75 volts across the lamps individually. The voltage, or potential, has been shared between the lamps to both provide light and heat. The lamps are dimmer because the voltage has been shared or divided.

Remember that voltage and volts are different. Voltage is pressure and volt is the unit of measurement. So, what does one volt mean? One volt is required to drive one coulomb, or approximately 6 quintillion, 242 quadrillion electrons, through a resistance of one ohm in one second. That's still a little confusing, so another way to explain this is that, to power this 1.5-watt lamp with a 1.5-volt battery would require one coulomb, or 6 quintillion,242 quadrillion electrons, to flow from the battery and through the lamp every second for it to stay on. To power this 0.3-watt lamp with a 1.5-volt battery would require 0.2 coulombs, approximately 1 quintillion, 872 quadrillion, 600 trillion electrons to flow from the battery and through the lamp every second for it to stay on. If we try to use a lower voltage, the lamp would turn on but it decreases in brightness as the voltage decreases. That's because there is less pressure to force electrons through it. Less electrons flowing, less light that can be produced.

The lamps are only rated for a certain voltage and current. If we use a higher voltage, then the lamp will become brighter because more electrons are flowing through it, but if we add too much voltage and current, then the lamp will blow because too many electrons tried to pass through at once.

If we look at some typical batteries, we can see that an AA battery has a voltage of 1.5 volts, and a nine-volt battery clearly has a voltage of 9 volts. These are sources of direct voltage, meaning, the pressure it provides moves the electrons in a constant current in one direction, much like the flow of water down a river.

Direct voltage is usually represented with a capital V, with some dots above this and a small horizontal line. You can see an example of this on the multimeter for the setting we would need in order to measure the voltage in a DC supply. If we plotted this voltage against time, it would produce a straight line because it is constant; it is direct in one direction. The voltage in our wall sockets is alternating voltage. This is a different type of electricity. In this type, the electrons alternate between flowing forwards and backwards because the polarity of the circuit is changing, much like the tide of the sea. If we plotted this voltage against time, we would get a sine wave as it moves forwards and rises to its maximum and then starts to decline. It passes through zero, and flows backwards but then hits its minimum and reverses direction again. This is usually represented with a capital V with a wave line above it

The voltage in sockets varies depending on where in the world we are. The majority of the world uses 220 to 240 volts, but North, Central, and some of South America, as well as a few countries scattered across the planet will use 110 to 127 volts. We can measure the voltage at our sockets and see that it actually changes slightly throughout the day as the demand on electricity network varies.

The reason for different voltages around the world goes all the way back to the beginning, when electricity first started being distributed. At first, there was no standardization, so each distribution network had its own voltage and frequency for whatever their engineers felt was best. Eventually, over time, some companies grew and dominated the market, and so voltage and frequency standardized as their products and services expanded.

Governments also had to step in and pass laws and regulations to help standardize their countries so that people could buy products easily but also trade products with other countries. This is still a problem to this day, but it's pretty much too late to fix, as everyone is now so reliant on their electrical devices and we would need to replace or modify them all to solve the problem.

For example, if we take a hair dryer from the U.S., which is rated at 110 volts, and we plug it into a wall socket in Europe, which has 220 volts, the hairdryer will burn out at full power because there is just simply too much voltage, or too much pressure, and the device just can't cope. If we took a hair dryer from Europe and plugged it into a U.S. socket, it probably won't turn on, but if it does, it's not going to be very strong; it's going be pretty weak because there just isn't enough pressure for it to function.

Some products can be used in different voltages, though. You need to check the manufacturer's labels on the product to first see if the product has been designed to cope with different voltages. Laptop chargers, for example, usually can be used on voltages between 100 and 240 volts.

So if voltage is the pressure, how do we measure the current? Well you've probably heard of the term "**amp** " which is short for "ampere". An ampere refers to the number of electrons that are flowing per second through something that conducts electricity. 1 ampere is equivalent to 6.24 x 10^18 electrons flowing per second. You don't really need to memorize that number but you should understand that electrical current refers to the amount of electron flow. And one ampere means that a LOT of electrons are flowing. And obviously two amps means that twice the electrons are flowing.

An electric circuit is a closed loop where current can flow around.
When there's no current flowing, there can't be any transfer of energy, so the light stays off. That’s the principle behind how electrical switches work. A switch has 2 pieces of metal inside it. When the pieces of metal touch, you get a complete circuit, and the light turns on. When the pieces of metal are pulled apart it becomes an open circuit and the light turns off.

Fuses work the same way. If a fuse which is rated for 15 amperes suddenly draws 30 amperes, the fuse melts, opens the circuit and prevents any current from flowing until the fuse is replaced. Very handy for when you don't want to die in a terrible fire.

Now there's one more tricky thing about electric current that most people don't know. There are actually two naming systems for electric current. One is called conventional current and the other is called electron flow. You may have heard that current flows from positive to negative. So you might imagine that with this circuit current is flowing from the positive side the battery towards the negative side of the battery. This system of current flowing from positive to negative is what all electrical engineers use, and it's called "conventional current". However conventional current is wrong! Back in the early days when scientists were still figuring out the basics of electricity, they didn't know whether it was the protons or the electrons that were flowing. They made a guess and thought that current flowed from positive to negative but the reality is that the actual flow of electrons goes from negative to positive. Unfortunately, every single formula that we use in electronics is based around the mistake of assuming that current flows from positive to negative. The good news is that the formulas are consistent and whenever we do any math in electrical engineering, we use the system of conventional current and it works. So, you can just pretend that electrons are moving from positive to negative even though that's backwards to reality.

To summarize, amperes is the number of coulombs flowing per second, and volts is the number of joules of energy transferred for each coulomb of charge that flows.

If we have a power supply connected to a motor, with 1.8 amps flowing, and for every amp 1 joule is being delivered, this means that 1.8 joules per second was getting delivered to the motor. This is what electrical power is.

Power is the rate at which energy gets supplied, or used up. Instead of constantly saying joules per second, we have a unit that we use for power, called the watt. 1 watt is equal to 1 joule being transferred per second. So, for our example with the motor, 1.8 joules per second means that 1.8 watts of power are being delivered to the motor. If we increase the voltage to 2 volts, more current flows and more energy gets transferred for each unit of charge, so now we are getting 4 joules per second, or 4 watts of power being supplied to the motor. Since more work is being done per second, the motor spins faster. Now in real life, no engineer is going to waste time converting volts to joules per coulomb, and amps into joules per second.

You can instantly calculate power with this very simple shortcut. Voltage x current = power.

Let's say a battery is capable of delivering one amp. Just because a battery (or any power source) is capable of delivering one amp, it doesn't mean that if you connect it to something it will definitely supply one amp. Voltage sources like batteries will only deliver as much current as the load needs. The amount that the load draws depends on the load: it could be a low resistance load that draws a lot of current, a high resistance load that draws barely any current, or it could be a complicated digital device like a microcontroller which draws a different amount of current depending on what it's doing.

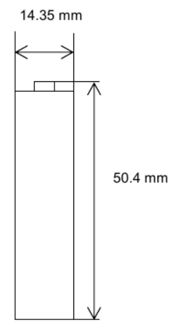
A 2Ah battery is capable of delivering over 4 amps, but connected to a motor, it might only deliver 2mA. And it can do it for hundreds of hours. But what does this mean?
Keep in mind that amps and amp-hours are two completely different things. You have already brush up on amps or amperes: the unit to describe how much electrical current is flowing.

But what is an **amp-hour** ? An amp-hour is a completely different unit: it's a measure of capacity, and it's used to estimate the amount of energy that a battery can hold. Here are the schematics for a
For example, here are the schematics for a rechargeable AA battery with the capacity is 2000mAh, or 2Ah (2 amp-hours).

FDK TWICELL

Cell Type HR-3UTG

Specifications



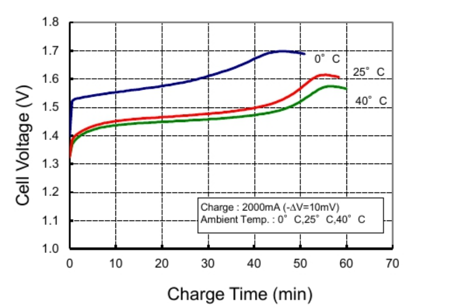
Dimensions (with tube)	D	14.35 mm
	H	50.4 mm

Type : Nickel-Metal Hydride Battery			Size : AA Consumer Type
Capacity 1)	Typical		2000mAh
	Minimum		1900mAh
Nominal Voltage			1.2V
Charging Current x Time		Fast Charge 2)	2000mA × 1.1h
Ambient Temp.	Charge Condition	Fast Charge 2)	0°C - 40°C
	Discharge Condition		0°C - 50°C
	Storage Condition	Less than 90days	-20°C - 40°C
		Less than 1year	-20°C - 30°C
Internal Impedance 3) (after discharge to E.V.=1.0V)			Approx. 25mΩ (at 1000Hz)
Weight 4)			Approx.27g
Size 4) :(Diameter) x (Height)			14.35(D) x 50.4(H) mm

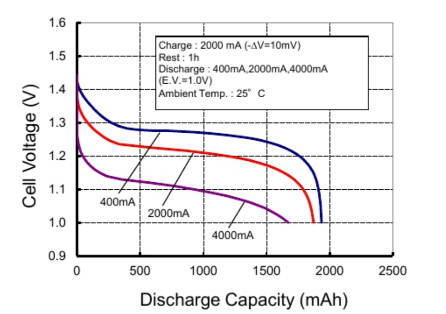
1)Single cell capacity under the following condition.
Charge : 200mA×16h, Discharge : 400mA(E.V.=1.0V) at 25°C
2)Use recommended charging system.
3)After a few charge and discharge cycles under the above 1) condition.
4)With tube.

Typical Characteristics

Charge



Discharge



2010/02

The simple explanation of what this means is that it can supply two amps for one hour until the battery runs out of energy. Two amps multiplied by one hour is 2 amp-hours. If we draw less current, the battery lasts longer. It could deliver one amp for two hours. And if we draw more current the battery gets drained faster. It can deliver 4 amps for half an hour.
So amp-hours are simple way of estimating battery life.
And in general, capacity (in amp-hours) divided by the load (in amps) gives you the battery life (in hours).

So, does that mean that this type of battery can deliver 120 amps for one minute?
If you'll try it, you'll see that it will be able to deliver only 9 amps per minute and it will heat up tremendously. Why?

Let's take a look at the schematics again: the battery has an internal impedance of 25 milliohms. It's as if there's a little resistor inside the battery, but in reality it's going to be a limitation of the battery's chemical reaction and electrodes. This internal impedance limits the amount of current that the battery can deliver and from electronics perspective it effectively becomes the source of heat when the battery is delivering current. This explains why very few batteries can actually deliver 120 amps. And it raises the question, how much current can a battery safely deliver?

Further down in the datasheet we can see the discharge curves of the battery, ranging from 400mA to 4A. So it's implied that we probably shouldn't be discharging this battery at a rate higher than 4 amps. Also notice how the effective capacity changes depending on how fast we discharge the battery.
It is only a 2 amp hour battery, when we discharge it at under 400mA. If we discharge it at 4 amps, the effective capacity is only 1.7 amp-hours because now we're losing a lot more energy in the form of internal heating. The overall trend is that the more current we draw, the lower the output voltage will be because we're dropping voltage across the internal resistance of the battery. So this 1.2 volt 2 amp-hour rating is only a guideline of what you can expect to see under ideal conditions. Okay that's amp-hours. Now here'ssomething to get you thinking. This is a 1.2 volt 2 amp-hour battery.

Now let's imagine a 9.6 volt 2 amp-hour battery pack.

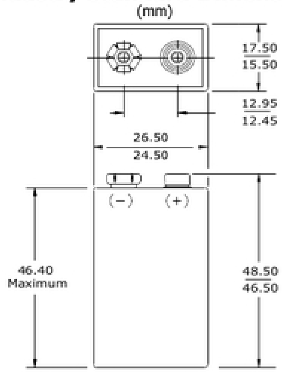
European Region
+ 44 (0) 208 920 2306
www.energizer.eu

Rechargeable 9V-175 (HR22)

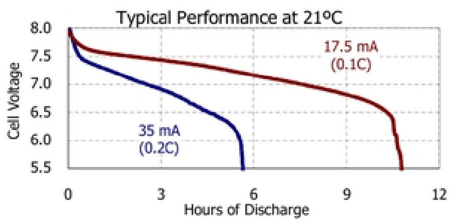
9V

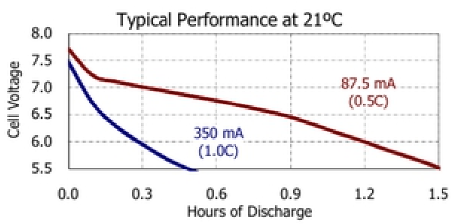
Industry Standard Dimensions

(mm)



Typical Discharge Characteristics





Specifications

Classification:	ACCU Rechargeable
Chemical System:	Nickel-Metal Hydride (NiMH)
Designation:	IEC-HR22
Nominal Voltage:	8.4 Volts
Rated Capacity:	175 mAh (to 1.0 volts) Based on 35 mA (0.2C) discharge rate
Typical Weight:	41.0 grams
Typical Volume:	21.7 cubic centimeters
Jacket:	Plastic

Internal Resistance:

The internal resistance of the cell varies
with state of charge, as follows:

Cell Charged	Cell 1/2 Discharged
1000 milliohms	1500 milliohms

(tolerance of ±20% applies to above values)

AC Impedance (No Load):

The impedance of the charged cell varies
with frequency, as follows:

Frequency (Hz)	Impedance (milliohms) (Charged Cell)
1000	950

Above values based on AC current set at 1.0 ampere.
Value tolerances are ±20%.

Operating and Storage Temperatures:

To maintain maximum performance, observe the following
general guidelines regarding environmental conditions.

Charge:	0ºC to 40ºC
Discharge:	0ºC to 50ºC
Storage:	-20ºC to 30ºC
Humidity:	65±20%

Operating at extreme temperatures,
will significantly impact battery cycle life.

Important Notice

This datasheet contains information specific to battery chargers manufactured at the time of its publication.

So, if there are both 2 amp-hour batteries, do they both hold the same amount of energy? Of course not! The 1.2 volt battery will theoretically deliver two amps for one hour with a voltage of around 1.2 volts. The 9.6-volt battery pack will also theoretically deliver two amps for one hour but with a voltage around 9.6 volts. So, one way we can compare the stored energy of these two batteries is to use another unit called **watt-hours** . **Volts x amps = watts** .

Therefore, you can probably guess that **volts x amp-hours = watt-hours** . The single cell has a capacity of 2.4 watt-hours and the larger battery pack has a capacity of 19.2 watt-hours. Now it's more obvious which battery stores more energy because we're comparing apples to apples and watt-hours to watt-hours.

Now, let’s imagine two batteries with a nominal voltage of 11.1 volts and a capacity of 2200mAh. They look the same but one of them has a 20C rating and the other is rated at 40C. What is that?

The **C rating** is an informal way of describing how much current the battery can safely deliver. If you show a battery discharge curve to most people, they'll have no idea what it means. And it's not very exciting marketing material. So, marketers use C ratings instead.

The "C" refers to the battery's capacity in amp-hours. So a 20C battery can deliver 20xC, or 20 x 2.2Ah, so it can safely deliver up to 44 amps. And the 40C battery can safely deliver 88 amps.

Now are you confused? Because you should be. Remember that amps and amp-hours are completely different units. C ratings are confusing because they screw up the units. You multiply the amp-hour capacity by the C rating and then you pretend the result is in amps.

1.3.2 Measuring equipment

Digital Meter
The digital meter (regularly known as a digital multimeter) is a test tool that is used to measure at least three variables:

- Voltage (AC and DC)
- Electrical current (DC)
- Resistance

A digital meter combines the capabilities of three tools into one: an analog voltmeter (measures volts), an analog ammeter (measures amps), and an analog ohmmeter (measures resistance).

Every digital meter should have:

- A display to show measured values.
- Button(s) to switch available mode options.
- A rotary switch to select the variable that will be measured.
- Input jacks for test leads.

The meter will have a range of unit scale measurements from millivolts (mV) to volts (V), from milliamps (mA) to Amps (A), and from milliohms (mΩ) to mega-ohms (MΩ).

You will need to know the range of the unit that you will be testing in order to select the right scale and obtain an accurate result.

Generally, for solar power applications, we will use the voltage, ohm scale, and sometimes amps.

Keep in mind that you will have test leads with insulated wires, which will be used to test electrical circuits. There will be a test lead for positive terminals (red), and a test lead for negative terminals (black). When measuring DC circuits, the colors (polarity) of the wires matter. It does not matter in AC because it is alternating. More on this later.

When you test voltage, you need to put the black lead in the ‘COM’ input and the red lead in the ‘V’ input. Then you need to select the ‘V’ variable on the rotary switch and place the positive and negative leads accordingly to obtain an accurate measurement. Otherwise, you will obtain a negative value.

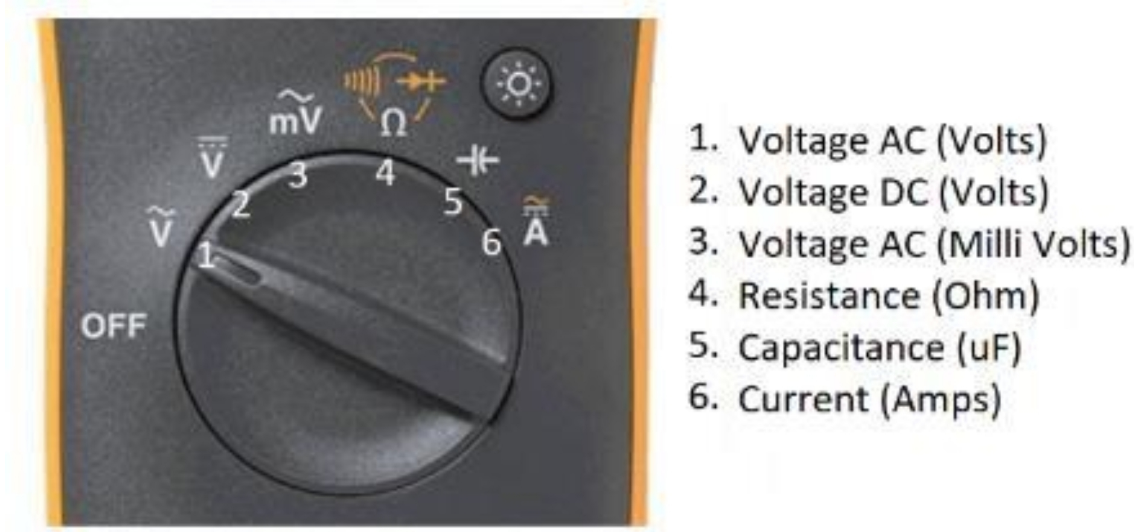
Input terminals of a multimeter (left: black, right: red)

The same concept applies to measuring resistance. The black lead will need to be put in the ‘COM’ input, and the red lead should be in the ‘Ω’ input, which is the same as the ‘V’ input. Select the Ω symbol on the rotary switch and measure the resistance of a device.

When you are testing voltage, you must measure it in an open circuit, which means measuring without load. For example, if you wish to measure the voltage that comes out of your power socket, you touch the positive and negative wire of both pins to the electrical wires.

If you want to measure resistance, you must measure it without any applied voltage. For example, if you want to check if a fuse is broken, you take out the fuse and measure at both ends of the fuse. If the display states a resistance of 1 or higher, the fuse is broken. Resistance is also measured in an open circuit.

Read the manual of the digital multimeter for further information on how to measure voltage, resistance, and current.
Although you could measure current using a digital meter, it’s better to use an ammeter for this. This is because current will flow through your meter, which will potentially damage it or blow a fuse inside if there is no load applied. There is really no need to measure current because you can calculate it using the formulas discussed in the next chapter.



Ammeter or Clamp Meter
The digital ammeter or clamp meter is a device that combines the advantages of a digital multimeter with an additional feature.

Similar to the digital multimeter, the ammeter is able to measure voltage (DC and AC), resistance, continuity, AC current, and other variables as frequency, temperature, or capacitance.

The main difference with the multimeter is that the ammeter includes a clamp that allows you to measure the RMS (root mean square) value of the electrical current. You simply need to open the clamps and close it around a conductor through which an electrical current is flowing. You cannot measure a cable that has a positive and negative wire inside of it. It can only measure one wire at a time because they will cancel each other out. An ammeter is only able to measure AC current, which is not very useful for solar systems.

This is possible because the current creates an electromagnetic field that the clamp is able to sense and transform into an electrical current value.

This instrument becomes really useful to measure current in the wiring system located after the inverter.

1.4 Electrical circuits

To perform calculations related to sizing an off-grid PV system, you will need to use some basic formulae and a basic understanding of the types of electrical circuits and its components. Don't worry it's very easy and easily remembered with a few tricks. Let's start with Ohm's Laws.

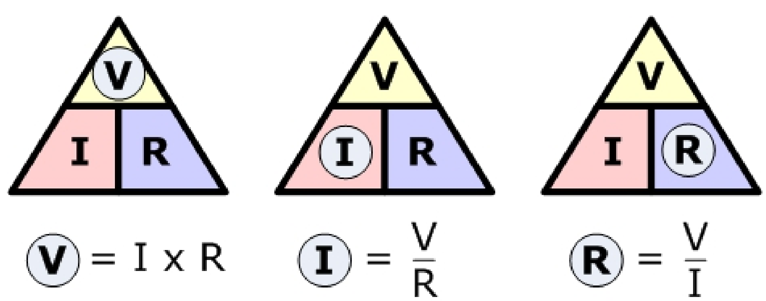
1.4.1 Ohm's laws

Ohm's Law is a relationship between voltage, current, and resistance, and how they relate to each other.

Ohm's Law was developed by German physicist, named Georg Ohm, who undertook many experiments to develop his theory, including measuring current by touching the live electrical circuits to see how much it hurt. As you might imagine, the higher the current, the more it hurt.

Now, there are three formulas we need to use for Ohm's Law, but we don't actually need to remember these, I'll show you a neat trick.
So, the three formulas we use for Ohm's Law are, voltage equals current multiplied by resistance, current equals voltage divided by resistance, and resistance equals voltage divided by current.

All we need to remember is Ohm's triangle, which looks like this.



So, you just need to remember these three letters in order. **V-I-R** .
Then we just write those down in a triangle with V at the top and we draw a line to separate the letters.
Now, all we do when we need to use a formula is cover up the letter we need.

So, if we want to find the voltage, then we write V = and then we cover up the V in the triangle. That leaves us with I and R, so we write I multiplied by R, which means voltage equals current multiplied by resistance. You can write a little multiplication symbol in the triangle between the two letters if it helps you.

Now, I know what you're thinking. Why is current represented with a letter I and not a C for current? Or even a letter A for the unit of Ampere. Well the unit of current is the Ampere or the Amp and this is named after Andre Ampere, a French physicist. A couple of hundred years ago, he undertook lots of experiments, many involved varying the amount of electrical current. So, he called this *intensité du courant* or the intensity of current.
So, when he published his work, they took the letter I and it became standard until this day. Now, you might also come across formulas where the letter E is used instead of V. The letter E stands for EMF, or Electromotive Force, but don't worry about that, just stick to using V and substitute V for E if you see it used in Ohm's Law's questions.

Anyway, so by covering V, we get voltage equals current multiplied by resistance. If we want to find current then we write down I = and then we cover up the letter I in the triangle. That gives us V and R, so as V is above the R like a fraction we can write V divided by R. Therefore, current is equal to voltage divided by resistance.

If we want to find resistance, then we write down R = and then we cover up R in the triangle. That leaves us with V and I. So, we write V divided by I, which gives us resistance equals the voltage divided by current.

Let's say we have a simple electrical circuit with a battery and a resistor. We don't know what the voltage of the battery is though. The resistor is 3 Ohms and when we connect a multi meter into the circuit, we see that we get a reading of two Amps of current. We want to find the voltage. So, using Ohm's triangle, we can cover up the V and that gives us V equals I multiplied by R. We know the current is two Amps so we can write that in and we know the resistance is three Ohms, so we can write that in also. Therefore, two Amps multiplied by three Ohms, gives us six volts. The battery is therefore six volts.

If we now double the voltage by connecting two six volt batteries in a series, we get 12 volts. If we now connect this to the same circuit, the current also doubles from two Amps to four Amps. If we double the voltage again to 24 volts, the current will also double to eight Amps. So, what's the relationship here? We can see that current is therefore directly proportional to voltage. If we double the voltage, we double the current.
Remember, voltage is like pressure, it's the pushing force in the circuit. It pushes the electrons around the wires and we place things like lamps in the way of these electrons so that they have to flow through these and that causes the lamp to light up.
By doubling the voltage, we see that the current also doubles, meaning that more electrons are flowing and this occurs as we apply more pressure or more voltage. This is just like if we were to use a bigger water pump then more water will flow.

What about finding current? Let's say we now have a three Amp lamp connected to a six volt power supply. To find the current, we cover up I in the triangle. That gives us V divided by R, so current equals voltage divided by resistance. We know the voltage is six volts and the resistance is at three Ohms, so the current is therefore two Amps and that's what we see on the multi-meter.

If we double the resistance to six Ohms, by placing another three Ohm lamp into the circuit, the current halves are just one Amp. If we double the resistance again to 12 Ohms, the current will half again to .05 Amps. We can visually see this because the lamps will become less bright as the current reduces from the increase in resistance.
So, what's the relationship here? We can see that the current is inversely proportional to the resistance. When we double the resistance, the current will decrease by half. If we half the resistance the current will double.

Current is the flow of electrons or the flow of free electrons. For us to make this lamp shine, we need to push electrons through it. How do we do that? We apply a voltage across the two ends. The voltage will push the electrons. The atoms inside the copper wire have free electrons in their valance shell, which means they can very easily move to other copper atoms. They will naturally move to other atoms by themselves, but this will be in random directions, which is of no use to us. For the lamp to turn on, we need lots of electrons to flow in the same direction. When we connect a voltage source, we use the pressure of a battery to push the electrons through the circuit all in the same direction. For example, to power a 1.5 Ohm resistive lamp, with a 1.5-volt battery, requires one Amp of current.
This is equal to six quintillion, two hundred and forty-two quadrillion electrons passing from the battery and through the lamp every second. And if you can achieve this, then the lamp will stay at full brightness.
If the voltage or current reduces or the resistance of the circuit increases, then the lamp will become dimmer.

Finally, let’s tackle the resistance. Let’s imagine a resistive lamp connected to a 12-volt power supply, we don't know how much resistance is adding to the circuit, but we measure the current at 0.5 Amps. To find the resistance, we write down R = and then we cover up the R in the triangle. We're left with V and I, so resistance equals voltage divided by current. We know the voltage is 12 volts and the current is 0.5 Amps, so 12 divided by 0.5 gives us 24 Ohms of resistance.
Resistance is the opposition to the flow of electrons. It tries to prevent electrons from flowing. That's why we use resistance in circuits to reduce the current and protect components such as an LED. If we tried to connect an LED directly to a nine-volt battery, it would blow out because the voltage and the current are too high. But, when we add a resistor into the circuit, then these are reduced, so the LED is protected and will shine brightly.
So, given the circuit, we can increase the current by increasing the voltage. Or we can also increase the current by reducing the resistance. We can also reduce the current by increasing the resistance.

It’s time for you to test your skills. Can you solve these problems?

Problem one : Let's say we have this lamp which has a resistance of 240 Ohms. If we plug this into an outlet in the US, which uses 120 volts, what will the current be?

Problem two : If I plug the same 240 Ohm resistive lamp into an outlet in the UK, we get a current of 0.958 Amps. So, what is the voltage being applied here?

Solution one:
$I = V \div R$
$I = 120V \div 240\ \Omega$
$I = 0.5A$

Solution two:
$V = I \times R$
$V = 0.958A \times 240\Omega$
$V = 229.9V$ (~230V)

1.4.2 AC and DC

There are two types of current electricity. That being alternating current, or AC, and then direct current, or DC. Alternating current simply means that the current flows backwards and forwards in a circuit as the terminals are constantly reversed. This is a bit like the tide of the sea. It goes in and out, reversing constantly. Now, alternating current is the most common source of power and the plug sockets in your homes, in your buildings, in schools, and work places, et cetera, these will all be providing alternating current, AC.

On the other hand, we've got direct current, or DC, and that simply means that the current flows directly in only one direction. It is not alternating. This is what's provided from batteries and almost all your handheld devices are from this, as well. So, we can convert AC to DC and vice versa using power electronics. And this is how we charge and power small devices, and it's also how solar panels can be used to power our homes.
Because solar panels produce DC power and our homes need AC power, we have to convert it to use it.

Building a solar power system, you will need to be able to read AC and DC signals. The solar panels, the batteries, and the charge controller will always work in DC. The inverter will transform the DC signal coming from the battery into an AC signal to power specific loads.

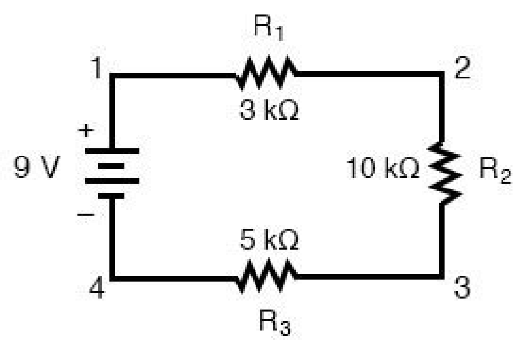
Therefore, when you test voltage or current in any part of the electrical circuit located before the inverter, you will have to measure in DC, while if you test any variable in a section located after the inverter, you will measure in AC.

1.4.3 Basic circuitry

When we connect components in electrical circuit, we can connect them either in series, or parallel, or we can combine these to make a series parallel circuit. Let's start with the series type.

Series

If we place two components in a line end to end, or with some wires in between, then these are connected in series, the electrons only have one path they can take, so they would all flow through each of the components.



Each component will have a certain resistance, the resistance opposes the voltage being applied.

We measure resistance in a unit of ohms.

In series circuits, we find the total resistance for the circuit by simply adding together all resistances.
We label each resistor with a capital R, and number them R1, R2, R3, et cetera.

The total resistance is shown with a capital letter R and a subscript T, which represents the resistance total or the total resistance. To calculate the total resistance of a series circuit is super easy. You simply add together the resistance value of each resistor. Let's say we have a circuit with a single resistor, that's our R1, and this has a value of 3 ohms, so what is our total resistance? Well that's easy, the total resistance is just 3 ohms, if we then add in the second resistor, R2, with ten ohms of resistance into the circuit, the total resistance is now 13 ohms: 3 ohms plus 10 ohms. If we added another five ohm resistor, then the total resistance is now 18 ohms.

In reality the wires too will add some resistance; even if it’s very small, you might need to account for this depending on how accurate your design needs to be.

As you have already learned, current is the flow of electrons: the higher the current, the more electrons are flowing.
We measure current by placing an ammeter into the circuit for the electrons to flow through. This is like a water meter, in the sense that water must pass through it for us to measure it. We can connect a multimeter into the circuit to also read the current. The multimeter must be placed into the circuit for us to take a reading, because the current will flow through this. The meter will add some resistance to the circuit but it's such a small amount that we can usually just ignore this.

We can calculate the total current of the circuit by dividing the voltage by the resistance. So, if we connect a 10-ohm resistor to a nine-volt battery, nine volts divided by 10 ohms give us 0.9 amps. If we added another 5-ohm resistor to the circuit that gives us 15 ohms of resistance, so nine volts divided by 15 ohms equals 0.6 amps, and if we added another five-ohm resistor that gives us 20 ohms of resistance, so nine volts divided by 20 ohms equals 0.45 amps

As we add more resistance to the circuit, the current reduces, so less electrons are flowing and that means we can do less work.

This is easily demonstrated by adding an LED with a resistor into a circuit. The higher the resistance, the dimmer the LED will be. We can also use resistors to protect components in the circuit. If I use a 100-ohm resistor with a nine-volt battery, the current will be around 0.09 amps, or 90 milliamps, and that will be too much it will blow the LED. If I use a 450-ohm resistor the current will be around 0.02 amps or 20 milliamps, so the LED should be okay. If you use a 900-ohm resistor, the current will be 0.01 amp or 10 milliamp, and the LED will be very dim then.

The most important thing to remember is that in a series circuit the current is the same throughout the entire circuit. That's because there is only one path for the electrons to flow, and they would all move together in the same direction, so the current must be the same. It doesn't matter where we measure or where we place the resistor, even if we swap the order of the resistors, the current will be the same anywhere in a series circuit.

How about voltage in a series circuit? If you remember, voltage is the pushing force of electrons. It's like pressure in a pipe, the higher the pressure the more water can flow, the higher the voltage the more electrons can flow.

When we measure voltage, we're measuring the difference or potential difference between two points. If we read across a 1.5 volt battery, we get a reading of 1.5 volts. But if we try to measure the same side we wouldn't read any voltage, we can only measure the difference between two points.

If we place a nine-volt battery into a series circuit we apply nine volts to the circuit, and we can increase this by wiring the batteries in series. If we place two nine volt batteries in a circuit in series, then we get 18 volts. Three nine-volt batteries will give us 27 volts.

Let's take a nine-volt battery, and add an R1 resistor of 10 ohms to the circuit. If we use a multimeter to measure across the resistor, we get a voltage reading of nine volts. If we add another 10 ohm resistor, we get a reading of nine volts across the two resistors, but we get a reading of 4.5 volts if we measure across either of the resistors individually.
The resistors divide the voltage.

If we replace the R2 resistor with a five-ohm resistor, the total voltage would again be nine volts, and that's what we’ll see if we measure across the two resistors. But if we measure across the 10 ohm resistor, we see a voltage of six volts, and if we measure across the five ohm resistor, we see three volts. You’ll find out why later on.

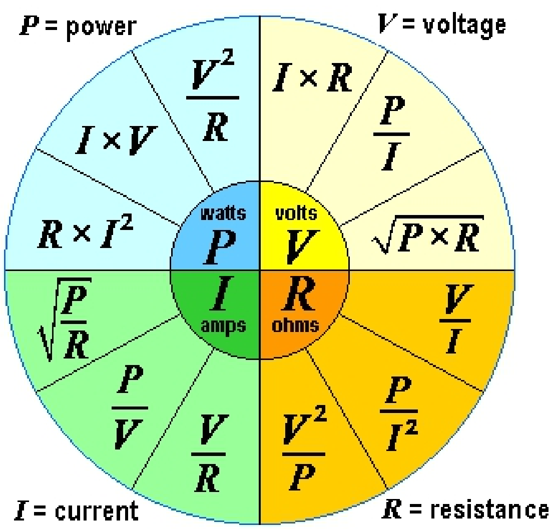
If we added another resistor, R3, with five ohms into the circuit, we again get a total voltage drop of nine volts across the three resistors. Across the R1 10-ohm resistor, we read 4.5 volts. Across the R2 five-ohm resistor, we read 2.25 volts. And across the last R3 five-ohm resistor we again see 2.25 volts.

We can combine these readings to find the voltage at different parts of the circuit, for example if we measure from the battery across R1, we see 4.5 volts. If we measure from the battery across R1 and R2, we get 6.75 volts, because 4.5 plus 2.25 volts.

Unlike current where it's the same throughout the circuit, the voltage will be different throughout a series circuit. The above-mentioned examples show us that the voltage is reduced by each resistor, so the resistor creates a voltage drop, that's the purpose of the resistor, to reduce the voltage or the pressure.

The resistor creates a more difficult path for the electrons to flow through, and as they flow through it they will collide with other electrons. This collision will convert the energy into heat, the same number of electrons will enter and exit the resistor, they will just have less energy or pressure as there's been a voltage drop. We can calculate the voltage drop across each resistor individually, by multiplying the total current in the circuit, by the resistance of each component.
The total voltage drop will be the total of all the individual voltage drops combined.

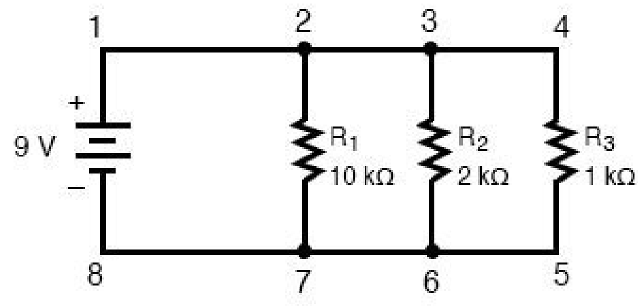
How do we measure power consumption of a circuit?



We can either use power, which is watts, equals voltage squared, divided by resistance, or we can use power equals voltage, multiplied by current.
You might be wondering how can a resistor consume power? Well as the resistor is creating a voltage drop, the electrons are losing some energy, where is this energy going. The electrical energy converts into heat: the power consumption is actually the heat being dissipated from the circuit.

Parallel

In the series configuration, there's only one path for the electrons to flow along. If we place two lamps in a series circuit, they will both light up, but if one of the bulbs breaks, then the entire circuit stops working because there's only one path for the electrons to flow along. You might have seen this with strings of light such as fairy lights. When one bulb pops, the whole string of light stops working.
A solution to this is to wire the lamps in parallel. When we do this, we provide the electrons multiple paths. If one lamp stops working, the circuit will continue to work except for the one broken path.



Let’s start by examining voltage in parallel circuits.
If we use a multimeter to measure across the two ends of a 1.5-volt battery, we will read 1.5 volts. But if we measure the same end, we get a reading of zero. Why?
Again, we can only measure the difference in voltage between two different points. When we connect a component to a battery, it experiences the difference in voltage between the two points or terminals of the battery. The voltage or pressure will force electrons to flow through the component.

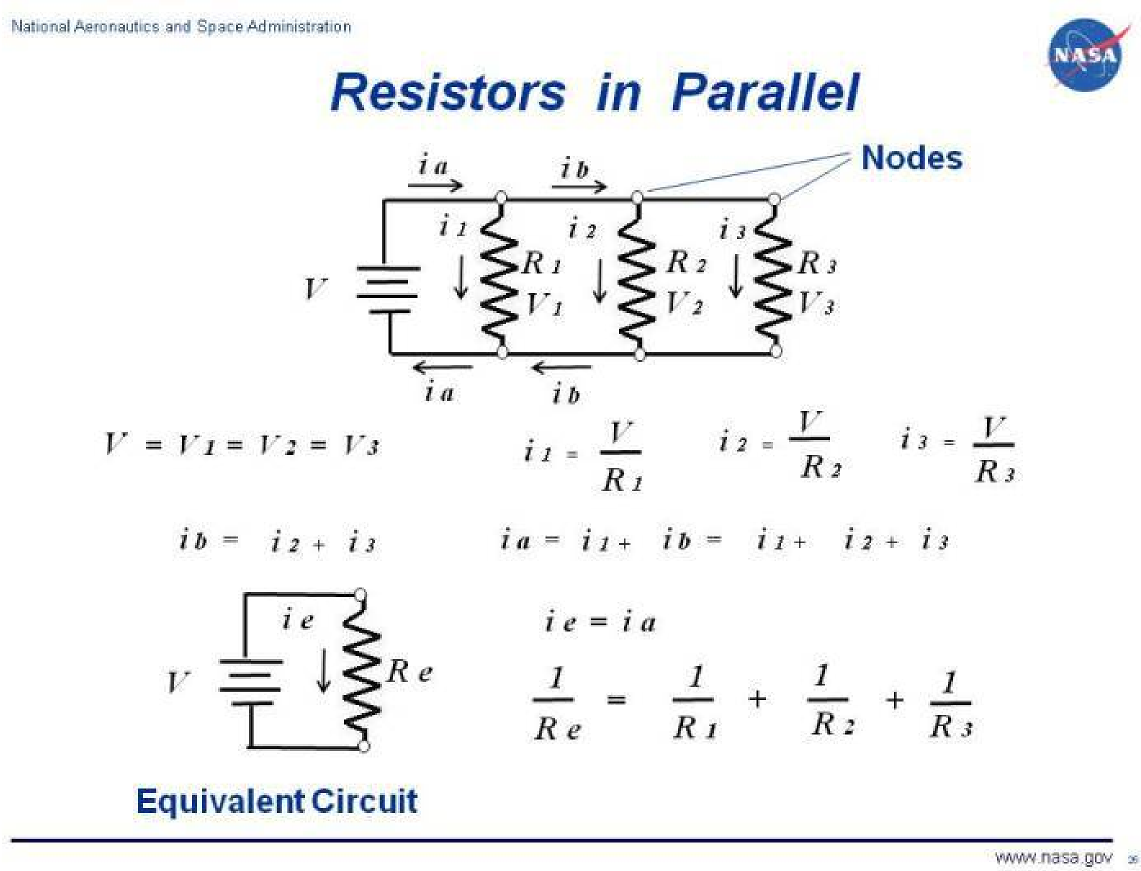
In parallel circuits, the voltage is the same anywhere in the circuit. It doesn't matter if we connect a multimeter here, here or here. We get the same reading. Why? Because each component or path is connected directly to both the positive and the negative terminals of the battery.
In series circuits the components were connected to each other, so the voltage reduced.
But with parallel there are multiple routes and each is connected directly to the battery. So, the voltage is simply the voltage of the connected battery.

But how does current flow in parallel circuits? Remember current is the flow of electrons. We need electrons to flow in the same direction, to power things like lamps. We apply voltage difference across a component to force electrons to move. As we apply more voltage, more electrons will flow. The speed of the electrons remains the same but the number of electrons moving will vary. The more electrons we have moving, the higher the current.

If we connect a lamp with a resistance of one ohm, to a battery rated at 1.5 volts, the total current in the circuit will be 1.5 amps. We can measure that by placing a multimeter into the circuit. Or we can calculate that using Ohm's law, and the formula current equals voltage divided by resistance.

If we then connect a second one-ohm resistive lamp into the circuit while in parallel, the multimeter reading the total current sees an increase to three amps. But if we measure the current through the lamps individually, we see the multimeter will read just 1.5 amps on each. In the wire between the two lamps, we also see a current of 1.5 amps.
The total current is the sum of the current in each branch.

How do we calculate the total resistance in a parallel circuit?
In a series circuit, the total resistance of the circuit was the resistance of each component just added together. Why? Because the electrons had to pass through each one. So the more resistors they pass through, the more total resistance increased. But, with parallel circuits, we are providing lots of different paths for the electrons to flow through. So, we are instead going to work out how conductive each branch is, or how easy electricity can pass through each branch. We then combine these values and we convert that back into a resistance. This is the easy-peasy formula to help you do just that, which is really just a derivation from Ohm's laws.



Power consumption in parallel circuits. The resistors and the components will convert the electrical energy into thermal energy as the electrons pass through and collide within the component. That's why they become hot and we can see that using a thermal imaging camera. So how much power are the individual components in the circuit in total consuming? We can use two formulas for this. Either voltage squared divided by resistance, or voltage multiplied by current

1.4.4. Calculating your load

One of the most important steps that you need to do when sizing your PV system is to estimate the load that you will have.
You might think this means simply adding up the wattage of all the lightbulbs, all the plug-in and hard-wired appliances, and then comparing this to the total capacity.
But think about it: isn’t it rare for all electrical appliances and lights to be active at the same time?

Most likely, you won’t run the heater and the air conditioner at the same time, for example; and probably you won’t be vacuuming while the toaster and the washing machine are running.

Professional electricians generally have alternative methods for determining the appropriate size for an electrical service or PV system. But to understand how to calculate your domestic load, you must first distinguish between resistive and conductive loads.

Resistive loads
There are mainly two types of resistive loads:

- Linear loads
- Non-linear loads

Linear type loads consume an average amount of power that is constant over time. There are no big fluctuations while running or starting them. These are generally associated with the behavior of electrical resistance; therefore, they are called resistive loads. This can be a lightbulb or water heater.

Non-linear loads have a behavior similar to inductors or capacitors, which have a consumption over time that is not constant. The resistive loads have a specific power consumption in their datasheets. This power consumption can be expressed in watts or amps.

You will typically find the nominal voltage of the load in the datasheet as well. Using the power formula **watts = voltage x amps** , you will be able to find the equivalent power that the load consumes.

In the following table, we can take a look at some resistive loads that are used for residential purposes.

Appliance	**Running Watts**
CD/DVD Player	35-100
Clock Radio	50
Desktop Computer	60-200
Laptop	20-50
Printer	30-50
Coffee Maker	650-1,200
Hair Dryer	1,000
Blender	1,200
Electric Water Heater	1,500
Fan	30-100
Iron	1,000-1,500
Microwave	1200
24” TVs LED	40-50
Air conditioner 5000 BTU	500
Electric Stove	2,000
Electric Fry Pan	1,200
Electric Blanket	200
LED lights	6-20

As you can see, the loads that consume more power are the ones that heat the space, cool the space, and generate heat for cooking.
These loads must be selected very carefully as they will draw a lot of power and energy from the PV system. Elements such as an electric stove, an electric frypan, or a waffle iron should be avoided and replaced by alternative energy sources like a natural gas stove. Replacing these energy-demanding appliances will reduce the cost of your setup.

Inductive loads
Inductive type loads draw more amps during their start cycle. If you are using inductive loads, you need to consider the surge current when starting these devices.

Refrigerator
Maybe the most important one of the inductive loads is the refrigerator. This load has multiple components, but the two most important for us are the electric motor and the compressor. The compressor takes a cool refrigerant liquid and transforms it into a hot refrigerant liquid with a higher pressure that is needed to complete the refrigeration cycle. To perform this task, the compressor needs an electric motor that generates movement inside the compressor. This means we will have a power surge while starting. Therefore, the off-grid PV system must always be able to provide this surge power.

Another factor that you must consider with refrigerators when sizing the PV system is that you cannot take the nominal power consumption and multiply it by 24 hours, which is the time that the refrigerator generally operates per day. This will lead to oversizing and is a common mistake.

Refrigerator datasheets often include a yellow label where you will find the energy consumption of the product per year or day. This is the reference that you must use in your calculations for energy yields. Power consumptions must be considered for the inverter's power rating.

Energy consumption of a fridge depends on many factors:

Type of fridge: A top loader will consume less power than a display fridge.
Size: The volume of the fridge will play a role in energy consumption.
Location: If the fridge is well ventilated at the condenser, it will require less energy.
Season: During the summer, the fridge needs to work harder because the temperature difference is bigger.
Usage frequency: Opening the doors frequently will lead to more energy usage.
Temperature set point: Check to make sure the temperature setpoint is not too cold.
Age: The age of the refrigerator also decides the energy usage. The newer, the less energy it will use.
Quality of the seals: If the seals do not properly close the door, cold air will leak out.

Depending on all these factors, refrigerators will generally consume 50% of their rated power in one day.

Washer/Dryer

Washers and dryers are also important pieces of equipment that require special attention.

There are two types of dryers: gas- and electric-based dryers. Electric dryers, similar to other heat applications, circulate an electric current through an electrical resistance to generate heat. Electric dryers consume a huge amount of electricity that can reach up to 725kWh per year and also consume a lot of power, reaching over 5,500W.

The amount of energy and power required to supply a dryer is simply too much for a simple off-grid application where there is a very small space available for solar panels. For example, if you are considering living in an RV and have an electric dryer included, solar power might not be the best option to supply it.

For these purposes, the best choice might be to go for a gas-based dryer. Using a dryer that works on natural gas comes with other important safety regulations like placing it in a well-ventilated place and allowing fresh air to enter the intake of the dryer. This can be accomplished by installing an external intake and exhaust pipes. Installing a propane detector is a good safety precaution.

RV Water Pump

An RV water pump is another type of load that you can add to your list. RV water pumps generally work at 12 VDC. They can draw between 2.5 Amps and 3 Amps under regular operation.

However, as they also include a DC motor, they could draw between 7.5 and 10 Amps, depending on the model during the starting process.

Keep in mind that these 12V water pumps are only designed for intermittent use. In other words, they are designed to be used during the time that you take a shower, wash your hands, or the time it takes you to flush a toilet. Therefore, energy consumption would be low. They work on DC, so they do not add to the peak power of an inverter.

Air Conditioner
If you are thinking about powering an A/C unit with solar panels, you must accurately estimate the energy consumption that this load will have. Otherwise, the consumption will be just too big to handle.

An A/C unit consumption cannot simply be calculated based on the nominal power by the number of hours of use. Doing this will represent a tremendous increase in energy demand, and your solar panel system will be oversized.

Commonly, you will find in datasheets or in A/C models that the air conditioner is expressed in kW. Despite that this is the same electrical power unit, kW is a thermal power unit, so make sure you do not use this unit for your electrical calculations.

This device also has a motor that runs the compressor. Therefore, it also requires a surge current. For A/C units, a good assumption is that the surge power will be equal to three times the electrical power that is on the technical datasheet.

A common mistake generally made is to assume the energy consumption of the air conditioner will be related to the number of hours of use.
For example, a simple A/C unit will consume its rated power of 1,200 Watts to cool down the room. After that, the compressor (outside unit) will stop while only the fan inside will work. The compressor and the fan will, therefore, have the highest energy consumption.

The energy consumption will greatly depend on the difference in temperature between the inside and outside and time of day, how many times you open the doors, the insulation, and many other factors.

Now that you know the different loads of the most common appliances in theory, let’s put it into practice!

Here are two simple methods to determining your electricity load:

1. Add together the wattage capacity of all the lighting circuits in your home.
2. Add the wattage rating of all your plug-in outlet circuits.

3. Add the wattage rating of all your permanent appliances, the inductive loads (refrigerators, dryers, water heaters, et cetera)
4. Subtract 10,000 from the resulting number.
5. Multiply the resulting number by 0.40
6. Add 10,000 to the resulting number.
7. Look for the full wattage rating of permanent air conditioners, and the wattage rating heating appliances (furnace plus space heaters). Add whichever is the larger of these two numbers to the resulting number. (You won’t cool and hat at the same time, so don't add both numbers.)
8. Finally, divide the resulting number by 240.

The total equals the suggested amperage needed to power the home sufficiently.

If you don’t want to go through the hustle of calculating your load there are an even simpler, albeit less precise, rule-of-thumbs:

- 100-amp systems are generally large enough to power a small- to mid-sized home's general circuits, plus one to two electrical appliances, such as a refrigerator, water heater, or clothes dryer. It may be sufficient for a house under 2,500 square feet if the heating appliances run on gas.

- 200-amp systems will manage the same load as 100-amp systems, plus electrical appliances and electrical heating/cooling systems in homes up to about 3,000 square feet.

- 300- or 400-amp systems are recommended for larger homes (bigger than 3,500 square feet) with all the most common electric appliances and electric heating/cooling equipment. A system of this size is necessary where the expected electric heat load is over 20,000 watts.

It is generally a good idea to oversize a PV system if you can do it, to make future expansion possible. A 100-amp service becomes quickly undersized by adding just a few electrical appliances. An oversized electrical system will also make it possible to run a sub-panel out to your garage, shed, or garden, if you need power there as well. Moreover, you should definitely consider oversizing if you are grid-tied. For off-grid project calculate your load accurately and decide beforehand which appliances will run solely with the PV system.

1.4.5 Equipment and tools

Besides the actual component of a solar power system, you will need some basic equipment.

Wiring

There are many types of wiring you can use. I highly recommend getting stranded wire, which consists of multiple wires in one. This has the advantage of being very flexible, while solid cables are very hard to work with.

If you are going to buy wires in the store, you will have two options. Buying copper wire or aluminum wire. Copper wire is a better conductor than aluminum, but it is also more expensive.

Since copper is a better conductor of electricity than aluminum, you need to increase the diameter of your aluminum wires to account for this. More information about this in the wiring chapter.

The diameter of the wire depends on the amount of current the wire needs to transport. The higher the current, the thicker the wire needs to be. If the wire is too thin, it will heat up, which will reduce its efficiency, or in the worst case, catch fire. Using fuses to protect the wires is essential. We will talk about choosing the right fuses later.

Wire Lugs

The wire lugs are metal-based components that are required to make a solid connection between the connections to the batteries. Wire lugs are used for the parts in your system where the highest amount of current will be. You will find multiple options available from different manufacturers and materials.

Basically, you can use any of them as long as you consider that the size of the battery terminal lug fits the wire gauge and that the terminal lug is also suitable in diameter for the battery posts.
You can buy battery interconnection cables that already have the terminal lugs included. This way, you don’t need special tools to fit these bigger wire lugs. Remember that the thickness of the wire depends on the current that has to flow through the wire.

Apart from the AWG size, you have two options when buying wire lugs. One is copper, and the other is tin-plated copper. Copper tends to corrode over time, while the tin-plated copper does not. I would highly recommend to use the tin-plated ones for your project.

Wire lugs are meant for thicker cables only. For smaller cables, you will need crimp connectors.

Crimp Connectors

The only downside to using stranded wire is that you need crimp connectors at both ends to connect your terminals to other devices.

Crimp connectors give a better point of contact to the device terminals, which reduces heat loss. It will eliminate the risk of corrosion at the exposed sides of the stranded wire.

There are several types of crimp connectors:

- Blade
- Ring
- Spade
- Ferrules
- Bullet

Ferrules, rings, and spades are the most used in solar applications. Ferrules are used to connect to the terminals of the devices while ring and spades are used to connect to busbars.

Like most crimp connectors, they come in several colors. Each wire diameter has its own connector color. We will discuss which wiring diameter you need in the wiring chapter.

Bullet connectors are used to fit MC4 connectors. These are used to transport the electricity from the solar panels to your combiner box. The plastic MC4 connectors protect the cable from moisture, dust, and rain.

They also function as a plug and play wiring method for combining solar panels in a string or array (series and parallel).

After stripping the wire insulation with a wire stripper, you can place the crimp connector, which will then fit through the MC4 connector. Use a crimping tool to apply pressure on the crimp connector and secure a good wiring conductivity.
Next, you need to tighten the connector to the wire using an assembly tool, which will most likely be delivered together with the MC4 connectors.

MC4 Assembly tool

If you do not want to make these cables yourself, you can buy them already made. This is easier and will reduce the possibility of error. Search for 'MC4 connector cables.' Make sure you select the right gauge size for the current that flows through it.

Busbar

In electrical power distribution, there is an element that is crucial to consider in any installation: the busbar.

They are copper or aluminum strips that can typically be seen inside switchgear or panel boards that carry all the currents in any electrical system. They act as the collection or distribution of electrical currents through which there is a path from the generation source up to the loads. They are also called a central wiring terminal.

There are smaller busbars mainly intended for small, off-grid PV applications with just a few pins for interconnection between components (inverter, charge controller, and batteries). In even smaller systems, you do not need any busbars.
Busbars are also useful in combiner boxes, more about it later on.

Displays

As you will find out, many of the components of the PV system will need to be placed into compartments where access may not be regular or easy.

In order to have a visual of the charging stage of your battery or the solar power output that is generated, you will need to have a display instrument. This device will constantly show the values of the variables related to voltage, current, and power that you can locate in any other place that has easy access.

There are many other displays available like the shunt, which we will discuss later in the book.

Combiner box
This component is a box that contains all the connections coming from every string of solar panels and joins them in a single wire. It is mostly used when connecting panels in parallel.

From this connection, two higher wire gauge output cables (one for positive terminal and one for negative terminal) contain all the generated DC electricity and transport it to the charge controller. The combiner box generally consists of a negative bus bar, a ground bus bar, a positive PV bus bar, circuit breakers or fuses, and an optional surge protection device.

The combiner box is usually set as close as possible to the string of PV modules in order to reduce voltage drop or DC wiring ohmic losses. Therefore, in residential or commercial applications, they are typically placed outdoors on the roof or on the ground, depending on the type of PV system. Refer to the mounting instructions of the combiner box if you are going to use one.

When selecting a combiner box, you must be aware of several factors:
Encapsulating Rating
Typical encapsulating ratings are classified under the National Electrical Manufacturers Association (NEMA) standards. Typical encapsulating ratings for combiner boxes are type 3R and type 4X.

The type 3R rating enclosure is constructed for either indoor or outdoor use and protects the equipment inside against incoming solid particles (dirt) and the ingress of water as well (rain, sleet, or snow). It also provides protection for the equipment against the formation of ice on the exterior side.

Meanwhile, the type 4X enclosure rated combiner box protects all internal equipment from windblown dust and for the ingress of water (in the rain, sleet, snow, or splashing water). It also protects against corrosion and the formation of ice on the exterior side as well.

In order to make the box weatherproof, the feeding of the cables should be done by using a PV wire cord grip.

The combiner box is also designed to withstand a specific voltage rating to provide insulation. Typical low voltage applications for off-grid purposes will be rated at 600VDC.

Also, the combiner box will generally have a specific rating for fuses and breakers in volts. The number of breakers/fuses that can be placed inside is also very important to consider, as this will indicate if the combiner box is able to connect all the PV strings.

Fuses and Circuit Breakers

Fuses or circuit breakers which are put inline in your solar system are not intended to protect the device it is wired to.
Devices like the charge controller and the inverter have their own fuses.
The reason why we put fuses or circuit breakers inline is to protect the wiring of the system from getting hot, melting, or even catching fire.

Therefore, the fuses or circuit breakers that are placed inline are calculated on the size of the actual wiring. This is to protect your system from catching fire if there is a higher current flowing through the wires at which they are rated for. This is how you determine fuse sizes:

1. Figure out the load.
2. Figure out the distance to the appliance (voltage drop).
3. Decide wiring thickness.
4. Decide fuse rating based on wire thickness.

There is an exception to wires that come directly from solar panels. The wiring coming from PV panels is bigger than it needs to be to minimize the voltage drop. The back of the solar panel will display the maximum allowed fuse size (more on this later).

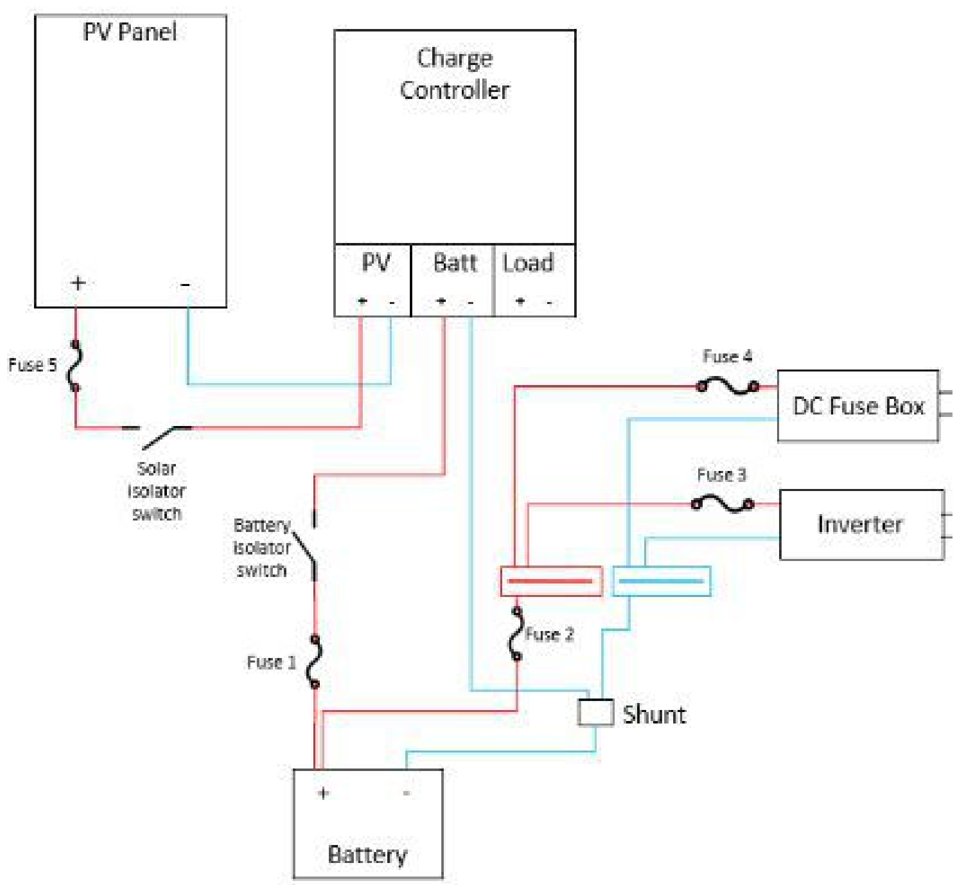
An example of this is that you will be running wires that are rated for 30 Amps to minimize voltage drop, but the maximum fuse for the solar panels is only 10 Amps.

Where to Place Fuses

Fuses should be placed as close as possible to the energy source. If current flows from your battery to your inverter, place it as close to the battery as possible. If current flows from solar panels to the charge controller, place it as close as possible to the solar panels. Only place fuses on the positive (red) wire.

Fuses should be placed in the following locations:

- On the positive wire from your solar panel(s) to your charge controller (as close as possible to the panel itself). You can use an inline MC4 connector fuse for this. You can put a fuse in a combiner box if you wire in parallel.
- On the positive wire from the charge controller to the battery.
- On the positive wire from the battery to the busbar.
- One the positive wire from the busbar to the inverter.
- On the positive wire from the busbar to the DC loads.



Fuses vs. Circuit Breakers

There are two types of DC protection devices are essential to guarantee the safe and effective functioning and operation of any PV system: fuses and circuit breakers.

Fuses are overcurrent protection devices that contain a filament inside that heats up as current flows through it. When a specific current located above the permissible limit passes through the filament, the filament heats up above its thermal capacity and melts. When the wire inside the fuse melts, the circuit gets opened.

An overcurrent can be produced by:

- An overload caused by excessive current demand from the electrical loads, above the design limit.
- A short-circuit caused by a fault that occurs in the circuit.

A circuit breaker is a thermal protection mechanism is based on a bimetallic contact that heats and expands when an electric current located above the rated value is present. This protects the circuit against overload. A magnetic protection mechanism instantly responds to high fault currents that protect the electrical circuit against short-circuits or over-currents.

Inside the DC breaker, two contacts split when an overcurrent passes through the protection device, automatically switching it to the OFF position.
The DC breaker needs to be put back in the ON position to allow electric current flow again through the circuit. There is no functional difference between fuses or circuit breakers.

If a fault occurs with a fuse, you need to replace it. With a breaker, you flip the switch back in the on position; but fuses are cheaper than circuit breakers.

Keep in mind that for solar power applications, you must choose circuit breakers that work on DC to protect solar panels and batteries. Circuit breakers that work on AC are used solely to protect the AC loads.

So, which protective device should you use for each application?

I recommend using fuses for parts in your circuits that do not easily trip. This is the DC part of your solar system.

Circuit breakers can be reused each time that they trip, and they are intended to protect multiple electrical circuits.
You will need to use fuses specifically for protecting the battery bank as higher currents flow through this circuit, and the protection speed of these devices will guarantee that the batteries will not suffer any damage.

Finally, for the main AC panel, it is more common to use circuit breakers to protect loads in residential-sized or off-grid PV systems.
Because of the high current in DC systems, it can get very expensive to use DC circuit breakers. Therefore, fuses are preferred.

Fuses and circuit breakers can also be classified according to their response speed.
The acting speed is the time it takes for the fuse to open once a fault current or overload passes through the filament. This is dependent mainly on the material used for the fuse element.
Selecting the accurate fuse type also involves selecting the appropriate speed response for the particular application that you are using. Choosing a fuse that acts too fast may not allow normal current operations to run, while choosing a fuse that is too slow may not interrupt faulty currents quickly enough.

There are 3 main types of fuse speeds: ultra-rapid, fast-acting, and slow-acting
Ultra-rapid fuses are mainly used for semi-conductors' (electronics) protection.
Fast-acting fuses can be used to protect cabling and less sensitive components such as batteries and PV modules.
Finally, slow-acting fuses feature a built-in delay that temporarily allows the flow of inrush electrical currents in electrical motors.

When checking the datasheet of the fuse, you may find some of the following marks, as described in the following table:

Marking	Description

FF	Very Fast Acting Fuse
F	Fast Acting Fuse
M	Medium Acting Fuse
T	Slow Acting Fuse
TT	Very Slow Acting Fuse

Generally, for battery and solar panel protection, you will need FF, F, or M type fuse ratings. If you intend to protect a more specific load like a motor or pump, you might need to select a slow-acting fuse in order to allow normal inrush (starting) current to flow.

Electrical engineers use a detailed analysis of this aspect considering time vs. current graphs of the fuse to ensure that the protection device acts when it needs to.

Let’s look at different fuses and circuit breakers.

Spade Fuses

A type of fuse that is widely being used in solar power applications are spade fuses, also called blade fuses. These can easily be found in the electrical fuse box of most cars. Their principle is the same as described before. You have to replace them once they trip.

These can be used to act as overcurrent protection for multiple DC loads.

The color of the spade fuses indicates their current rating.

Color	Current
Dark blue	0.5 A
Black	1 A
Gray	2 A
Violet	3 A
Pink	4 A
Tan	5 A
Brown	7.5 A
Red	10 A
Blue	15 A
Yellow	20 A
Clear	25 A
Green	30 A
Blue-green	35 A
Orange	40 A

Red	50 A
Blue	60 A
Amber/tan	70 A
Clear	80 A
Violet	100 A
Purple	120 A

Spade fuses can be used in the part of your system where DC loads are attached. Use a fuse box to neatly organize your DC load box for led lights or ceiling fans.

ANL Fuses

ANL fuses are especially used in off-grid applications, in RVs, or boats due to their simplicity and their integrated case box.

These fuses are used for high current applications, mainly as the fuse between:

- Battery and charge controller
- Battery and DC loads
- Battery and inverter

They typically go from 60A up to 500A, depending on the manufacturer. Just as with any other fuse, when an overcurrent exceeding the rating of the fuse passes through it, the fuse will instantly break.

Two metal prongs are available at the ends of the fuse to attach it to a specific case box that can later be mounted on any surface using screws.

Circuit Breakers

There are mainly three types of circuit breakers.

- Single pole
- Double pole
- Triple pole

Single-pole models are suitable for most circuitry. Simple loads such as fans, TVs, microwaves, coffee makers, home theater equipment, and any other load that works in 120VAC will need a single-pole one.

Other loads such as air conditioners, washing machines, dryers, and some motors work in split-phase configuration requiring nearly 240VAC. Therefore, they need double-pole circuit breakers. Finally, some loads will need to work on three-phase systems at 208VAC. Therefore, they will need triple pole circuit breakers.

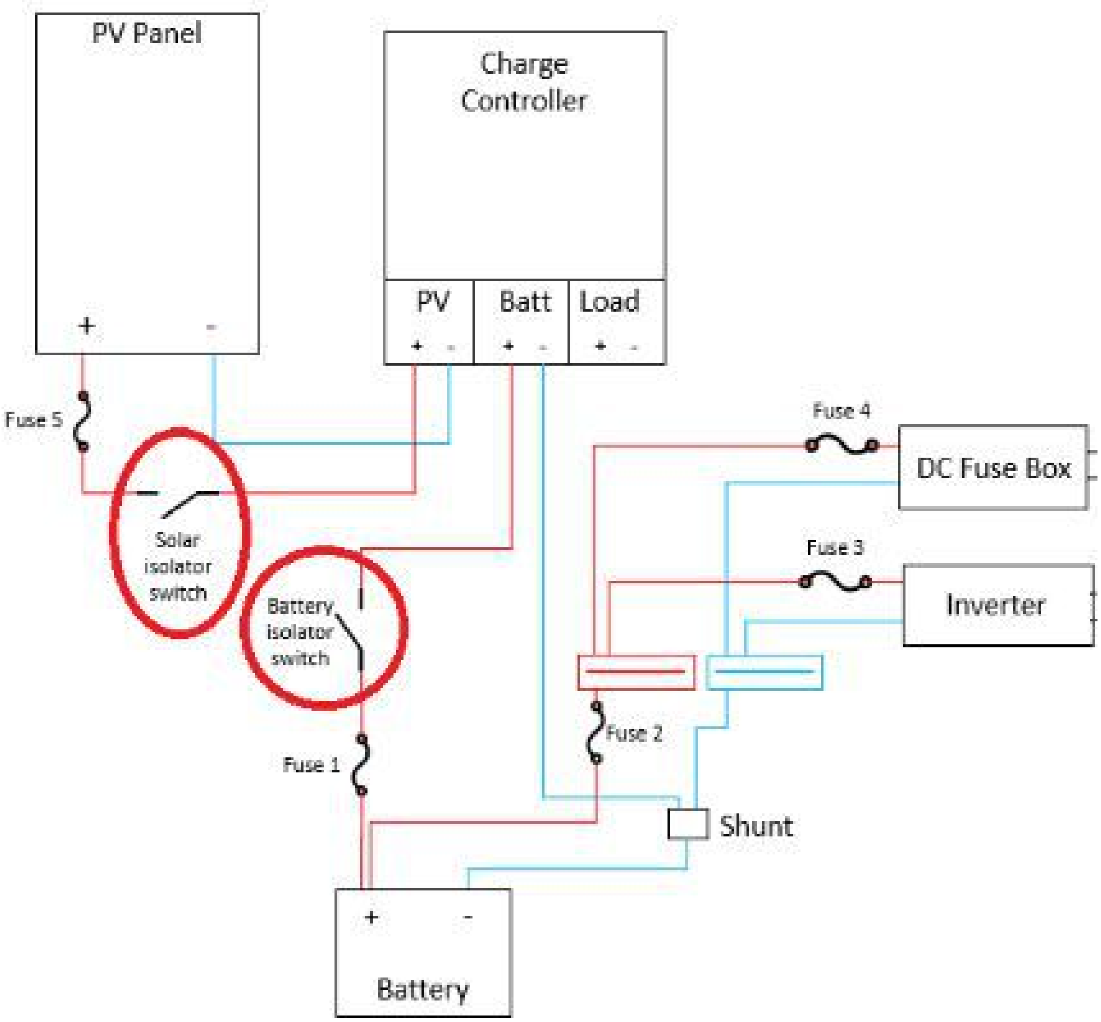
I recommend buying fuses and breakers from well-known brands. It only has to fail you once, and you are in trouble. Instead, opt for a brand trusted and certified in the solar industry and purchase your equipment from there.

DC Isolator Switch

DC circuit or DC isolator switches are used to decouple parts of the solar system from each other. They are used when maintenance needs to be done to the components in the system.

DC isolator switches are placed in the following locations:

- Decoupling solar panels from the charge controller.
- Decoupling batteries from the system.



Before you buy a DC isolator switch, make sure it complies with the system's current and voltage. For example, the DC isolator switch (solar disconnect switch) that is coming from your solar panels has lower current but higher voltage while the isolator switch from the battery requires higher current but lower voltage (depending on the voltage of your battery bank).

I do not recommend using regular circuit breakers as a disconnect switch because they are not built for switching under load that often.

Always buy an isolator switch that has a higher voltage and current at a specific point in your system.

Wire Stripper

A wire stripper is a multi-use tool that is necessary for any electrical installation (including solar photovoltaic). It allows you to strip and cut any wire with gauges between 10-24AWG. The tool will allow you to easily cut either copper or aluminum wires with precision and without damaging the metal part of the electrical wire. Moreover, an integrated swivel knob can adjust the precision of the two jaws effectively to modify the power as needed.

Cable Stripper

A cable stripper is also needed to strip cables from #5AWG to 4/0AWG, something that a wire stripper wouldn't be capable of doing. The cable stripper is capable of cutting PVC, rubber, foamed polyethylene (PE), along with other insulating materials.

You will be able to make longitudinal, circular, spiral, and mid-span cuts to the end of stripping to remove the jacket of the cable. The tool includes a cable holder that makes the cutting process easier and precise. It can be easily adjusted to the gauge of the cable. The cutting is made through a blade depth knob that adjusts the blade (which is also replaceable) to fit the size of the cable.

Always calibrate the tool on the wire end to make sure the blade is adjusted properly.

Lug Crimping Tool

This product is specially made for installations with battery banksh. The product can crimp battery cable lugs with standard sizes between #8AWG and 1/0AWG.

The tool is generally built with a high-quality carbon steel material that ensures a long service life, and that is equipped with an ergonomic grip that is wrapped up with an anti-slip rubber material that makes it comfortable to use. The stripping of the cable to introduce the lug must be done with another tool.

Hammer Lug Crimper

Another option for the same purpose is a hammer lug, which is a manual and more economical solution to crimp the cable lugs for your battery bank. The tool is capable of crimping cable lugs for gauges between #8AWG and 4/0AWG (which covers all possible cable gauges for battery applications).

The crimping process with a tool like this is done very simply by adjusting the ram head according to the wire and the terminal sizes. Then, the lug is placed in the jaw of the crimper while it is struck with a hammer (1-2 times is enough) to press the lug against the copper or aluminum.

Crimping Tool

This tool is suitable for crimping individual wires. It integrates a ratcheting mechanism that has an adjustable clamping force useful for precise and repeatable crimps that also adds more crimping power into each squeeze.

Its ratcheting mechanism allows you to secure a wire connector even before inserting the stripped wire into the small barrel.
You will be able to crimp wire terminals for gauge sizes between 22 and 10AWG split into three cramping options marked by the colors red, blue, and yellow that will indicate the gauges ranges for each purpose. It has also been designed with an ergonomic material that offers a comfortable and secure grip.

Conduit Cutter

The next tool in our list is the conduit cutter. Conduit is generally used in electrical installations to protect cables or wires from water and/or physical damage.

However, for the conduit to fit your wiring installation, you must be able to cut it to adjust the length properly. For this purpose, a conduit cutter tool is needed.

The conduit cutter can be used for multiple applications that go from cutting PVC pipe to cutting PEX pipe. It is also suitable for cutting CPVC, PP, and PE-XB pipes that will allow you to cut the pipes within a few seconds.

Metal Conduit Cutter

The metal conduit cutter is an excellent choice for electrical installations where metal conduit is used.

This tool has been designed to make clean cuts on multiple metal materials such as aluminum, brass, copper, and even thin-wall steel. The steel tube cutter also features a large and ergonomic knob which provides a firm grip to cut tubing faster and easily. It is important to know that a metal tubing and conduit cutter can perform neat cuts for tubes that can go between 3/16 inches to 1-1/8 inches.

Insulated screwdrivers

Screwdrivers are needed in almost any installation. However, for electrical installations and specifically for photovoltaic installations, using an insulated screwdriver is essential.

For this purpose, purchasing a screwdriver set with 6 pieces that have been tested to be able to resist up to 1,000 Volts AC or 1,500 Volts DC is the best choice. Each tool will be covered with a non-conductive material that can reach such a rating, and that makes it safe for electrical installations where high voltages are used.

A soft handle with an outer cushion grip allows you to add 40% more torque than traditional plastic handles.

Needle Nose Pliers

The needle nose pliers are the perfect tool to bend wires and other metal structures. Their half-round tapered jaws are longer and narrower, quite useful in occasions where other pliers cannot reach.

This tool also features a serrated gripping surface that provides a secure grip with less slipping while featuring an integrated side cutter for cutting soft, medium, and hard wires. These pliers come with a cutting tool but are generally not used for that purpose.

The needle plier can generally be found in three handle styles: plastic coated handles, comfort grip handles, and the 1000V insulated handle that meets IEC standards, which is the model for electrical installations.

Wire Cutters

The wire cutter is another invaluable tool that you must consider in any electrical installation where you will need to cut wires.

Cable Cutter

There may be occasions where the wire cutter alone might not be enough to perform all the required work for heavy-duty applications with thicker cables. The cable cutter is the perfect choice for this purpose since it is capable of cutting up to 0AWG gauge cables, and cutting both copper and aluminum.

Hex Nut Ratchet Set

The hex nut ratchet set is something that you need in order to perform electrical installations of any kind, including photovoltaic installations. You will need them to tighten the battery terminals.

Torpedo Level

Whenever you are performing measurements to install devices, or for any structure equipment that needs to be installed on a wall or simply recessed, you need to keep the equipment balanced and straight, that´s when a level will come in handy.

Hole Saw

You will need a hole saw set to make holes in wood, PVC boards, plastic, drywall, and metal as well.
The cutting depth can vary from 43-mm to 50-m.

Hacksaw

To cut and fit the installation frame of your solar panels. Your hacksaw should be built with a 45° or 90° blade angles, which are used respectively for standard and flush cuts. Moreover, the design of the hacksaw can withstand heavy-duty use thanks to the high tension that holds the blade.

Cordless Drill

A cordless drill is suitable for drilling pilot holes and mounting screws or bolts on any wall-surface. It is just another essential piece of your toolkit.

The cordless drill generally features two-speed transmission sets at low speed (about 500RPM) and high speed (about 1,900RPM), suitable for a wide range of drilling and fastening applications.

The most useful feature is that this kind of drill does not need an AC plug connection.

Safety Goggles

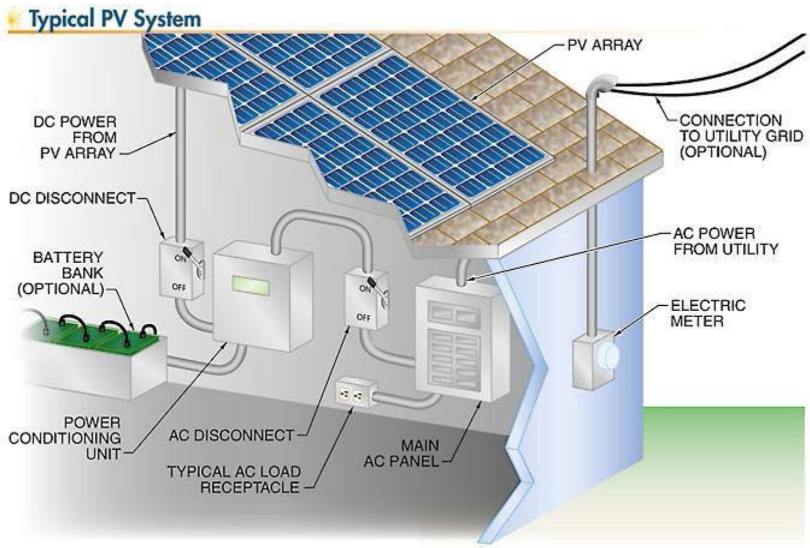
Last but not least, to protect your eyes during the installation of solar equipment, you will need to use safety goggles

2. The components of a solar system

After reading up on the basics of electricity, you must have one burning question: How can I design my own photovoltaic system? Let's start with the main components you will need to build your very own PV system.

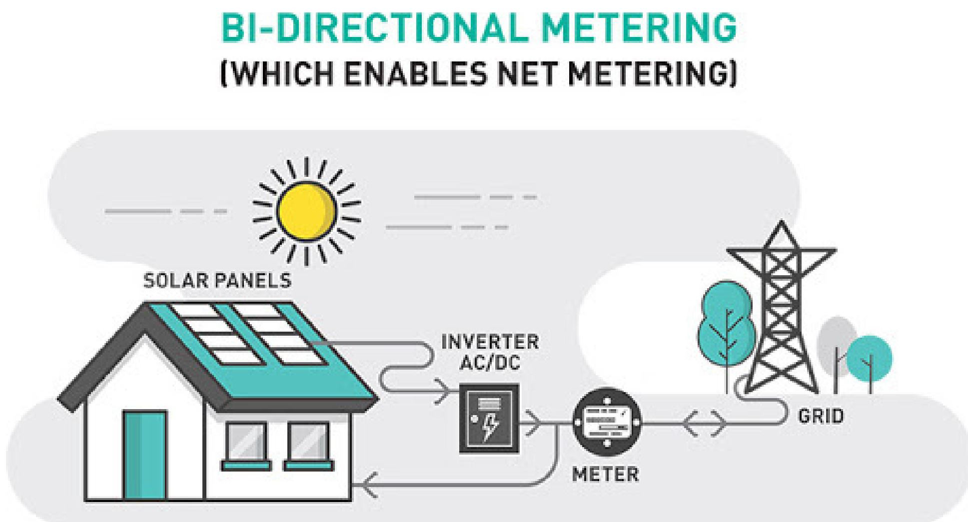
Photovoltaic or PV system is a combination of components that enables us to harness the power of the sun in our own homes or businesses. A PV system includes all the components required to convert the energy from the sun and be able to use it with our regular appliances.

Typically, this consists of two main components, a PV module, or several, and an inverter. Depending on the topology of the system, you might also require a battery.



On a normal day with the sun out, the **PV modules** on top of this rooftop are busy converting the incoming irradiance into photo-generated power.

The **grid-connected solar inverters** used in the system are also constantly converting the DC output of the solar modules into usable AC power. The PV system is able to meet the load demand of the household. On a different day, if it's a very sunny day, the PV system is providing much higher power than what the load requires. Under such a condition, the excess power is fed to the grid. In most countries, the consumer can offset his electric bills in this manner. This facility is called net metering. We can illustrate the same system topology in the following image.



Here you can see a grid connected PV system. The grid connected topology is especially very common in countries that have supporting solar policies, where excess power generated by the consumer can be fed back to the electricity grid.

In a grid connected system there are 2 main components, an array of PV modules and a grid connected Inverter. In this case, the PV modules are responsible for the power generation. The PV generated power is not only able to meet the load requirements, but is also able to feed the excess power generated to the electricity grid when the supply exceeds the load demand.

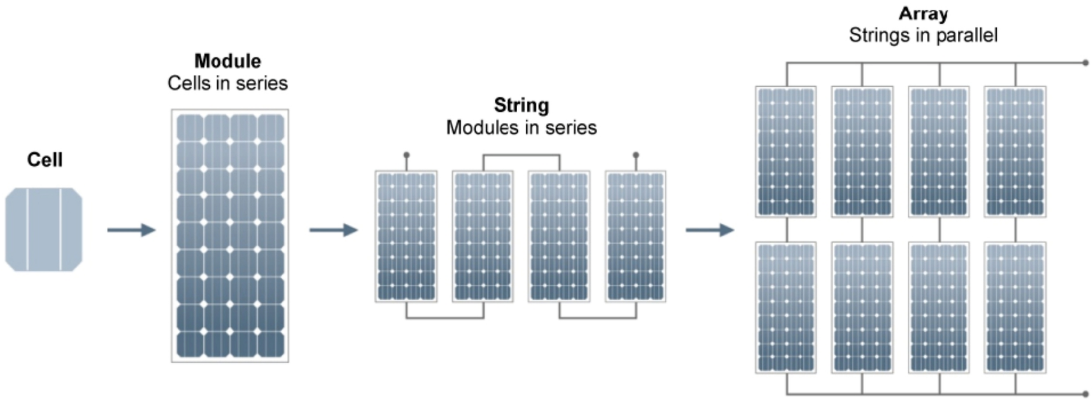
The modules are made from a collection of solar cells. Typical crystalline silicon PV modules are made from a number of crystalline silicon solar cells. These cells are then connected to form a PV module, which in turn is connected together with other modules to form a PV array.

There are different ways in which the cells in a module can be arranged, which influence the characteristics of a module.

In a series connection, the open circuit voltage of each cell adds up, whereas the current through the series of cells is constant, assuming steady state conditions.

The second option is a parallel connection of the cells. The voltage across all the cells in parallel is constant, however the current produced by each cell now adds up.

But how does that look on a module level?



With the data of one cell you can easily calculate the voltage of the entire module. This is equal to the voltage of each cell, which is usually 0.6V, multiplied by the number of cells, 36. This gives us a total open circuit voltage of 21.6V.

What do you think should be the overall module short circuit current now?

Exactly! 5 Ampere, because the current remains constant in a series connection.

Now, let's imagine two rows of 18 cells in parallel. The voltage across the two rows should be equal. But how do we calculate that? Well that's easy, we now only have to multiply the voltage of one cell, which is still 0.6 Volts, with the number of cells that are connected in series, which is 18. This gives us 10.8V for the open circuit Voltage. As we have 2 rows in parallel, we have to multiply the short circuit current by 2 to get the module short circuit current.

If we do this, we'll get 10 amperes for the module short circuit current. The product of the open circuit voltage and the short circuit current are roughly equal to 108W in both modules. However, the specifications of the module are different. This has to be taken into account when selecting the other components of the system such as the inverter, or battery.

How do PV modules behave in a system? They respond differently depending on the weather conditions and their placement. PV modules perform best when irradiated with direct sunlight. Let's take a look at what is meant by the module tilt and orientation, and how you can maximize PV module performance.

What do we mean by orientation and tilt? Tilt is the degree of freedom that defines the elevation or the pitch of the solar module with respect to the horizontal. Orientation is the degree of freedom that defines the azimuth or the yaw of the module with respect to a position, which, in this case, is the geographic South. Note that different places and people have different practices of defining the azimuth. The most common reference points are the geographic North and South. These changes of the orientation and tilt are very important for the amount of direct sunlight the module receives. And like mentioned before, the more direct sunlight the module receives, the more energy is converted into usable electricity.

Other effects that play an important role are shading, and the temperature effect on the module efficiency. They can have a significant effect on the performance of a PV system, but we will get into more details about that in the chapter on orientation.

There are two main types of solar panels. They are monocrystalline and polycrystalline.
The main difference between the two is their efficiency.

Taking as examples a polycrystalline panel rated at 160 watts with dimensions of 58 by 26 and a monocrystalline one rated at 175 watts with dimensions of 57 by 26, the two are within about an inch of each other in physical size, but the monocrystalline panel is capable of producing 15 more watts per panel, which means that you could potentially be gaining an extra five to 10 amps per day, per panel, if you opt for monocrystalline over polycrystalline.

If your roof space is limited, like on a RV, go with the monocrystalline solar panels. You'll get more power out of the same space leaving more room for vent fans and rooftop dance parties.
The polycrystalline will also be fine if you're really trying to pinch pennies, but maybe the solar panel isn't the place to skimp as it's going to likely be one of the more difficult components to replace on down the road. Do it right, do it once.

Batteries store the solar energy.
Solar batteries work by storing the DC energy being produced by solar panels and giving it back to you when you need it. There are different types of batteries used in solar systems and you can choose them according to your specific requirements. Batteries are connected in series with each other to increase the voltage of the system. Each battery has a positive and negative terminal, and you can connect them in parallel or series to change the voltage and the capacity of your off-grid system.

There are three main types of batteries on the market. Lead Acid, AGM, and Lithium.
Lead acid batteries require maintenance and they vent corrosive hydrogen gas. They were the standard for a while, but then technology caught up. Although they can work in some setups, in my opinion, they're generally more hassle than they're worth.
AGM & Lithium are the two more commonly used types of batteries in campers, currently. Lithium batteries are significantly more expensive up front, but they're cheaper over the long run. My recommendation, go with lithium. It's lighter, it's more powerful, you get bigger bang for your buck in the long run. If you can't afford Lithium, go with the AGM, but get the size of AGM battery that you can switch out to Lithium in the future if you happen to change your mind.
To clarify, a Battle Born battery is about 12 ¾ by 7 by 9 inches. The Renogy AGM battery is 13 by 7 by 9 inches. So, if you're living for the moment and need to go with AGM batteries now, you can buy, say, three of the AGM batteries. Once they wear out or you need more capacity, you can swap in three lithium batteries directly in their place, bolt them up, change a few parameters on your charge controller, and be good to go.

Which would effectively triple your capacity with the exact same battery footprint. So, plan for the upgrade now, and it'll make the upgrade less expensive and easier when it's time.

The **charge controller** manages the power going into the battery bank from your solar panels. It also ensures a healthy charge profile for the batteries, and stops the power running backward to the solar panels overnight.
Put it simply, the charge controller takes the solar power from the solar panels and then converts it into a form of more organized and useful power.
The power is coming from the solar panels at varying voltages, anywhere from 16 volts to potentially in the hundreds of volts, depending on the setup.
The charge controller regulates that voltage down to the 12 to 15 volt ballpark if you're on a 12 volt battery bank, to properly charge said battery bank.

There are two main types of charge controllers on the market, MPPT and PWM, which stand for maximum power point tracking and pulse width modulation.

PWM is an older technology. Your solar panels must be within a fairly narrow set of parameters to even be compatible with a PWM controller. They're less efficient, as they are, pretty much, just a regulator. The only pro to a PWM controller is that they're less expensive.

MPPT controllers are a newer, much more sophisticated technology and have more processing power behind them. Which lets them do more calculations depending on the input voltage to optimize the output voltage to the maximum amount of amps possible to be stored in the batteries for use.

Basically, comparing an MPPT controller to a PWM controller is like comparing Netflix to Blockbuster. The buy-in fee is a little higher, but the satisfaction of being able to pick out a movie while not wearing pants just can't be beat. The buy-in is a little a higher, but the added flexibility and performance will give you more bang for your buck in the long run. My recommendation, get the MPPT controller.
Unless you're strapped for cash, then save up, and then get the MPPT controller.

The **inverter** converts the direct current or DC output of the batteries into the alternating current or AC, which enables you to power your AC appliances with the use of batteries.

I really like the inverter/charger combo units for off-grid systems, such as RV or boat PV systems. It's pretty much just that, an inverter and a charger all wrapped up into one box. Your battery stores power at 12 volts. If you have something, say, a coffee maker or an instant pot, you'll need 110 volts aka, a normal household plug. The inverter takes the 12 volt power stored in the batteries and converts it into 110 volt power so you can power those household appliances.
Inverters come in a few different types: square wave, modified sine wave, and pure sine wave.

We aren't going to talk about the first two: essentially, the power they make isn't a clean power and can damage certain electronics. I don't recommend those because I don't like recommending products that have an inherent risk of damaging other equipment. Look for a pure sine wave inverter.
This inverter actually does the best job of mimicking the power that is actually coming through a standard plug that you can find in any on-the-grid wall.

The monitoring device will be connected to the charge controller and is responsible to provide you with information about your solar set such as voltage, current, power, temperature and so on.

DC and AC breakers provide methods for us to stop current and voltage being supplied to the equipment, so when we would like to remove or service those items, or in the event of an overcurrent, they come really handy.

Solar panels and batteries are the DC sources. Therefore, **DC switches** are used for solar panels and batteries. A DC switch is connected to the inverters output and protects the inverter and consumers in case of abnormal conditions.

Using the **AC switch** , we have the control over the AC output.

In a off-grid system, two connections come out of the batteries. One from the positive terminal and the other from the negative terminal. Battery positive goes to the charge positive battery terminal and battery negative goes to charge the negative battery terminal.
The busbar makes it possible to split the connections. This means that the positive is connected to two places and the negative is also connected to two places. Then the negative connection once goes to the charger and inverter and the positive goes to the charger and inverter. This is called the rail or din rail which is a metal strip that is used for securely attaching electrical and industrial control products such as circuit breakers or terminal blocks, so you can mount your switches on it.

Turning the DC switch on, will connect the batteries to the charge controller and will turn it on. Turning the inverter and AC switch on will bring power to the plug, which you can use to power your plug-in appliances.

3. Selecting your components

Now that you are familiar with all the main components of your solar system, let’s take an in-depth look at your options. There isn’t a one-size fit all solution. You will need to accurately size your system and, of course, take your planned budget into consideration. Moreover, you will have to determine whether you want to go off-grid or take advantage of net metering, should that be an option. Here are just some general recommendations, based on my own experience and A LOT of trial and error (unfortunately!)

If you have enjoyed the book so far and it has helped you start your DIY solar power project, please leave a review on Amazon, so that other readers can reap the same benefits.

3.1 Battery

You have three options when it comes to battery banks: flooded lead-acid batteries, absorbed glass mat batteries or AGM batteries, and lithium ion batteries.

Flooded lead-acid batteries are the tried-and-true traditional battery technology: this technology has been around for well over a hundred years and it is still in use today. Granted they've adapted this technology into more renewable energy applications but it's still an old technology.

Absorbed glass mat or AGM batteries are still considered a LED acid battery; in effect, there is still lead acid technology inside of it but it is configured just slightly different than the flooded lead-acid battery.

Lithium ion batteries are the new kid on the block: the latest and greatest technology when it comes to solar batteries.

When it comes to **maintenance** of each of these batteries, flooded lead-acid batteries have a huge disadvantage: they need to be both watered as well as equalized.
Watering means physically adding water to each of the battery cells and equalizing is doing an over charging method to prevent sulfation, which is one of the major causes of battery failure.

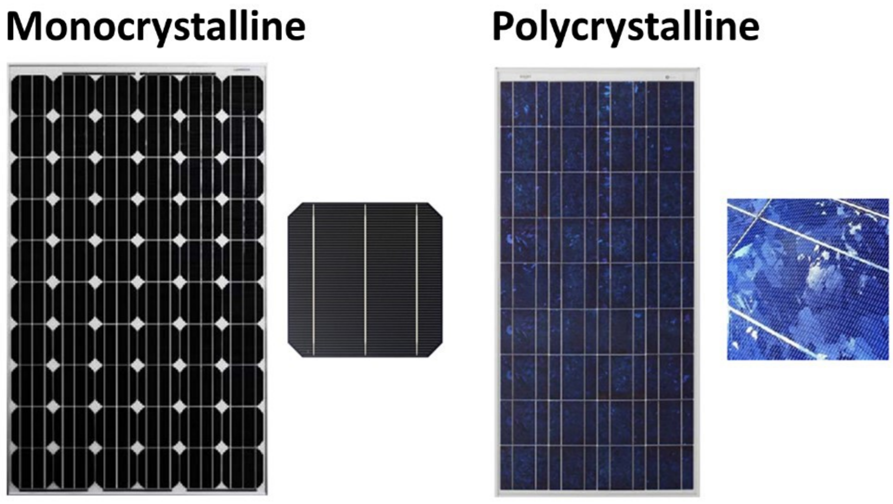
With AGM and lithium-ion batteries you don't need to really worry maintenance, just make sure you're consistently charging them properly.

The **percentage of usable energy** when it comes to each type of battery is hugely surpassed by lithium-ion batteries, because they can use about 80 percent of their total capacity when it comes to the battery storage.
With flooded or AGM batteries you can really only use about 50 percent of the total capacity and the reason is that when you drop below the 50 percent threshold, you start to damage those batteries which can then affect the lifespan of the batteries.

Speaking of **lifespan** , the flooded lead-acid batteries can last from seven to ten years or around a thousand cycles, if they're properly maintained.
AGM batteries, if they're properly maintained, they can last anywhere from maybe six to eight years or around 700 cycles.
The huge advantage goes to lithium-ion batteries which can last anywhere from 3,000 to 5,000 cycles. This is significantly better than the flooded and the AGM batteries and it could last you 20 plus years if you treat them right.

But, what about **price** ? Flooded lead-acid batteries will run you from a hundred and fifty to a hundred and sixty dollars for a six volt 225 amp hour battery. But it will vary depending on the cost of lead in the market.
AGM batteries will run you about double the cost of flooded lead-acid batteries so a 220 amp power 6 volt battery, will cost you around $300.
Lithium-ion batteries are at a huge disadvantage when it comes to the initial startup cost in this category: for example, a 100 amp hour 12 volt lithium-ion battery will run you around 900 to $1,000, that may seem like a crazy cost for the amount of battery that you get but consider that the lithium-ion batteries will last you about five times longer than the flooded lead-acid batteries so when it comes down to total cost over the lifespan of the batteries lithium-ion batteries are without a doubt your best bet.

3.2 Solar panels



If you look at monocrystalline and polycrystalline solar panels, a couple of things stand out right away with their appearance. This is due to how solar cells, or the individual squares are made.

The monocrystalline panel is a consistent black or very very dark blue color. It is cut into wafers from a conical silicon ingot that's grown in a lab. To make the ingot the silicon rocks are melted at 2,500 degrees Fahrenheit, and then a seed crystal is lowered into the melted slush, and slowly pulled up while rotating. It's almost like making a hand dipped candle, but instead of melting wax, you are melting rocks. Because of the round shape, there is a lot of material wasted as they cut it into the required square shape. That's why they usually have rounded corners, to help minimize the waste. If you look at older solar panels, they actually made them with round cells.

Polycrystalline cells are made a different way. They load about 1300 pounds of silicon rocks into a 3 foot by 3 feet quartz mold to create a square shape, and then load it into a 2500 degree Fahrenheit furnace. It takes 20 hours to melt, and about 3 days to cool down. The polycrystalline panel has a blue mottled look, like a piece of particle board, it looks like it is made up of multiple pieces of silicon pressed together. That is actually caused from when the melted silicon cools and hardens, it crystallizes, like frost on a window. When it is sawn into the wafers, there much less wasted material from the square ingot than from the round monocrystalline ingot, and is a less expensive manufacturing process. Due to the higher cost of manufacturing, monocrystalline panels tend to be a little more expensive than polycrystalline panels. Although efficiencies in manufacturing processes are really reducing the cost difference.

So, monocrystalline panels look different and cost a little bit more than polycrystalline. But the big question is, is it worth worrying about the difference? To help answer that, let's talk about **performance** differences.

Monocrystalline solar panels tend to be more efficient than polycrystalline solar panels. Let's say on average about 17.5% vs.15.5% module efficiency. So they are 2% more efficient. What does that really mean? It means that you can have slightly more power in the same amount of space with monocrystalline than polycrystalline.
For a size of about 38" x 66", the monocrystalline panel outputs 270 watts, and the polycrystalline puts out 260 watts. If I were to build a system with 20 monocrystalline panels, I'd get 5400 watts. To do a similar system with 260W polycrystalline panels, I'd need to use one more panel for 21 panels to get 5460 watts. That would mean a little bit more space, a little more racking, and if using microinverters or DC Optimizers, more equipment needed.

So, while the cost of the solar panels may be less for polycrystalline, the overall system cost may be the same when you take the extra equipment into account.

One performance difference is how they react to temperature. Monocrystalline panels handle the heat slightly better than polycrystalline. How slight is slight? Comparing the temperature coefficient of the two types shows us that monocrystalline short circuit current drops 0.04% for every degree kelvin over standard test conditions of 25 degrees Celsius, or 77 degrees Fahrenheit. So if it is 20 degrees hotter on the roof than in the test suite, which is highly likely in the summer, the monocrystalline solar panel can lose .06 amps out of a rated 8 amps. For polycrystalline, it loses 0.051%. That equals losing .08 amps. So, the difference is two one hundredths of an amp. In extreme desert conditions, the difference may be big enough to matter, but for most residential environments, the difference is quite small.

Finally, monocrystalline panels tend to behave a little better in less than perfect light conditions. No solar panel, regardless of their type, performs well in the shade. Period.
But, if you have slight shading issues, or tend to have hazy skies, monocrystalline panels may perform a little better. However, with the availability of microinverters and DC optimizers maximizing each panel in the solar array, the difference may not be noticeable. Or if you've located your solar array so that there are no shading issues, there's no difference at all.

Ultimately, your choice of which crystalline technology to use will come down to space constraints.

3.3 Charge controller

The charge controller goes between the solar panel and the deep cycle battery. A charge controller is the heart of a battery-based systems, i.e. off-grid system. They are not used in straight grid-tied systems, as they do not have batteries to charge. Their primary role is to manage charging the battery bank.

It prevents it from overcharging, and many of them control the rate of the current and voltage at which it charges.

Some charge controllers have load control, where you connect the DC load right to the charge controller instead of to the battery, and it will turn it on and off based on voltage of battery and/or time of day, for example turning the load off if the battery gets too low or turning on a light from dusk to dawn.

At night, the voltage of the battery bank is higher than that of the solar array that is connected to it. Since electricity flows from high voltage to low, without a charge controller, the tendency would be for the electricity to flow out of the battery bank. A charge controller prevents that from happening, allowing the flow to only go one way, into the batteries.

Many charge controllers manage charging the batteries by varying the voltage and current to the battery bank based on how full the battery is. Much like pouring a glass of water, when the glass is fairly empty, you can have the faucet on full blast, but when it starts to get full, you want to turn down the flow to prevent overflowing. Likewise, a charge controller sends a lot of power to the battery when it is low, but as it approaches full, it slows it down. Once it is full, it will send a smaller amount of power, a trickle charge, to keep it topped off. This is called multi-stage charging.

With Bulk Charging, when the battery is low, it will accept all the current provided by the solar array. At Absorption, the battery has reached the regulation voltage, the controller begins to hold the voltage constant. This is to avoid over-heating and over-gassing the battery. The current will taper down to safe levels as the battery becomes more fully charged. Equalization is done with flooded batteries, not sealed batteries like AGM and Gel.

Many batteries benefit from a periodic high voltage boost charge to stir the electrolyte, level the cell voltages, and complete the chemical reactions. Your battery specs will tell you how often and at what rates it wants to be equalized. Float charge is when the battery is fully recharged, the charging voltage is reduced to prevent further heating or gassing of the battery. There is a wide variety of features that are optional on some, but not all controllers. In most cases a display does not automatically come with the controller, but can be added separately for a remote display.

A few even have Bluetooth connections, allowing you to monitor your system over an app. Temperature compensation will improve the battery bank charging, by adjusting its output based on the temperature.

Low Voltage Disconnect is a great feature that allows you to connect your DC load to the charge controller. If the battery voltage gets low, it will turn off the load, preventing the batteries from becoming too low and getting damaged.

Some controllers can be used as a diversion, or dump, load controller, turning power on to a heater to burn off excess power.

There are others that have light control functions, turning lights on and off automatically based on dusk and dawn.

Voc is Open Circuit Voltage, or what you will measure from a solar panel in perfect test conditions with nothing but a volt meter connected to it. Vmp is voltage at Max power, or what the solar panel will put out when it is connected to equipment like a charge controller or inverter.

Nominal voltage is a way to categorize battery based solar equipment. Because a higher voltage is required to charge a battery, nominal voltages are used to help see what equipment goes with what.

So, a nominal 12V panel, which actually has a Voc voltage of around, 22V, plus or minus a volt or 2, and a Vmp of around 17V. And if you count the number of cells, or silicon squares on the front, it will likely have 36 cells.

Likewise, a panel that was designed to charge a 24V battery bank will have a Voc of around 44V and a Vmp of around 36V. Counting the cells will come up with 72, twice as many as a 12V panel. If you wire 2 24V panels in series, or 4 12V panels in series, you can charge a 48V battery bank. This was all well and good for off-grid systems, but then along came grid-tied systems, and 12, 24, and 48V became meaningless. So, the industry sort of standardized on 60 cell, 20V nominal panels. Alone, they are too big to charge a 12V battery, and too small to charge a 24V battery.

An MPPT charge controller solved that, by reducing the voltage down to the required range, and in doing so, increasing the current output, so you are not losing power.

There are 3 main types of charge controllers. Shunt controllers, that just turn the flow to the batteries on or off are rarely used anymore, so we won’t go into them. The 2 main types you’ll find these days are PWM and MPPT.

PWM are generally the less expensive option of the two. A PWM charge controller pulses the power sent to the battery bank, allowing it to do the different charging stages we discussed. When using a PWM charge controller, the nominal voltage of the solar panel must be the same nominal voltage as the battery bank. So if you are using a 12V battery, you must use a 12V solar panel.

If you have a 24V battery bank, you must wire two 12V panels in series, or one 24V panels to make 24V. If you have a 48V battery bank, you must wire four 12V panels in series, or two 24V panels in series, to make 48V. Make sure the charge controller you select is designed for the battery bank voltage. Some can support multiple voltage ranges, others are designed only for 1 voltage. Note if a PWM charge controller says it can support 12 or 24V, both the panel and battery bank must be one or the other. It is NOT saying it can take a 24V panel to charge a 12V battery. It is saying it can work in EITHER a 12V or a 24V system.

A Maximum Power Point Tracking, or MPPT, is the more sophisticated, more expensive type of charge controller. It tracks the output of the solar array and adjusts itself so that the output is always maximized. In doing so, it can increase the production of the array by up to 30%. Another great advantage is that most MPPT charge controllers can take a higher voltage array, for instance a 60 volt array, to charge a lower voltage battery bank, like a 48V.

This is required if you have a 60 cell, 20V grid tied solar panel, that are common, and thus less expensive, and use it to charge a 12V battery. It’s also very useful if you have to go a distance from your array to your battery bank. The higher the voltage of the solar array, the lower the current going across the wire. Therefore, you can use smaller gauge wire, which will cost less, and have a lower voltage drop, which gets more of your power to the batteries.

There are also a few MPPT charge controllers that can take a lower voltage panel and charge a higher voltage battery bank. These are great to use a 12V panel to charge a 36V golf cart. But most MPPTs require a higher or equal to voltage panel. Be sure to read the specs carefully.
Unlike a PWM charge controller, it doesn’t just throw away the extra voltage, it increases the current on the output to maximize the power out. There are now higher voltage charge controllers available, with some accepting as much as 600V in. This is very useful if the array is a long distance away from the battery bank. So again, check the specs to find the right charge controller for you.

3.4 Inverter

The solar inverter is one of the most important power electronic devices that makes the modern PV system widely usable. Solar panels get all the glory, but it’s the inverters that do all of the work in the solar energy system.

It makes the DC power from the modules usable for all the appliances in our house. Although these appliances might internally either work with DC or AC, all of them are used to an AC grid.

To know what an inverter is, we must first understand its precise function in the PV system. The output of a PV module is Direct Current or DC. What is meant by that? DC, or direct current is the unidirectional flow of electric charge. DC is produced by power sources like batteries, laptop chargers, and solar cells. It is common to talk of quantities like DC voltage, power and current.

AC, or alternating current on the other hand, is the flow of electric charge such that it constantly reverses direction. The usual form of an AC power is a sine wave.
So why do we need AC power? After a brief 'war of currents' in the 19th century, AC power was chosen as the standard for central power generation, transmission and distribution. Until this day, almost all national electric grids are AC based. Most households have what is known as the "AC mains socket". Consequently, most household electric appliances expect to be fed AC power, even though sometimes the internal circuitry of the appliances might use DC.

Nevertheless, the fact remains that solar power produced needs to be converted to an AC form, so that it is more "usable" in the electricity framework we have today. How do we make this conversion from DC solar power to the easily usable AC power? By using an inverter!

The inverter converts a DC electric signal into an AC one. Let’s talk about the features of the solar inverter and its applications in the modern PV system. Inverters are classified based on their mode of operation, their size, or implementation topology.

Let’s first discuss the classification based on the mode of operation; there are inverters for grid-connected systems, ones for stand-alone systems and inverters that can be applied in situations that require both connection types, called bimodal inverters. The first two types are the most common ones.

The DC PV modules are connected to the regular AC electricity grid via a grid connected inverter, sometimes called grid tied inverter. In this case, the PV system is grid connected, this means that the load can be supplied either by the PV system or the grid, depending on the available irradiance and the demand. The inverter latches on to the grid’s frequency and voltage. So, the inverter that supplies AC power to the grid acts as a current source, while the role of the constant voltage source in the system is fulfilled by the grid. The grid connected system topology can only be applied when there is an electricity grid available. In some places there is no grid availability. Consequently, the inverter must be a standalone inverter. In this case, the PV system is not connected to the grid, which means the load can only depend on the PV system for power. So, the inverter that supplies AC power to the load has to appear as a voltage source with a stable voltage and frequency, supplying power at 230Vac or 110Vac, whichever is the standard at the location.

As already implied in the name, this is the basic application of an inverter in the PV system: power conversion from DC to AC. Can the inverter perform any additional function? The answer is yes!
Thanks to the advances in power electronics, it is common to have inverters that implement a maximum power point tracking or MPPT mechanism before inverting the voltage, thus ensuring that the PV modules or arrays are operating at their maximum power point or MPP.

Apart from the modes of operation, inverters are also classified on the basis of the implementation topology. There can be 4 different categories under this classification.

Central Inverters , which are usually around several kW to 100 MW range. **Module inverters** , or microinverters, typically rated around 50 to 500W. **String inverters** , typically rated around 500W to a few kW. A string is nothing but a number of PV modules connected in series. And finally, **Multi string inverters** , typically rated around 1kW to 10kW range.

Let's start with the central inverter. This is the most traditional inverter topology in use. It is simply the implementation of one central inverter catering to all the PV modules in a PV system. While this inverter topology increases the ease of system design and implementation, it suffers from several drawbacks.
In large systems, large amounts of DC power will be transferred over long cables to reach the central inverter. This increases DC wiring costs, and also decreases safety, as DC fault currents are difficult to interrupt. An MPPT implementation inside the central inverter will only cater to the entire system as a whole. If the various modules, strings are mismatched, let's say due to partial shading, the overall system output is drastically reduced. Also, the system is usually designed for a fixed power. There is little scope for extendibility of the system if more strings and modules need to be added.

Next, let's look at micro inverters or module level inverters. As the name suggests, each module has a dedicated inverter with an MPP tracker. Therefore, the topology is more resilient to partial shading effects as compared to the central inverter topology. Clearly, the micro inverters provide the highest system flexibility, since extending the size of a system under this topology is far simpler.
Furthermore, the DC wiring costs are greatly reduced. However, the investment and maintenance costs tend to increase, especially if the cost per Wp are compared.

Then we have the string inverter concept, which seeks to strike a balance between the module level inverter and the central inverter topologies. The string inverter topology is more resilient to mismatch than the central inverter, because each string is independently operated at its MPP, thus guaranteeing a higher energy yield. String inverters are smaller than central inverters. However, the implementation is more complex than the module inverter. Also, the partial shading will have a greater influence over the string inverter topology than over the micro inverter topology.

Finally, Multi String inverters. This concept seeks to combine the higher energy yield of a string inverter with the lower costs of the central inverter. Each of the strings is pre-power-processed using low power DC-DC converters. Each string has its own MPP tracker implemented alongside the DC-DC converter. All the converters are connected via a DC bus to the inverter, and ultimately to the grid. Within a certain power range, only a new string with a dedicated DC-DC converter has to be included to expand the system size.

We now have an overview about the solar inverters and their topologies. Of course, the choice of your topology for implementation would depend entirely on the system needs, size, and budget. But in general, while choosing an inverter for your PV system, what are the requirements for a good solar inverter? There are several characteristics expected from a good solar inverter. As every power processing step expends power itself, the solar inverters are expected to be as efficient as possible. This is because we wish to deliver maximum PV generated power to the load or the grid. Typical efficiencies are in the range of more than 95% at rated conditions. Depending on the topology, it is expected that the inverters have built in MPP trackers.

Grid-tied inverters are expected to have active islanding detection capability. Islanding refers to the situation in which the inverters in a grid-tied setup continue to power the system even though the power from the grid operator has been restricted. Due to safety issues, islanding needs to prevented. Therefore, inverters are expected to detect and respond by immediately stopping from introducing power into the grid. This is also referred to as anti-islanding.

Since in a lot of situations, the solar inverters are exposed to ambient conditions, they must comply with the temperature and humidity conditions of the location. Since grid-tied inverters pump power into the grid. They are expected to maintain very high quality, so as to not corrupt the power flow in the grid. Thus inverters are expected to have very low harmonic content on the line currents.

It is a work in progress to increase the lifespan of the inverter, the crucial power electronic device in the modern PV system. A good inverter will probably reach, under favorable conditions, around 10-12 years of lifetime. This is a bottleneck in the modern PV system's lifetime, especially considering the fact that PV modules can last over 25 years.

If you can budget for it and you are planning a PV system for over a 300-amp electricity load, then do yourself a favor and get the microinverters. They were developed out of Fremont, California by a company called Enphase. These guys were working on the central string inverters for a big company until they decided to go out on their own and figure out a way to make an inverter that would convert the energy produced by the panel into usable AC voltage for your house. Nobody else is doing this, and it's really thrown the central string inverter companies for a big loop because these new inverters are warrantied for 25 years instead of 10 years.

The undeniably best thing about Enphase is their inverters are double insulated and small enough to be placed at each individual panel. NOW each panel has its own inverter and if a panel goes down because of shading or some mechanical, then just that panel goes down. All your other panels will continue producing clean energy for you.

These types of microinverters are UL Listed relating to voltage and frequency, synchronization, disturbances, faults, and reconnect time. This UL Listing ensures that your grid direct system meets IEEE 1547.1-2005 which specifies the type, production, and commissioning tests that have to be performed on these microinverters.

Moreover, the Solar panels can be installed at different angles and azimuth orientations unlike central string inverters that require all the modules in each source circuit to be at the same tilt and orientation.
So that you won't be running high voltage DC circuits through your attic or across your rooftop, but AC voltage instead.

4. Design methods

Before starting to choose components, or even just determining what sort of PV system you want, you must complete 4 crucial steps. It will take a bit of calculations, but unless you are fighting for your survival in a post-apocalyptic world you have all the time that you need.

1. **Estimate the daily load** (how much electricity your appliances will consume in 1 day)
2. Use the estimated daily load to **calculate the battery bank size**
3. Use the battery bank size to **calculate how many solar panels you need**
4. Use the solar panel array size to **calculate the solar charge controller size**

Step 1: Estimate your daily load
Please refer to the section “Calculating your load” in the first chapter.

Step 2: Calculate the battery bank size
Now that we know how much power we need daily, we can calculate the size of the battery bank.
First, let’s round up our daily power requirement to make the math easier.
For example, for a daily requirement of 1130 watt hours to 1200 watt hours.
Now we need to estimate how much backup power we want to have. Winter time, rainy days, and shady parking spots will reduce the power produced by your solar panels. The battery bank should be large enough to compensate for these times.
Idealistically, you want as large of a battery bank as possible.
But if you have a mobile system such as an RV, and weight is a factor, I would recommend 2 days of power as a backup.
If you need a battery bank for a home, depending on the size, 3-5 days of backup power is typical.

Daily appliance load of 1200 watt hours x 2 (days of backup) = 2400 watt hour battery bank required

But here's the catch! If you use the cheapest lead acid batteries, they can be safely discharged to only 50% capacity without causing damage. A lithium battery, which we will talk about later, does not have this problem.
So if you require a battery that can deliver 2400 watt hours of power, you will need either:
• A 4800 watt hour lead acid battery
• Or a 2400 watt hour lithium battery

Step 3: Calculate the number of solar panels

Because space is limited, especially for small cabins or mobile set-ups, filling your roof with as many solar panels as you can safely fit is usually the best option.
But keep in mind that if you have too many solar panels, you may accidentally charge your battery bank too fast, which will reduce the life of the battery bank. So, if you fill your roof with solar panels, make sure that you build a battery bank large enough to handle it. This applies mainly to lead acid batteries (which have a lower charge rate when compared to most lithium batteries).

Lead acid batteries also need to be fully charged after every use. They also like it when they are fully charged once a day. To keep your batteries healthy, you need a solar panel array that is large enough to charge your lead acid battery bank in one day (in six hours of full sunshine).
A lithium battery does not require a daily charge after it is used, and only needs a full charge every couple of months.

Solar Array Estimates (no math required):

For a single 1200-watt hour lead acid battery (which is a 100 amp hour, 12 volt AGM sealed battery with a max charge rate of 35 amps at 12 volts), use:

- A minimum of 200 watts of solar panels
- A maximum of 400 watts of solar panels

For a single 1200 watt hour lithium battery (which is a 100 amp hour, 12 volt lithium iron phosphate battery with a max charge rate of 100 amps at 12 volts), use:

- No minimum solar array size. Just be sure to fully charge it every couple of months
- A maximum of 1200 watts of solar panels

The suggestions above are just estimates! Each battery bank will have a slightly different charge rate. Be sure to check your batteries manual to see what it recommends. Most solar application batteries will give you a minimum and maximum solar array size recommendation.

You have probably realized that lithium batteries work well with nearly any size of mobile solar panel array. This is usually true, but be sure to check the manual. The charge rate of a lithium battery is dependent on how the battery is designed. Most can handle large charge rates, but not always.

This is not the case with deep cycle lead acid batteries. They usually have consistent charge rates.
But the charge rate of lead acid batteries can change depending on how many you are using. If you parallel connect multiple small lead acid batteries, the charge rate will usually be much higher than if you were to use a single, large lead acid battery (unless the large battery is designed to handle a fast charge rate. But typically, having smaller batteries in parallel will be faster).

The estimates above will give you a general idea of your solar array size. Ultimately, the individual battery charge rate will determine how many solar panels you can attach to it. If you are lazy or smart, call the battery manufacturer and ask them how many solar panels they recommend.

If your batteries manual does not list how many solar panels you can safely use with it, or you want to calculate it manually, we can figure it out. You will need to read the batteries manual (or data sheet that can be found online) and find the “maximum safe charging rate” in amps. As long as the maximum power produced by the solar panels is less than the maximum charge rate of the battery bank, we will be good to go.
Maximum Solar Power < Maximum Charge Rate of Battery Bank

In order to find the maximum power produced by a solar array, we divide the total solar panel watt rating by the voltage of the battery bank.

Example:

1. If we have 400 watts of solar panels in a system, divide this number by the voltage of the battery it plans to charge, which is typically 12 volts
2. 400 watts divided by 12 volts = 33.3 amps

33.3 amps is the maximum amount of current that our 400 watt solar power system can produce at 12 volts. A typical 100 amp hour, 12 volt lead acid usually should be able to handle 35 amp charge rate.
35 amps is larger than 33.3 amps, so we are good to go!

If you plan to wire multiple 12 volt lead acid batteries together in parallel, you can add the maximum charge rates together. Let’s say you have 3 batteries that can each handle 35 amps each. If you wire them in parallel, they can handle a combined maximum charge rate of 105 amps!

How to calculate the minimum solar array size for a battery?
For this calculation, we need to know how much solar power is required to charge the battery bank in 6 hours of full sunshine. This will allow the battery bank to charge to full capacity every day.
Divide the usable watt hours of your battery bank by 6:
Battery bank size in watt hours / 6 = Minimum solar array size

- Your battery bank has a total usable capacity of 1200 watt hours. Dividing this number by 6 will give you 200. So, for this battery bank, the solar array should be at least 200 watts in size.
- Your battery bank has a total usable capacity of 2000 watt hours. Dividing this number by 6 will give you 333. So, for this battery bank, the solar array should be at least 333 watts in size.

If you are using lead acid batteries, determining the minimum solar array size is important because lead acid batteries require a full daily charge cycle to prolong the life of the battery. If your solar array cannot charge your battery bank within 6 hours, you risk a reduction in lead acid battery bank life. If you have a lithium battery, this factor is not important.

Tips:

We need to consider the real world output of a solar panel. Many solar panels that are rated for 100 watts usually produce about 70 watts in full sunshine. We still need to calculate for a system that has 100 watt solar panels, so that the system can handle the power if it is ever produced.

If you are strapped for cash, it is ok to start with the minimum solar array size and build your way up. If I was shooting for a 600 watt solar array, but I could not afford it yet, I would install a 400 watt solar array first. You may find that a 400 watt solar array is plenty for your needs! Just be sure to buy a larger than needed solar charge controller so that you can always add more solar panels or batteries when necessary.

Solar power output is largely determined by where you live. If you live close to the equator, you will obviously have more power. The angle of the panels, time of day and weather conditions will also determine how much power your solar array will produce.
If you live far from the equator, your solar panels may never create the power they are rated to produce, so you may need to experiment with “over-paneling” your system. Over-paneling allows you to wire 2 to 3 times the amount of solar panels to your system, without damaging the charge controller. This requires using a solar charge controller that has this capability, or using a fuse between the solar array and the solar charge controller.

Example:
You live in Alaska and your 100 watt solar panels only produce 40 watts in full sunshine. So instead of using a 400 watt solar panel array, you decide to use an 800 watt array and a solar charge controller that has over-paneling protection. This will enable you to harvest more power from the sunshine available to you.
If you cannot find a solar charge controller that has over-paneling protection, use a fuse to protect the charge controller. If you have a 40 amp MPPT controller, and you wish to over-panel it with 800 watts of solar panels, you will need to calculate the fuse size for the voltage that your panels produce. This is for advanced users only! If the fuse is not the correct size, you will destroy your solar charge controller.

Step 4: Calculate the solar charge controller size

There are 2 variables that will determine the size of your controller:

1. The solar power array size will determine the “amp rating” of the solar charge controller. Solar charge controllers are rated in “amps” and this rating refers to how much current (in amps) the controller can create at your battery bank’s voltage. The more solar panels you have in your system, the larger the controller needs to be. If you buy a 40 amp charge controller, the maximum charge it can deliver at 12 volts, is 40 amps. The amp rating does not refer to the amp rating of your solar panels.

To calculate the amp rating of your controller, take the total solar panel array wattage and divide it by the voltage of your battery bank. This will give you the minimum amp rating of your controller.

Solar Panel Array Wattage / Battery Bank Voltage = Minimum Solar Controller Amp Rating

Example:
Your solar array is 400 watts and your battery bank voltage is 12 volts.
400 (watts of solar on your roof) / 12 (voltage of your battery bank) = 33.3 amps (minimum amp rating of your solar charge controller)

Controllers are usually sold in amp rating increments of 10 and 20. If you go online, it is easy to find controllers that are rated for 10/20/40/60/80 amps. If we need to find a controller that can handle at least 33.3 amps, we should use a 40 amp controller. It is usually a good idea to buy a larger than necessary controller, just in case you wish to add more solar panels in the future.

2. The maximum input voltage rating of the controller. If your solar panel array creates a voltage that is larger than the controller can handle, the controller will be damaged. Usually, you do not need to worry about this figure unless your system is very large, or you are wiring panels in series and producing hundreds of volts. For most mobile systems, the maximum rated voltage will not be exceeded (you should still check the manual of your solar charge controller to be on the safe side).

Typical controller input voltage ratings are 70-150 volts (but be sure to check your manual).

To summarize:

- For small systems (100-250 watts of solar), use a 20 amp controller
- For most systems (300-450 watts of solar), use a 40 amp controller
- For large systems (450-700 watts of solar), use a 60 amp controller
- For extra-large systems (700-950 watts of solar), use a single 80 amp controller

(80 amp controllers cost a lot, so it is usually cheaper to buy 2x 40 amp controllers)

A few last notes on efficiency:
The math given earlier is great for estimating a battery bank and solar array size, but it will not tell you the true output of your system. Without going into too many details, consider that:

- On average, you will have a 2%-5% wire loss (they give off a small amount of heat)
- Solar Charge Controllers produce heat and create a 2%-30% loss
- Storing electricity in a battery will experience a 1%-15% loss (unless the battery is damaged or old, then it will be more)
- When you use an inverter, you will have a 10%-15% loss (sometimes larger)
- Appliances are not entirely efficient, and they use various regulators and resistors that give off heat. Expect another 1-5% loss.
- Solar panel efficiency drops if they are too hot. This can vary depending on the panel and how it is mounted, and materials used to make it, but it’s another efficiency factor to keep in mind.

One bad connector will choke an entire solar system. The losses can be huge! All connectors, which connect the wires to the batteries/charge controller, need to be crafted properly. To check them, feel them with your hands to see if they are getting warm. All connectors and wires should be cold to the touch (unless they are carrying a lot of electricity, such as during full sunshine or during inverter operation).

So, what I like to say is that if you have a 100 watt solar panel on your roof, you only have 50 watts of usable power. This only applies if you have a properly designed system. If you use cheap parts, small wires, or have bad connections, you will not have much power at all. I would not be surprised to see a 100 watt panel producing only 20 watts on a badly designed system.

No matter how perfect your math is in planning your system, you will always have losses and you will need to create a system that is slightly larger than what you need.

If you are planning for a mobile solar system, you should also consider that adding solar panels to any vehicle causes changes in the aerodynamic profile, which can change the efficiency (miles per gallon) of your vehicle. If you plan to travel constantly, you will need a slightly different system than someone who stays stationary. Also remember that system components can be heavy, especially the battery bank. The heavier your vehicle is from carrying a large battery, the harder it is for your vehicle to stop, and the harder the engine and transmission has to work to move the vehicle.

After you build your system, you may need more power. This is very easy to do with proper planning. You simply add more solar panels and/or batteries. Try to create the system in a way so that it is easy to expand it, such as buying a larger solar charge controller than needed, or using larger gauge wires than necessary. This will ensure that your system is scalable to some degree, or working to its full potential.

When you design any system, do it right from the beginning and you will save yourself from months of frustration and problems. A properly designed system is also safer and the chance of experiencing an electrical fire is practically non-existent.
Once the system is installed, you don’t have to think about it! You have free electricity for years, and it’s amazing. I am currently writing this book with solar power, and it’s awesome!

Now that you have determined the size of your system, let’s talk about your options!

4.1 Grid-tied solar power systems

The grid tied system is the most common solar systems installed in locations that have electricity available from the utility company. A grid tied system simply takes the power generated from the solar panels during the day, and uses it real time in your house. If you have any extra power available, it sells that power back to the grid for a credit, and at night or on days when you don't generate enough power, you use that credit to buy power back from the grid. Any more power needed is just bought as usual.

Let's go over how to size the different components.

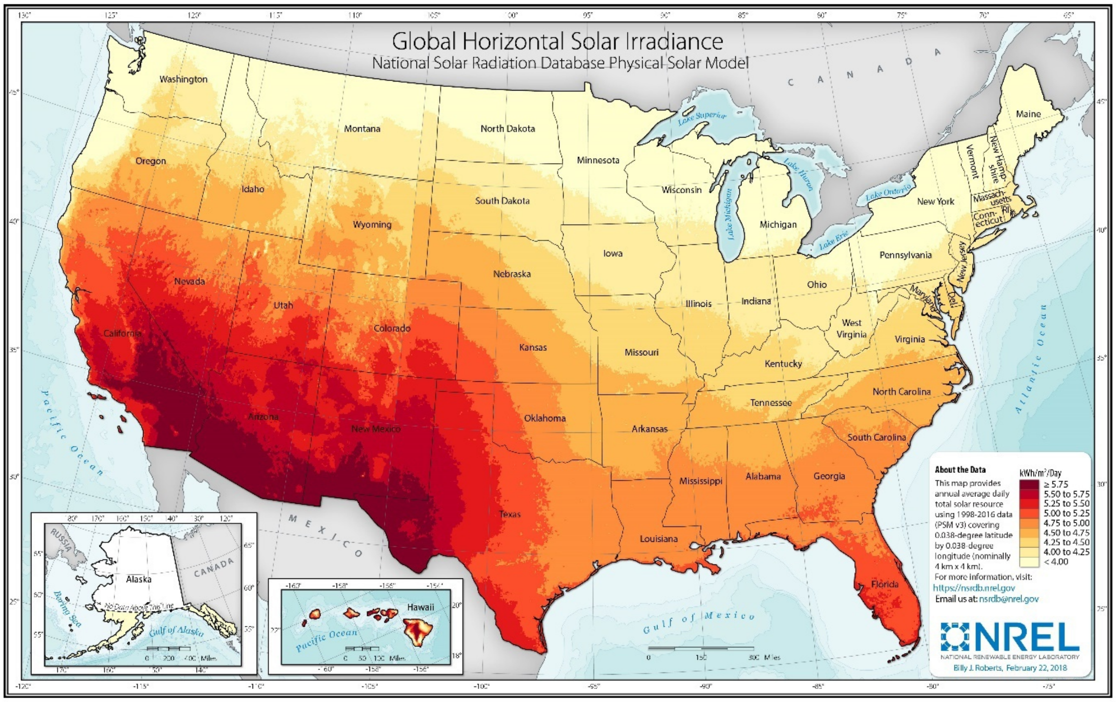
First you need to determine how much power you currently use, if this is for an existing house. From your current monthly bill, you can figure out how much power you use a day. Based on your location, and the amount of sun you get, you can determine the size of the solar array needed. From there you figure out what racking, inverter, and breakers you need.

Let's go through each of these steps. First, how much power do you use? Take a look at your electric bill. It is generally billed by the month. You can see here on this bill, it is higher in the summer due to using the air conditioner.

If we had electric heat, you might have seen higher bills in the winter instead. The nice thing about higher usage in the summer, is that that is when there is the most solar energy available as well. From this bill, add up all of the monthly kwh, and divide it by 365 to get a daily kwh average.

In my case, that's 50.6kwh a day. We'll use that daily kwh number to size the solar array. But first we need to figure out how much sun you get on average. Insolation maps show the available sun hours for your area.

This map of the United States gives you a good idea of the solar potential.



The darker the color, the better the sunshine. Obviously the southwest and Hawaii are the best for solar, but even locations not known for their sunshine, like New England and the Pacific northwest still have enough sunshine on average to make solar a very good solution.

The ideal angle for installing solar is at latitude, but my roof isn't that steep, and I'm just going to mount them flush without tilting them up, so I'm going to use the Latitude minus 15 degrees row. The good news is, for my location, I'll get the same amount of power as if I was at the "ideal" angle. Because we don't live in an ideal world, I also need to take into consideration less than ideal conditions.

Generally, for a grid tied system, we calculate that we will lose about 23% due to losses in the system, from voltage drop in the wires to bird poo on the panels. Now let's do some math! We take that daily average kwh from earlier, multiply it by 1000 to get watt hours, divide it by your annual average sun hours, to get 11,254W. We divide it by 77% to take into account the system losses, which gives us 14,615 W of solar to provide 100% of our electricity needs. As we said earlier, most grid tied systems don't try to make all of their power, just cut their existing bill. So, for this example, I'm going to cut that in half to provide half of my electricity with solar. Therefore, I need a solar array of about 7300 watts.

Now let's use this information to pick out the rest of the system. Grid tied inverters are sized based on the size of the solar array they are connected to. There is a certain window of number of panels in series and in parallel that will work with the inverter.

When selecting the inverter, you'll find that most inverter manufacturers these days have an online calculator called a "String Sizer" to help select the right inverter for your panels.
You just have to enter the temperatures that the panels will be seeing during daylight hours, and if I'm mounting them on a roof or on the ground. This matters because the solar panels' voltage changes pretty dramatically based on temperature, so the string sizer needs to be able to calculate the highest and lowest voltages it will see.
You also will have to select the solar panels I'm going to use. I picked Kyocera's 250W panels, they are a terrific panel at a very good price. Since I'm looking at around 7300 watts of solar, I picked the ABB Uno 7.6kW inverter. I can see that depending on how many parallel strings I do, I can use series strings of anywhere from 4 to 14 long in series. However, these may not be the ideal string lengths, if there are any warnings, the string sizer will alert you in a note. I picked 2 sets of 2 strings of 8, for a total of 8000W, the inverter is very happy with that size. It's a little bigger than my 7300W that I calculated that I needed, so it will actually generate more than half my power. So now I've got 32 Kyocera 250W panels, and an ABB Uno 7.6k Transformerless inverter.

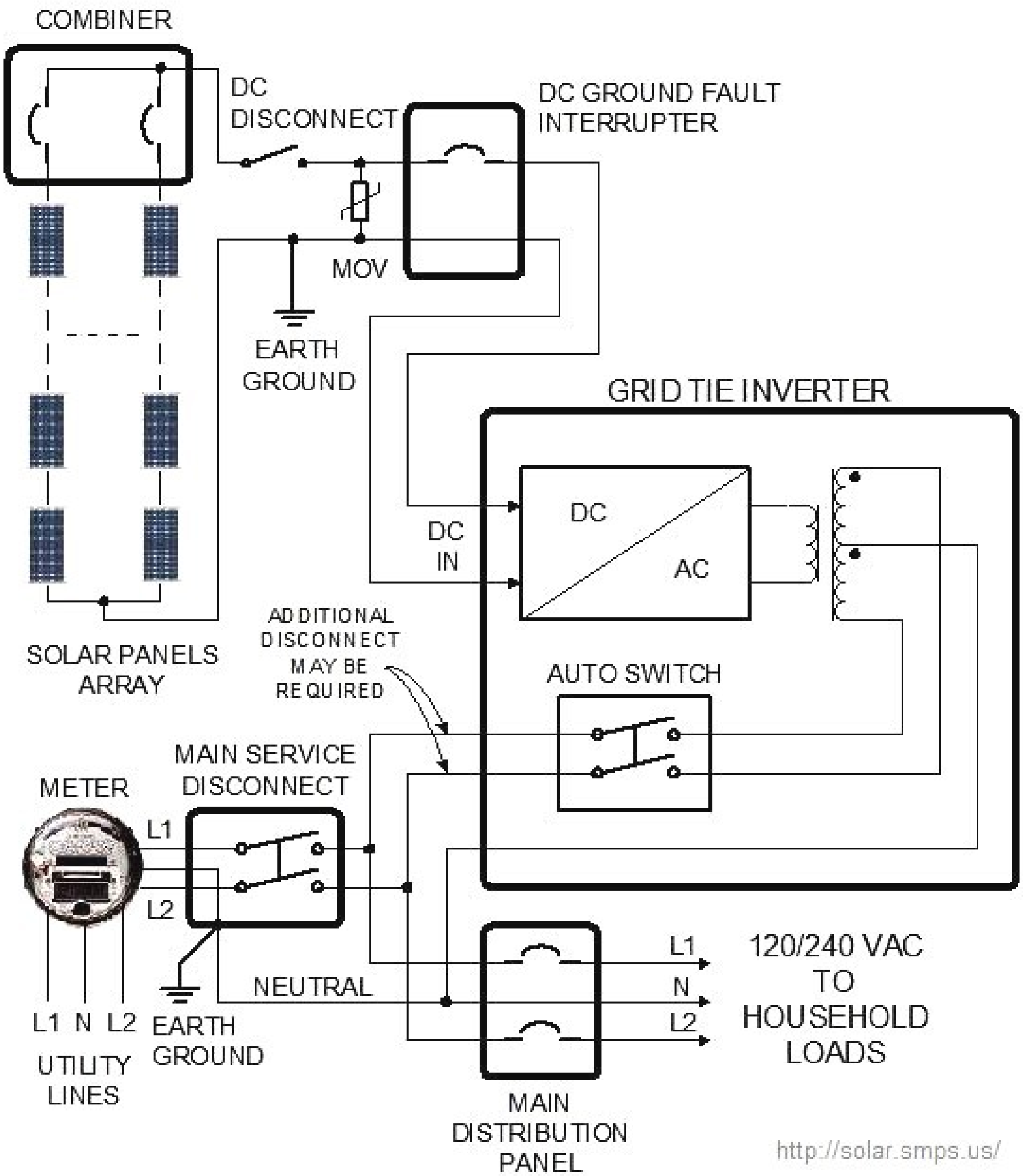
So how will I mount them? Luckily for those of us doing a lot of designs, IronRidge also has a time saving Design Assistant to help speed up the design work. They've got one for roof mounts, and one for ground mounts. I’ll give you an example with the roof mount one. You enter what solar panels you are using, how many, and how they are laid out. For example, 2 rows of 16, flush against the roof. For my area, the building code requires the system be designed to withstand 100mph winds and a snow load of 40psi. For 4' spacing between mounting feet, which lines up with every other rafter, it tells me I can use the IronRidge XR100 rails. Just a few more inputted details, like what color clamps to match the panels and it outputs a bill of material, and the manufacturer's suggested retail price.

They do suggest a flashing for an asphalt shingled roof, so if you have a different type of shingle, you may need a different flashing to prevent leaks. The last piece is over current protection, protecting your system in the event something goes wrong. In a grid tied system, there are 2 locations we need to put in over current protection, on the DC side by the solar panels, and on the AC side in the main breaker box.

The combiner box I would chose for this example is a disconnecting combiner box. It allows you to turn off the power coming out of the panels right by the panels, in compliance with NEC 2014 Rapid Shutdown requirement. Each string of panels gets its own fuse. The datasheet of the panel usually tells you what size fuses to use, for grid tied panels under 300 watts, it's usually 15A. To calculate it, you take the solar panel's Short Circuit Current, and multiply it by 1.56. The combiner box wires the strings into parallel, and gives you a place to transition the wire into conduit. It's also a good place to put a lightning arrestor. The AC output of the inverter goes into a dual pole breaker in your home's main breaker box.

To calculate the size breaker to get, you take the watts of the inverter, in this case 7600 watts, divided by the AC voltage output, 240V, and multiply it by 1.25 to oversize for NEC's requirement for devices being used for more than 3 hours continuous. This gives you a 40 amp dual pole AC breaker. So, what have we got? We have a combiner box with 15A fuses, 32 of the Kyocera 250W panels, wired in 4 strings of 8, an ABB 7.6k Transformerless inverter, and just over 200' of IronRidge XR100 rail, with the and clamps, and mounting feet. You would enter the details for whatever physical layout works for your roof. Then you would get a 40A AC breaker that fits in your main breaker box.

Now let's look at a schematic to see how this all schematic that shows how this all fits together.



We have 4 parallel strings of 8 panels in series, going to a combiner box with a 15A fuse for each string. The combined strings are sent in conduit to the string inverter. The AC output of the inverter may be required by your electric company to go to a lockable AC disconnect by your meter, so that the linemen can turn off your system if needed. it then goes into a 40A breaker in your main breaker box, to your house. Then any excess power goes out to your bidirectional meter, which will be spinning backwards or forwards, depending on if you are selling or buying power. From there, it goes out to the grid.

4.2 Off grid solar power systems

A DIY off grid solar system can be daunting, but thankfully you have done the smart thing and bought this book before starting out. I will explain you how to design an easy DIY off-grid solar system, easily modifiable to your specific needs in 6 easy steps!

Step 1: Figure out how much power you need! This is the most important step. I never tire to repeat it: it is of vital importance, especially for an off-grid system, and yet many people try to skip over it. Don’t. Planning a solar system without knowing how much power you need is like planning a car trip and not knowing how far you are going, and in what vehicle.
Ok, now go buy gas for the trip. How much? Well, that depends on your distance and gas milage. Same with solar. You can’t just say I’m going to buy a couple of solar panels and a battery and hope it will be enough for your needs. You’ve got to remember absolutely everything that will be powered by your system. Seemingly little changes can make a big difference. For more details on making a loads list, refer back to the first chapter

Step 2: Calculate the amount of batteries you need. Now that you know how much power you need, you need to figure out how many batteries you need to store it. Do you need only enough storage for a day or two, do you have another power source like a generator or turbine that will kick in if the sun doesn’t shine, or do you need to have enough batteries to store 3 or 4 days, or more, worth of power? Will you be storing the batteries in a warm room, or will they be in a cold location? Batteries are rated for storage at around 80 degrees fahrenheit, the colder the room, the bigger the battery bank you need to compensate, by over 50% more for below freezing. Each of these answers affects the size, and cost, of your battery bank What voltage battery bank do you need, 12V, 24V, or 48V?

Generally, the larger the system, the higher voltage battery banks are used to keep the number of parallel strings to a minimum and reduce the amount of current between the battery bank and the inverter. If you are just having a small system, and want to be able to charge your cell phone and power 12V DC appliances in your RV, then a basic 12V battery bank makes sense. But if you need to power much over 2000 watts at a time you'll want to consider 24 volt and 48 volt systems. Besides reducing how many parallel strings of batteries you'll have to have, it'll allow you to use thinner and less expensive copper cabling between the batteries and the inverter.

Step 3: Calculate the number of solar panels needed for your location and time of year. Now you can figure out how much solar power you need. The second half of our off-grid calculator can help you figure out how many solar panels you'll need for your solar system. After knowing how much energy you need to make per day from the load calculator, you'll need to tell it how much sunshine you'll have to harvest from. This available energy from the sun for a location is referred to as "sun hours". The number of "sun hours" is basically how many hours the available sun shining on your panels at an angle throughout the day equals sunlight as if it were shining directly on your solar panels when they get the most power, like at noon. As you know, the sun isn't as bright at 8AM as it is at noon, so an hour of morning sun may be counted as half a sun hour, where the hour from noon to 1PM would be a full sun hour. And unless you live near the equator, you do not have the same number of hours of sunlight in the winter as you do in the summer. You want to take the worst case scenario for your area, the season with the least amount of sunshine that you will be using the system. That way you do not end up short on solar energy part of the year. If it's a summer camp, you don't need to plan for winter, but if it is a year round home, or a hunting cabin, you need to tell it the number of sun hours that correspond to winter. Luckily, it's easy to figure out the sun-hours for anywhere in the world with sun-hour maps.

Step 4: Select a solar charge controller Alright, so we have batteries and we have solar, now we need a way to manage putting the power from the solar into the batteries. An extremely rough calculation to figure out what size charge controller you need is to take the watts from the solar, in our example here it was 500W, and divide it by the battery bank voltage, in this case 24V. That gives us 21A. Add another 25% for a safety factor, and you're going to need a charge controller that can handle at least 26 amps. so we'll probably round up to a 30A charge controller. Now there's also a bit more to consider with selecting the charge controller. Charge controllers are available with two major types of technologies, PWM and MPPT. We've done a video explaining the difference between the two, you can see that here. But in short, if the voltage of the solar panel array matches the voltage of the battery bank, you can use a PWM charge controller. So, if you have a 12V panel and a 12V battery bank, you can use PWM. If your solar panel voltage is different than the battery bank, and can't be wired in series to make it match, you need to use an MPPT charge controller. If you have a 20V solar panel and you have a 12V battery bank, you need to use MPPT.

Step 5: Select an Inverter Now that we have efficiently charged batteries, we need to make the power usable. If you are only running DC loads straight off your battery bank, you can skip this step. But if you are powering any AC loads, you need to convert the direct current from the batteries into alternating current for your appliances. It is very important to know what type of AC power you need. If you are in North America, the standard is 120/240V split phase, 60Hz. In Europe and much of Africa and some countries in South America, it is 230V single 50Hz. In some islands, it is an interesting mixture of both. Some inverters are configurable between voltages and/or frequencies, many are fixed. So check the specs carefully of the inverter you are interested in to make sure it matches your needs. If you do have the North American standard, you must figure out if you have any appliances that use 240V, or if they are all just 120V. Some inverters are able to put out 240V, and you can wire the output to use either 120V or 240V. Other inverters are stackable, each one outputting 120V, but when wired together, or stacked, can create 240V. And others are only capable of outputting 120V, and cannot be stacked. Again, read the specs to determine which inverter is right for you. You also need to know how many watts total your inverter will need to power. Luckily, way back in step one, you created a loads list that figured out both the constant watts and surge requirements of your loads. Please note that an inverter is designed for a specific voltage battery bank, like 12, 24 or 48 volt. They are not field selectable. So you need to know what voltage battery bank you are going to have before you settle on the inverter. Keep this in mind if you think you may be growing your system in the future. If you plan on having a higher voltage battery bank later, be aware that the lower voltage inverter won't work in the new bigger system. So either plan ahead and go with the higher voltage to begin with, or plan on changing out your inverter in the future.

Step 6: Balance of System.
OK, yes, I'm kind of cheating by lumping everything else into one step for balance of system, but there are a lot of other little components needed, like the fuses and breakers for over current protection, what breaker boxes will you use, how are you going to mount the solar panels, what size wire do you need. I will tackle that in details in the chapter on wiring.

4.3 Mobile solar power systems

With solar power on your RV, you gain independence from any utility grid – you feel free to park wherever you want, and you don't care about finding shore power.
Mobile solar power systems are known for their lack of maintenance. In a residential photovoltaic system, you usually have a flooded lead-acid battery to maintain. In RVs and motorhomes, batteries are typically maintenance-free – AGM or lithium-ion ones. What is more, solar panels mounted on your caravan are easier to tilt and clean than panels on the roof of your house.
Mobile solar power systems are safe and reliable as long as they are sized and installed correctly. They usually operate at 12 V and up to 40 A.

Important:

- Here are the most important benefits of using solar panels for camping and boondocking:
- Solar power is free (although solar power investment is not free).
- Solar power is everywhere you go.
- Solar power enables you to travel to sites with no power hookups available.
- Solar power allows you to save money on conventional power.
- Mobile solar power systems are maintenance-free, excluding the occasional solar panel cleaning. Also, no other activity is required, unless you need to replace your battery after 7-10 years or decide to add more panels to the system.
- Extends the life of your leisure battery.

Differences between residential and mobile solar systems

Photovoltaic systems installed on RVs, caravans, campers or boats do not differ much from typical off-grid residential systems regarding the components used – solar panels, charge controller, battery, inverter, cabling, breakers and fuses.
Mobile solar power systems, however, differ substantially from home off-grid photovoltaic system in the following:

- They have much less installed solar power as a result of the limited space of your RV, caravan, camper, or boat.
- The system voltage is most commonly 12V DC.

In residential photovoltaic systems, longer cable runs – between the solar array and the controller or between the battery and the inverter – are quite common. For the sake of reducing voltage drops and avoiding cables of larger gauge, home photovoltaic systems typically are based on a system voltage of 24V, 48V or higher. In RV and marine systems, a system voltage 12V DC is okay since distances are shorter, voltage drops are not so significant, and larger cable sizes are usually not needed. Also, 12 V DC is very convenient as a system voltage for RV and marine solar as many appliances operate directly on 12 V DC.

- Batteries are smaller – in weight, dimensions, and capacity – and typically sealed.

In mobile solar power systems, battery banks are smaller due to the typically lower daily consumption. What is more, flooded lead-acid batteries are rarely used. Instead, the most widely used battery types are sealed lead-acid (typically AGM, rarely gel ones) or lithium phosphate (also known as ‘lithium-ion’ or merely ‘lithium’) ones. In vehicles, wet lead-acid batteries are a safety hazard, while sealed batteries are much easier to handle, transport, and maintain. Sealed batteries can be turned upside down without the risk of spilling the electrolyte and are maintenance-free.

- In an RV solar panel system, it is possible to use high-power devices (such as air-conditioner, heaters, etc.) as long as the RV has been parked and connected to shore power. In residential solar panel systems, high-power loads are generally excluded and replaced with their energy-efficient options.

In an off-grid system, using any high-power appliances with the purpose of air-conditioning or heating is not recommended from an energy efficiency point of view. Using large loads would require a costly battery bank which is expensive, needing a long time to get fully charged and tough to maintain.

- An RV or marine solar panel system typically includes an AC charging system to charge the battery when connected to shore power automatically.

As long as everything with the battery management system is okay, a leisure battery can be charged by several sources at the same time – a solar array, an external generator, and a shore power outlet.

- The solar charge controller can be designed to charge both the leisure battery (which is a deep-cycle one) and the vehicle starting battery.
- Marine solar systems (unlike RV solar ones) should be built with components resistant to the corrosive environment.

Often components for marine and RV solar systems are referred to the same way. Due to the highly corrosive salty air marine environment, marine solar components can be used in RV, while the opposite is often not possible. For this reason, solar components intended for use in marine PV systems are often denoted as 'marinized.'
Most devices and appliances used in RV or boats run on 12V DC. The size of the battery and the panels depend on how much electricity you need daily, which in turn is up to the appliances you plug in. Often it comes out that you have neither enough room for a battery of specific capacity, nor sufficient space on your roof for the installed solar power you need. In such a case, you have to reduce your power usage.

4.4 Hybrid solar power systems

A backup power generator modifies a stand-alone system into a hybrid one. A hybrid system is a combination of a photovoltaic generator and an alternative power generator – wind or fuel one. Such a generator charges the batteries upon lack of sunlight and is used either as a backup one or when the PV system alone cannot meet the specific energy needs.

In a hybrid system, the combustive fuel generator is a source of AC electricity. AC electricity is converted to DC electricity and then is stored in the battery bank.
The batteries are charged both by the PV array and by the generator. The available loads in the building draw power from the batteries.

You can do without a backup generator in a stand-alone system but at a higher cost – you have to oversize your system and choose a battery bank of a higher capacity.

Such a strategy, however, is highly impractical for two reasons:

- The initial costs of batteries are incredibly high.
- Such a system will work with maximum performance just a few months throughout the year (probably in winter), while in the rest of the time it is going to operate far below its maximum efficiency. The value of the electricity produced probably will be not enough to cover the expenses needed for the maintenance support of the battery bank.

The wind and fuel generators on the one hand, and photovoltaic generators, on the other hand, have rather few in common.
This implies the need for additional knowledge of different technologies, each one having its specifics. The minimum overlapping, however, means that the advantages of the other one can easily compensate the drawbacks of the first technology.
A wind generator appears as a suitable supplement to solar generator since in general windy periods very often coincide with periods of sunshine lacking – for example, when it’s cloudy or at night.
Also, it is reported that a combination of a solar generator and a wind generator often makes the use of an additional fuel generator redundant.
Fuel generators are the most popular power backup generators. Their main advantages and disadvantages are listed below.

	Advantages	Disadvantages
Non-renewable fuel generators	• Low initial expenses • Available on demand • Portable • Very popular	• Relatively costly maintenance • Noise pollution • Air pollution • Low fuel to power conversion efficiency (maximum 25% but upon partial loading often goes below 10%) • A lot of the produced energy is dissipated in form of heat

Fuel generators and wind generators generate AC power. In a stand-alone system, the AC power produced by the fuel generator is used:
By the existing AC loads, and
By the battery charger to generate DC power used by the existing DC loads.

Important :
PV arrays and fuel generators do not produce the same kind of electricity. PV generators are sources of DC power. In a stand-alone solar system, the DC power produced by the PV generator is used:
By the existing DC loads
For charging the battery bank.

Upon receiving enough sunlight, the needed AC power is provided by the inverter converting the solar-generated DC power into AC power. If the sunlight is not sufficient, the needed AC power is provided by the fuel generator.

When compared to wind generators, fuel generators have some benefits:

- Quite an affordable price.
- Easy to launch.
- Highly portable.
- Operate independently on weather, at any time of the day.

In hybrid systems, fuel generators do not operate continuously but rather during sunless periods only.
So, they have:

- More efficient use of fuel.
- A longer lifecycle.
- Lower maintenance costs.

Benefits of hybrid power systems

A cost-effective solution, except for the remote spots with difficult access, where maintenance and fuel delivery can be quite expensive.
Low initial cost – fuel generators have affordable prices. There is a great variety of models available at the market.
Increased reliability – there is a simple rule “2 is more than 1”, which is applicable if there are two instead of one battery charging sources – a solar array and a generator.

Increased efficiency – a fuel generator is used not only to charge the batteries but also to provide power to the loads operating simultaneously at a given moment. Thus, a generator could be turned on together with a large load consuming lots of power (for example, a dryer and washing machine). If such appliances are not used every day, this might be a preferred way to avoid supplying them with solar-generated power.

A hybrid power system is recommended:
If the daily consumption of electricity is more than 2.5 kWh.
For regions with poor sunlight for long periods.
In these cases, a stand-alone solar system cannot meet your energy needs.

5. How to mount your solar panels

At this point, you should have completed most of your planning. At the very least, you should have an idea about the max load you need and the number of panels that will help you deliver that max load. So, it is now time to plan how you will mount the panels and how you will make ensure they get maximum exposure to sunlight.

As such, let’s consider some of the fundamentals of solar panel mounting.

Dimensions of the panels

The first item to consider is the dimensions of the panels themselves. In essence, the greater the capacity on the panels, the larger the size. This relates specifically to the number of cells contained in the panel. Thus, more cells mean more surface to capture sunlight and therefore produce more energy.

Given this rule of thumb, you can then proceed to figure out the best spot for your panels. As I mentioned earlier, many folks like to mount their panels on their roofs. This is a good idea when you have a Gable roof. In addition, having a sloping roof pitched to one side would certainly be of benefit.

Of course, given the dimensions of the panels themselves, they may be too big or too heavy for your roof. This is something that you might want to get a second opinion. The last thing you want is to put additional weight on your roof, thus compromising the structure of your home.

Furthermore, roof mounting may not be the best course of action if you have an older roof that’s not in the best of shape. However, roof mounting may be your best choice especially if you don’t have much land on which to mount your panels.

You could have smaller panels though having multiple panels may be more of a hassle than a benefit. Also, if you choose to mount your panels on the ground, make sure that they are in a spot where they can get direct sunlight most of the day. Before actually mounting them, monitor the area in which you would like to mount your panels. It could be that shadows set in at a given hour in the afternoon. This could severely limit the overall effectiveness of your solar power system.

Tilting panels

However, you choose to mount your panels, bear in mind that they need to be at an angle. The reason for this is that when panels are mounted on an angle, they will capture the greatest amount of sunlight for the longest period of time.

Tilt your panels at a 45° angle. Now, this is not set in stone as conditions may vary in your part of the world.

One interesting calculation is as follows: If your latitude is below 25°, then multiply the latitude by 0.87. This factor represents the ideal angle for your panels, given your geographical location. Due to the curvature of the Earth, sunlight does not hit the surface of the Earth at an even angle. So, you need to compensate for this.

So, if you are at a latitude of, say, 23°, you would multiply this by 0.87. Thus, 23 * 0.87 = 20.01. This means that you would have to tilt your panels to a 20° angle.

The previous calculation is intended to maximize exposure to sunlight during daylight hours. That is why roof mounting may not be your best option, especially if you live around taller structures. Hence, the afternoon shadows may block out your afternoon sunlight.

In the event that your latitude is between 25° and 50°, then take the latitude and multiply that by 0.76. Then, add an extra 3.1 degrees to the equation. For example, if your latitude is 45°, then you would have 45 * 0.76 = 34.2. Add in the extra 3.1 degrees, 34.2 + 3.1 = 37.3 degrees. This is the angle at which you should tilt your panel. This will ensure the greatest amount of sunlight given the latitude at which you find yourself.

In case you are unsure about what latitude you are located at, don't worry. You can search for your geographical position. With the aid map tools such as Google Maps, you can easily determine your current position.

Which way to face

A common mistake that newbies make is placing their panel is a random direction. Given the fact that the sun rises in the east and sets in the west, there is a predictable pattern in which sunlight will travel. In addition, the curvature of the Earth will not distribute sunlight evenly. In fact, sunlight will be distributed in a specific direction, given your geographical location. For instance, if you live in the northern hemisphere, then your panels should face south. If you live in the southern hemisphere, then your panels should face north. Unless you are living in the exact equator, you should point your panels in the opposite direction of your hemisphere.

If you are unsure about which direction is north and which is south, you can look at a map tool such as Google Maps, or you can use your car's GPS. Those are two very simple ways in which you can determine your north/south position.

The reason for tilting in the opposite direction of your hemisphere is related to the way the Earth itself is tilted. The Earth tilted axis is the reason why we have seasons. As such, when it is winter in the northern hemisphere, it is summer in the southern hemisphere and vice-versa. The only part of the world, which gets an equal amount of sunlight throughout the year, is the exact equator. So, unless you are living right at the Earth's equator, heed this recommendation.

Peak hours

Earlier, I mentioned that the peak hours for sunlight were roughly between 10 am and 2 pm. This is when the sun is at its brightest and will deliver the most amount of sunlight. In addition to the tilting of your panels, your system should capture the greatest amount of energy during these peak hours.

Now, depending on the part of the world you live in, your days may be longer or shorter. That is why you need to maximize your exposure to sunlight. This is especially important if you live in a part of the world that doesn't get much sunlight.

Of course, you might be tempted to place your panels on a flat surface facing straight up. Sure, this will work best when the sun is directly above your position. However, it will not be very efficient once the sun begins to set, and it is at an angle.

Furthermore, the north-south facing tilt will ensure that the panel begins to capture sunlight right from sunrise all the way through sunset. This is something that would be virtually impossible if the panels are facing straight up.
One good rule of thumb, if you are partially connected to the grid, is to switch to regular electrical power during peak hours. That way, you can give your batteries a good chance to charge up. Once the peak hours have passed, then you can resume using your solar power system. This will help you to charge the batteries faster.

The mounting structure for your panels

Since the panels will be at an angle, your most immediate option would be to use your roof.
The best type of roof to use is a Gable roof since it has the two sides parted down the middle. Since each side is on an angle, then it might be feasible to use your roof. In that case, you can look for the support beams that hold up the roof.
Next, you will find that the panels have holes where screws, or bolts, can be used to fasten it to the surface that they will be mounted on to. You can use long, 2-inch bolts to drill through the shingle and the support beam.
If you decide to drill all the way through the support beam, then make sure you go straight through the middle. This will not comprise the integrity of the beam. However, if you drill at an angle, then you might weaken the beam at that point.
Once you have the hole drilled, you can place the mounting bracket. Bear in mind that you will not place the panels directly on the shingle. Rather, the mounting brackets will support the mounting rail. It is on the rail that you will place the panels on. Then, you can screw the panel onto the support rail.
Using the support rail system is a good idea, especially if you have larger panels. If you are using smaller panels, then you could just install the mounting bracket and place the corners of your panel on the bracket. This is doable, especially since the panel won’t weigh as much as a larger one.
If you are home or structure has steel beams with tin sheet roofing, then mounting will be a lot easier because you can use the same spots where the tin sheets and bolted into the support beams. All you would have to do is remove the bolt, place the mounting bracket, and away you go.

The main reason for not mounting panels directly onto the roof is related mainly to rain and snow. If the panels where to be mounted directly on to the surface of the roof, the rainwater would flood the panels. If the panels as slightly raised above the surface of the roof, the water can flow beneath it. The same goes for snow.

Concrete roofing

Now, let's assume you are mounting panels onto a building with a flat, concrete roof. This job poses a higher degree of difficulty, as most concrete roofs are flat. While they may have an angle in order to allow water to flow, this angle will be inadequate for efficient sunlight capture.

So, you will have to fabricate your own mount that takes into account the recommended angle.

There are two ways in which you can fabricate your own mount. You can make these mounts out of wood or metal. The mount will look like two triangles joined by straight beams.

If you are looking for a quick and cost-effective way of making your own mount, you can use regular lumber to make the mount. Depending on the size and weight of the panels, you can use regular 2 x 2 lumber all around. If you use the larger and heavier panels, you might consider using 3 x 3 or 2 x 4 lumber. This will give your panels the support they need.

Don't worry about using lumber to mount the panels as the panels will not catch on fire. If anything, it is the batteries that pose a greater fire hazard.

Mounting on to wood is a lot easier since the screws that you use will dig into the wood. So, make sure you use wood screws, or at least, cone-shaped screws that have the spiral thread. Try to avoid using the flat-tip screws as you will have to drill into the lumber in order to pass the screw through the wood.

Alternatively, you could nail it down with a regular flathead nail. Ideally, you would use a nail gun to do this. You could use good, old-fashioned elbow grease and hammer the nail in. However, you must be very careful not to hammer the surface of the panel. If you do, you may damage individual cells or the entire panel altogether.

Personally, when working with wood, I would prefer to use 1-inch wood screws. They will go a good job of holding the panel in place. If you must nail the panel in, make sure the head of the nail doesn't go through the hole of the panel. Otherwise, it would be as if you hadn't nailed the panel down.

Another type of mount that really works very well is a steel frame mount. These can be made by a blacksmith to suit the exact needs of your panels. You can use regular aluminum, such as the frames used in windows, or you can use heavier steel.

The blacksmith will take the measurements of your panel, and them weld the pieces of metal together. If you wanted to save yourself the hassle of screwing down the panel, you could have the blacksmith weld the frame of the panel onto the mount. This can be done by soldering a few points all around the panel and the mount. The only downside to this is that if you ever need to remove the panel, you will have to work quite a bit to break to weld points. In addition, the blacksmith needs to be very careful not to heat the panel too much. Otherwise, it could blow the whole panel.

So, your best option here is to screw the panel down with a nut and a bolt. The blacksmith can drill the holes in for you so that all you have to do is line up the holes, thread the bolt through, and secure it on the other end with a nut. You can then fasten the nut with a wrench. All you need to do is just hand-tighten the nut and bolt in order to securely fasten it to the mount. If you use a gun to tighten the bolt down, the added torque of the gun may crack the frame of the panel.

Breaking through the roof

Even if your panels are big and heavy, it is always a good idea to secure them to the roof. This is especially true if you live in a windy area, or an area prone to tornadoes and hurricanes.

In order to mount your wooden or metal mount, you can break open a small hole into the roof itself. It doesn’t have to be very deep. Usually, an inch deep is enough. Don’t feel like you need to bust through all the way to the rebar.

Now, let’s assume you have a wooden mount. Wood and concrete don’t mesh very well together. So, you can just set the lumber into the holes in the roof, pour some concrete on it and let it sit there.

Of course, you could do that. However, the wood might rot, and you will have to break open the same spot again and remove the rotten mount.

So, the solution is to open a small hole, about two inches wide and about an inch deep. Then, you can get large, two-inch bolts. You can set the bolts into the hole and pour concrete around the bolt, thereby filling in the hole. What you will have is the bolt protruding from the roof. Next, you can drill a hole all the way through the wood, set the mount over the bolt, and then tighten with a nut over the bolt.

You can use four bolts, one for each corner, to fasten your mount to the roof. If you would like added security, you use 6 or 8 bolts. As long as you let the bolts set into the concrete properly, you should have no trouble with the wind blowing your panels away.

If you are using metal mounts, then you can break the holes into the concrete roof just like before, but this time, you can actually set the frame directly into the concrete. Since metal and concrete get along very well, you won't have to worry about your panels blowing away. You can set each corner into the roof, and you will be good to go. So, when you get the blacksmith to make your mount, you can ask them to leave a one-inch tip. This is the tip that will go into the roof.

When setting metal mounts into a concrete roof, be sure that the spot you choose is the spot that will hold the panels forever. Since metal sets very well into concrete, you will find it nearly impossible to pull the mount out without tearing the roof apart. While you could just hacksaw through the metal tips, removing a metal mount will require additional time and effort. In this regard, wooden mounts are much easier to deal with.

Installing panels on the ground

If you choose to install your panels on the ground, try to avoid installing them on grass or plain dirt. This is especially important if you get a lot of rain. The reason for this is the ground will get soft, become muddy, and then the panels will sink under their own weight.

So, if you have grass or simply dirt, you can pour some concrete down to hold the panels in place. Ideally, you would lay down a concrete slab the size of the panels. This will ensure that your panels will not blow away. Now, if you are on a tight budget, you could lay down smaller slabs around each other corners of the mount. You can dig a one to the two-inch hole, pour the concrete in, set the mount, and let dry. Once the concrete is dry, you can lay the panels down.

If you are unsure about how to do this, you can enlist the help of a mason or a foundation expert. They are good at setting solid supports in the ground. The only caveat with installing your panels on the ground is that you need to make sure they have enough open space so that they are not covered by shadows at various points throughout the day. If you have a large backyard of a good piece of land, then you might just get away with it.
If you are laying your panels down in a forest, say, for a cabin, then you need to see if the trees around the land may cast a shadow on your panels. Otherwise, mounting panels on the ground provide a good option for you to set them up any way that suits your best.

6. Wiring the system

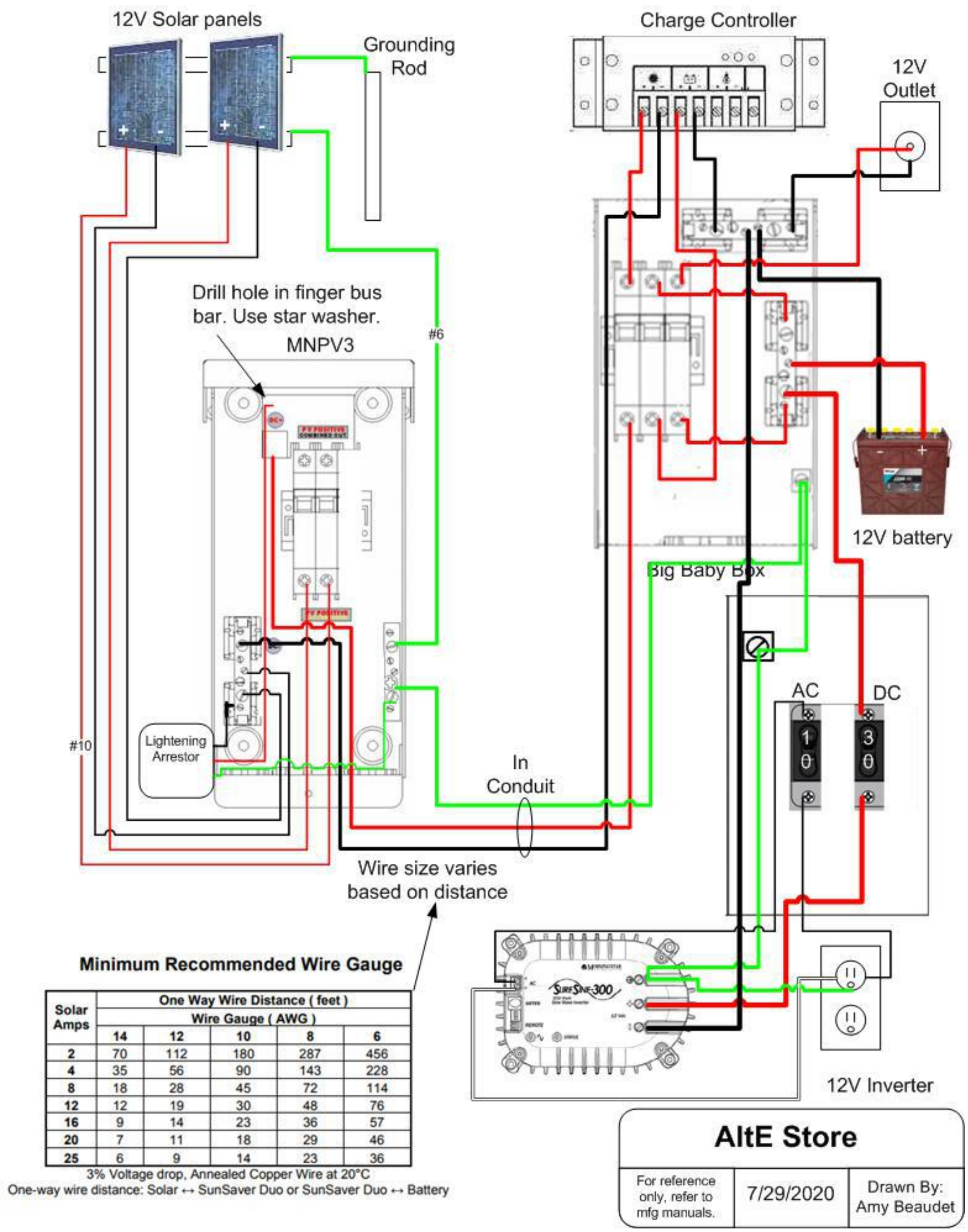
In order to explain in the easiest way possible the wiring of a PV system, I have chosen a easy schematic and I will walk you through a general overview of this system that can be easily scaled up. So, read on!

As you can see, in the example we have two 12V solar panels. They are wired in parallel, so that makes the plusses together and the minuses together. And that keeps it at 12V.
Let’s go to the combiner box: a Midnite PV3 combiner box.
The plus and minus from solar panel 1 come in to, the plus goes into its own breaker. And the minus goes into the negative bus bar. Then the plus and minus from solar panel 2, the plus goes into a separate breaker, and the negative goes to the negative bus bar. The output of the breakers is combined with this included positive finger bus bar. So, it slides into the top of the breakers and that combines the positives. The negative bus bar combines the negatives. And that gives you your parallel wiring.

There is also a lightning arrestor that will protect us from any lightning strikes. And notice the ground going to the grounding bus bar, the positive going to the positive bus bar, and the negative going to the negative bus bar. The ground comes from the racking going into the grounding bus bar. So, the rails are grounded through this, and then the grounded mid-clamp from IronRidge takes that ground, across the rail, up to the edges, the frame of the solar panels.
This setup gives a nice bonded connection through all of it.

I would then go off to a grounding rod, and that would give me my nice earth ground connection.
Because this example is a portable system, I've transitioned to "invisible conduit". But know that this is going to be conduit all the way into the house.

Let's transition into the house to our DC Load Center.
The DC Load Center is really just a fancy way of saying breaker box. The combined negative, positive, and ground, all come into our DC Load Center. We have it going into a breaker. It's coming out of the breaker, into the PV In to the charge controller.



Minimum Recommended Wire Gauge

Solar Amps	One Way Wire Distance (feet)				
	Wire Gauge (AWG)				
	14	12	10	8	6
2	70	112	180	287	456
4	35	56	90	143	228
8	18	28	45	72	114
12	12	19	30	48	76
16	9	14	23	36	57
20	7	11	18	29	46
25	6	9	14	23	36

3% Voltage drop, Annealed Copper Wire at 20°C
One-way wire distance: Solar ↔ SunSaver Duo or SunSaver Duo ↔ Battery

My negative is also coming in, and it's actually just transitioning right on out. It's just going in there as a nice place to land the negative. But it's going in and then it's coming right back out and it's going to the negative PV In of my charge controller.

Then the battery is out from the charge controller. I've got the plus and minus going into the DC Load Center. The plus is going to a breaker, and it's going to be coming out, and going to my positive bus bar. The positive bus bar is going to be going to my battery. So, I've got the negative coming out of the charge controller, going to the negative bus bar. And that negative is also going to be going to my battery. So, that's going from the charge controller, to the battery.

Basically, what the busbars do, is give a nice easy way to connect everything to the battery. So, you only have one connection to the battery, because it's just connecting into the busbars. So, anything you need to connect to the battery, you can just connect to the busbar, through a breaker. So I have going from the positive and the negative, I'm actually going to a cigarette outlet.

Now you have the DC load. From the positive bus bar, to another breaker, and out to the DC input of my inverter. And here comes the 12V inverter. The negative is coming from the negative bus bar, which is just acting like the battery, going to the negative of the inverter. The inverter turns that into 120V 60Hz pure sinewave, because I'm in North America.
If I was someplace that used 230V 50Hz, I would just use a different inverter for that.

The inverter creates the AC power for me and goes to an AC breaker box. For the example I imagined a Midnite Baby Box, but if you've got a lot of AC loads, you would have a bigger AC breaker box.
Through my breaker, out to an AC outlet, let there be lights! You are totally wired!

Conclusion

I hope you have enjoyed this book as much as I have enjoyed writing it and sharing my modest knowledge in all things solar! If this book has helped you design your very own solar system or at least made for an interesting read, please leave a review on Amazon and let’s share the knowledge to make renewable doable!