THE COMPLETE OFF GRID SOLAR POWER FOR BEGINNERS...

A Detailed Methods and Strategies To Building and Installing the Most Efficient OFF GRID SOLAR SYSTEM for Indoor and Outdoor Living.

TASHI TSENKYAP

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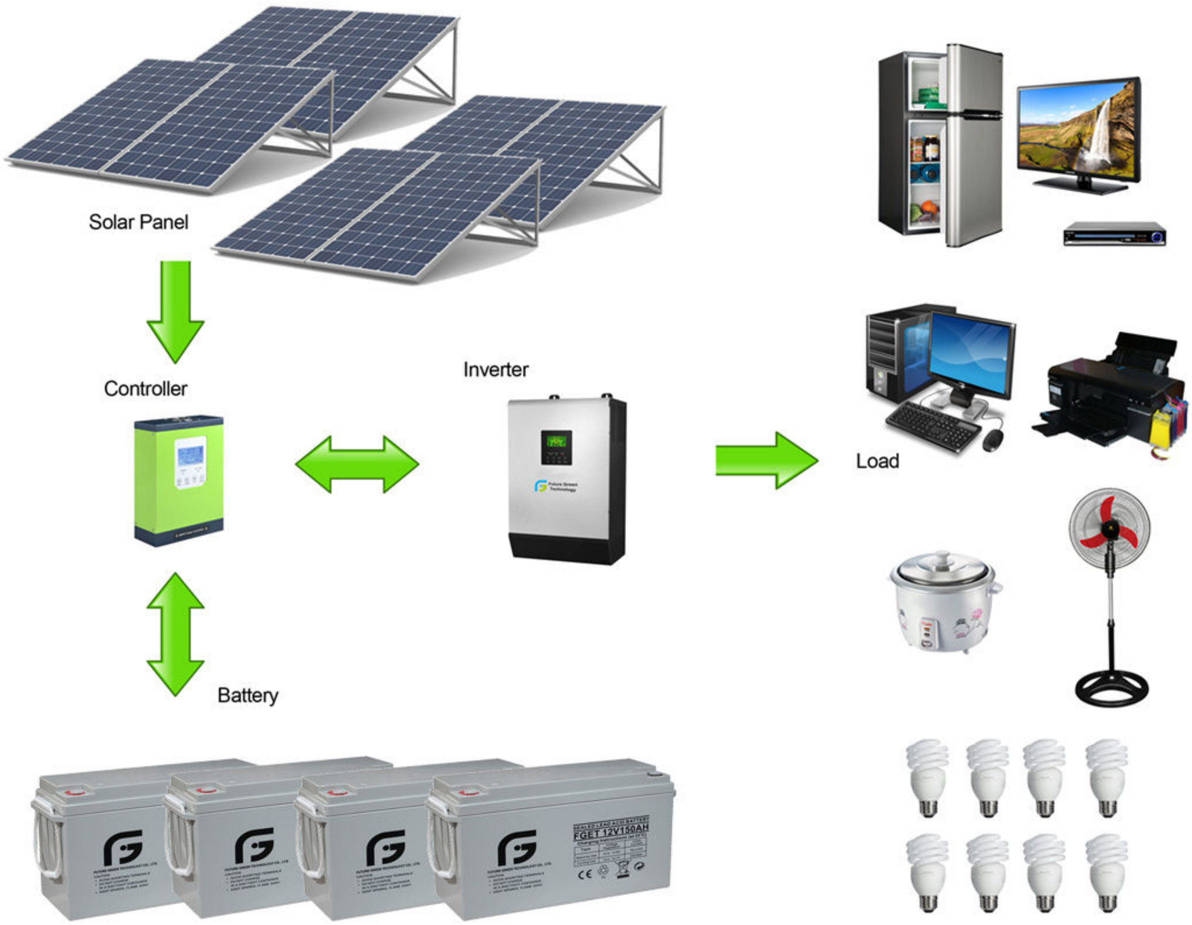

Solar Panel
Controller
Inverter
Load
Battery

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Introduction

This book is written for solar power enthusiasts making their first steps in the world of solar photovoltaic energy. Here are the essentials of off-grid solar panel systems revealed.
The book, however, is also targeted to intermediate and advanced solar users due to its systematic and simplified step-by-step approach to solar system design. The essentials of off-grid and mobile solar panel systems are explained in an easy-to-follow-and-grasp manner. Furthermore, every solar enthusiast, regardless of their experience level, will benefit from the essential information revealing how to scale up fast, easy and cost-effectively a solar power system.

Off-grid solar electric systems are not connected to the electricity grid. They are preferred in remote areas where buildings are far from any utility infrastructure.
Although mobile solar systems are a subset of off-grid solar, they do require some particular attention and do have their specifics when it comes to component selection and system design. All these details are carefully noted and explained in the book. What is more, a whole chapter devoted to mobile power system sizing explains in a step-by-step manner how to design a system that is both best-performing and cost-effective.

As a rule, in off-grid solar systems, the produced electricity is matched to the user's energy needs. A typical off-grid system requires an electricity storage system because electrical energy might not be needed at the same time when generated. For this reason, battery banks are used for electricity storage, and most off-grid photovoltaic systems are battery-based. The other option for power backup is a hybrid solar system where the capacity of the electricity storage can be enhanced by adding an extra power source – for example, a diesel generator.
In areas located away from any existing utility poles, it is often less expensive to install an off-grid photovoltaic power system than pay a fortune to get connected to the grid. Therefore, off-grid solar panel systems are a good solution for households located away from the public electricity grid and business clients in industrialized countries as an option for lower-cost production methods.
It should be noted that not all the household might be dependent on solar-generated electricity. A solar power system might be an option for individual devices and applications – lamps, pumps, SOS telephones, traffic signal systems, ticket machines, clocks, solar radios, mobile and measuring equipment on cars and vans, etc.
Off-grid solar panel systems are attractive, as they:

- Are a reliable source of power
- Are practically unlimited in size – an off-grid solar power system could serve a single device or a couple of buildings with a complex electrical network
- Can be installed almost anywhere in the world
- Can be less expensive than paying for getting connected to the utility grid
- Can provide electricity to the most household devices
- Can be used on vehicles – RV and marine.

Here are some of the primary applications of off-grid solar panel systems:

- Small solar systems for household use
- Providing power to remote homes or summer villas
- Recreational vehicles
- Water pumps and cooling
- Power supply for telecommunication equipment
- Street infrastructure equipment – street lamps, bus station dashboards, parking meters, etc.
- Remote meteorological stations and airports.

The purpose of the author is to provide you with all the practical information you need to build an off-grid solar system fast and easy by yourself.

Furthermore, you are going to acquire the essential knowledge to make you confident when reading technical documentation, communicating with solar vendors and installers, and selecting the components of the off-grid system configuration that fits best your needs and available budget.

We wish you lot of success in your solar endeavour!

Part I: Playing the Energy Game.

With the federal election and sustainability being a hot topic, the states competing with each other to become the best state for sustainability, and the media coverage about proposed electricity price increases - it feels like everyone's talking about solar power. But is it all hype, or is the proposed investment into solar power by normal people like us a solid investment? We've questioned whether investing in solar power now is a good idea and have come up with a solid case for immediate action and beginning your investment now. Here are our reasons.

Solar is a High Yeld, Low Risk Investment

The risks of solar are low - most solar PV systems and solar hot water heaters come with long-term warranties of up to 25 years. Solar is low (or no) maintenance because it has no moving parts - some solar PV systems have been operating for decades already. Solar will continue to show you a return on your investment every day as the sun rises, almost like an annuity payment.

Energy costs are almost guaranteed to rise. The cost of solar PV and hot water systems may come down in price slightly with increased uptake and lower technology costs, but this risk is low and should be more than completely offset by the rise in energy costs. The sooner you invest, the sooner you can reap the returns.

The returns of your investment will come once the cost of installation has been offset - sometimes within the first 2 years of installation (this will depend on your sun exposure, the efficiency of the system you choose, and the costs of energy you would be using).

What About the Risk of the Technology Improving Significantly?

Some people we talk to say that they'd prefer to wait to invest in solar - waiting for the newer model that will no doubt be more efficient - in the same way that we hold out for the new iPhone. Gains in solar technology have been huge in the past few years, and this perception is valid. No one can predict how much technology can improve until it has, but many solar professionals tell us that they believe the technology has a long way to go before it jumps again. To liken solar to a techie theory, we're told that solar is where mobile phones are - every model can have has a camera, internet connectivity, music, and usually a touchscreen, and the next major improvement is nowhere in sight.

Increases the Value of your Home

Although there are no solid statistics in this area yet, early reports show that houses with lower annual utility bills sell for a higher price - and sometimes the difference is more than what the original investment was.

In Victoria (and soon federally legislated we're sure) houses for sale will have a compulsory star energy rating associated with them. With the higher visibility of a home's energy efficiency, you can be sure that more and more consumers will be looking to buy homes that are sustainable that they will not need to retrofit in the future.

The value of your home increases by at least the 'improvement' value - and remember that some of that improvement value will not be paid directly by you but by the state or federal government in the form of rebates.

Protection Against Future Energy Price Increases

We all know what happens when the mortgage rate goes up. We have less disposable income, sometimes forcing us to cut corners into necessary items. Price hikes in utility bills are a high risk (64% price increase predicted in NSW over the next 3 years). Installing solar protects you against these price hikes by ensuring that you have the ability to make your own energy that doesn't fluctuate.
While you may not remove this risk entirely, you will definitely reduce the effect that price hikes will have on your lifestyle in future. That means that when you get a salary raise based on inflation (which is also calculated with utility prices in mind) you get more of your raise to use as you wish - not on life's necessities.

Rebates Make Investment Costs Lower and Returns Higher

Are rebates for solar energy going to be around forever? They may very well be, but we've all learnt not to count on a rebate structure being around for very long! Today's rebates are excellent, and you will get a collection of federal and state rebates as well as RECs. You can be sure that investing into solar will always be a priority of the government, but you can't be sure that there will always be enough money for rebates. The rebates currently available should be taken advantage of now.

Make Money on Selling Excess Electricity Back

You can make money if you generate more energy than you use. Simple. Even if you don't generate more than you use, in some cases you will still receive payments from your utility company for generating your own electricity that can completely offset the costs of your energy usage when solar energy creation isn't at peak.

Once you have a system, it's relatively simple to add more PV panels to create more energy. If you have the space and the position, you can make your initial investment back more quickly and make a continuous return - similar to dividends on a stock that you own (but more predictable).

Good for the Environment

Global warming and climate change is a reality. Doing nothing about it now means that we'll all suffer more lately – and no one wants that. Solar hot water systems reduce carbon emissions by at least 20% per home, and solar PV systems reduce unsustainable energy use.

Of course, you can also back up your investment in solar by reducing your overall energy usage, which means you'll make more money from any excess solar energy that you feed back into the grid.

It's easy to get quotes and install solar PV or HWS

Thinking about Solar investments can be complicated – but getting quotes and advice couldn't be easier.

Chapter 1: Helping the World through Solar Power

Solar energy is the radiant light and heat from the sun. This free accessible energy has been harnessed by humans since ancient times using a range of ever-evolving technologies. Still today, only a infinitesimal fraction of the available solar energy is used. Solar power provides electrical generation by means of heat engines or photovoltaic. Solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, day lighting, hot water, thermal energy for cooking, and high temperature process heat for industrial purposes.

Energy obtained from solar energy is clean. Clean energy from the sun can replace power sources that pollute the environment. The few emissions of greenhouse gases or air pollutants generated by solar energy technologies occur mostly during the manufacturing process. A 100-megawatt solar thermal electric power plant, over its 20-year life, will avoid more than 3 million tons of carbon dioxide (CO2) emissions when compared with the cleanest conventional fossil fuel-powered electric plants available today.

Many countries through several national and international institutes and agencies have started taking actions to reduce (or eliminate) the pollutant emissions and to attain a sustainable supply of energy. One way to achieve this is by using solar energy as much as possible. This is in compliance with the agreement signed in the December 1997 in International Kyoto Conference on climate change, where a list of fifteen concrete proposals emerged for the reduction of global greenhouse gas emissions. The list includes, among others, the use of solar energy.

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. The importance of energy in economic development is recognized universally, and historical data verify that there is a strong relationship between the availability of energy and economic activity. Increase in economic activity also increases environmental problems. The growing evidence of environmental problems is due to a combination of several factors, since the environmental impact of human activities has grown dramatically. This is due to the increase of the world population, energy consumption and industrial activities.

The most important benefit of renewable energy systems is the decrease of environmental pollution, clean energy with no emissions or noise pollution, low operating and maintenance costs, emissions from manufacturing and construction are quickly offset, reliable systems, useful for grid connected and remote applications, modular systems that can be constructed to any size, and creation of new jobs.

The negative environmental impact of solar energy systems includes land displacement and possible air and water pollution resulting from manufacturing, normal maintenance operations and demolition of the systems. However, land use is not a problem when collectors are mounted on the roof of a building, the maintenance required is minimal and the pollution caused by demolition is not greater than the pollution caused from demolition of a conventional system of the same capacity.

It can, therefore, be concluded that solar energy systems are friendlier to the environment and offer significant protection of the environment. The reduction of greenhouse gases pollution is the main advantage of utilizing solar energy. Therefore, solar energy systems should be employed whenever possible in order to achieve a sustainable future, thus applying the slogan ''THINK GLOBALLY- ACT LOCALLY''.

Part II: Understanding Solar — Just the Facts,

How does solar energy work? It's a question that's being asked increasingly often now this technology is becoming much more practical, marketable and affordable. It's not uncommon for you to see advertisements for home installations and comparison charts between competing solar energy companies. What goes on behind all those pricey panels, and is it really the next big thing like everyone says it'll be?

A Short Solar Energy Guide

If you've ever seen a calculator that doesn't need a battery to run - the ones with a black strip near the top front - then you've seen a solar cell. Photovoltaic or solar cells are specially designed modules of treated silicon that can generate an electric current when hit by light. In a nutshell, electrons in the cell's silicon lattice can be struck loose by the energy of the sun, and their movement creates a current in the cell.

With enough cells in place, this generated energy can add up to a significant amount - enough to power a home or building in some cases. Large enough arrays of solar cells can create enough to replace traditional electricity in some cases, meaning lower power bills. The savings is one of the biggest solar energy advantages that make it so attractive.

Solar cells aren't all that new; they've actually been in use for many years now. It's just that, up to about a few years ago, they were limited to the aerospace industry because it was only folks like NASA that could afford them. Nowadays, though, they've figured out ways to produce the cells themselves for less, meaning more solar energy for everyone.

But What If...

It's understandable if you were to have doubts about this technology at first. After all, it's a technology that has only hit the mass market in the past few years. As far as consumers are concerned, it's still fairly new - and relatively costly technology.

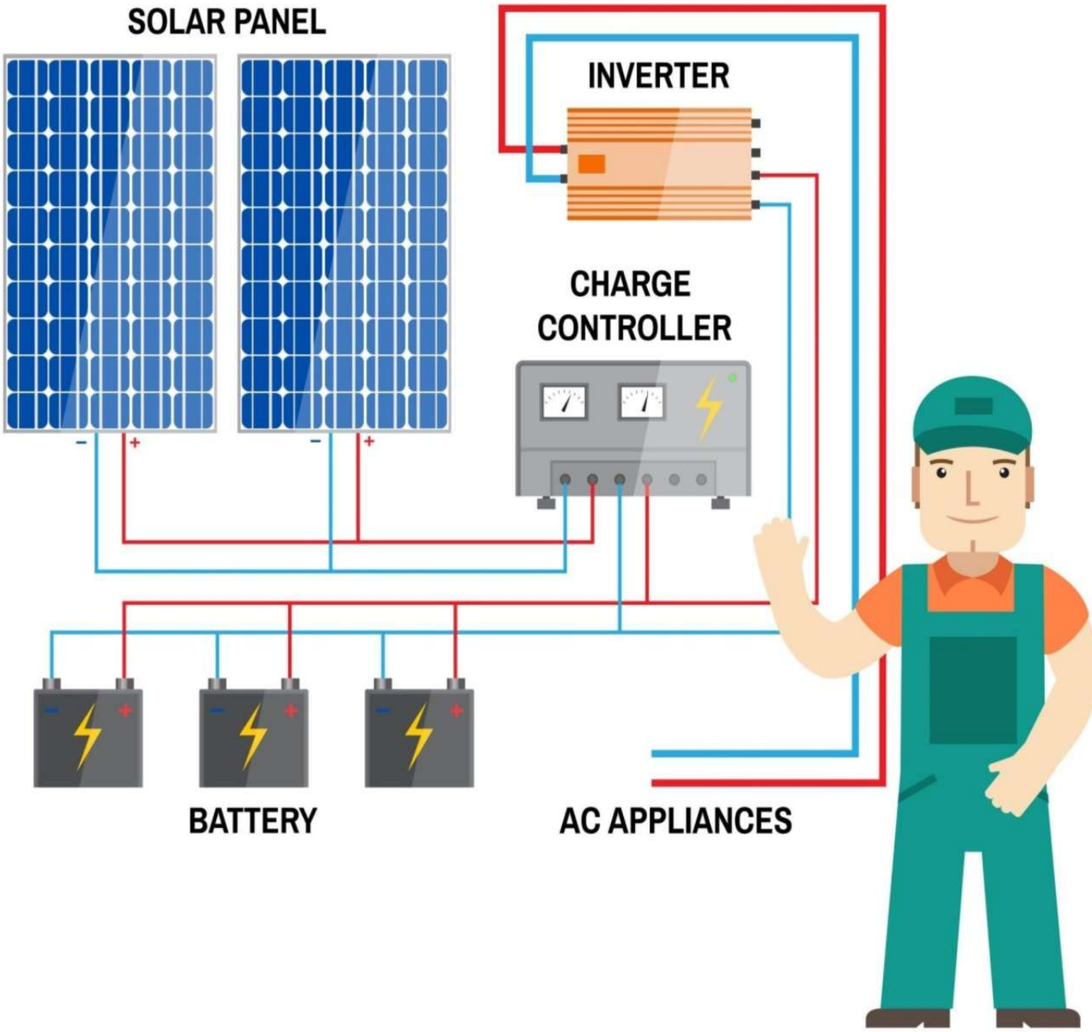
Cost-wise, for example, it's still not as cheap as people would like it to be. Installation of solar cells (and the solar cells themselves) tends to require a fairly big amount of cash out of your own pocket. Once you factor in the savings, though, it's a whole other story.

How does solar energy work on cloudy days? It's an apprehension that many have, and is easily remedied. Almost all solar for RVS, camper vans, boats, cabins, and tiny homes setups can direct the generated electricity to a battery that stores the power. This stored energy from the sun can then be used at a later time, meaning you can use solar power even on a dark night in the dead of winter.

If it's all about what you stand to gain from solar energy, advantages of the technology come in spades. Besides just the money you stand to save, there's also the planet and the environment that you're helping to save in the process.

Before you buy solar energy, make sure you continue to read this book to learn a lot more about the ins and outs of solar energy and power. Continue reading to get all the info you need before you decide to get this green and power saving technology!

Chapter 2: Working with Solar Basics



When starting a new home DIY solar energy project, one of the many question asked by a beginner is: What component parts will I need to complete my solar energy project? Before you start connecting together the individual component parts on your roof, it helps to get a good quality solar guide that will walk you step by step through the whole process of building, installing and setting up your own home solar energy system. Aside from the obvious of time, tools and instructions, let us look at the basic components you will need to go solar.

For installing a grid-tied solar power system for your home, there are basically 7 main components you will need and we will organise these in the order in which they will be connected into your home solar energy system.

1. Solar Panels

In most home DIY installations these panels will be built by you from individual parts. You can order discount photovoltaic cells online, and assemble these into complete 80W, 100W, or 120W Solar Panels. But if you do not have the time or skills to build a solar panel from scratch, there are plenty of commercially available panels to choose from. Once built, individual panels are wired together to make larger solar arrays.

2. Solar Array Disconnect

This is basically just an electrical switch but is an important part of the system. It allows you to disconnect and cut-off the DC power output from your solar panels and array should any repairs be required or if there is a problem with the solar system. This disconnect switch needs to be strong enough to handle the full power output from the panels on a bright sunny day.

3. Battery Charge Controller

Most home solar systems are built with a battery backup included for when the sun does not shine such as on dull days or at night. The battery charge controller ensures that a consistent amount of electrical power is sent to the batteries so that they are not over charged, and to ensure that the backup batteries do not discharge back through the system at night. In many ways this component is similar to your automotive battery charger so will not be too expensive.

4. Deep Cycle Batteries

In order to store the solar power generated by your solar panels, your solar system will need deep cycle batteries. Deep cycle batteries are not the same as shallow charge automotive batteries which are designed with thinner lead plates for cars. Deep cycle storage batteries for solar systems are more robust and are designed for the type of charging and discharging cycles they need to endure. New deep cycle batteries are expensive but reconditioned batteries are cheaper. Better still, you may be able to get old dead batteries for free used previously in fork trucks, golf carts, and electric buggies and recondition them yourself.

5. System Power Meter This can be optional, but it is listed here as its inclusion will give you a clear way to see how much free solar power is being supplied to your home from your solar panels. Having a system power meter also helps you improve your system to gain the maximum efficiency from your solar installation as well as having the advantage of letting your neigbours know how much money your solar system is saving.

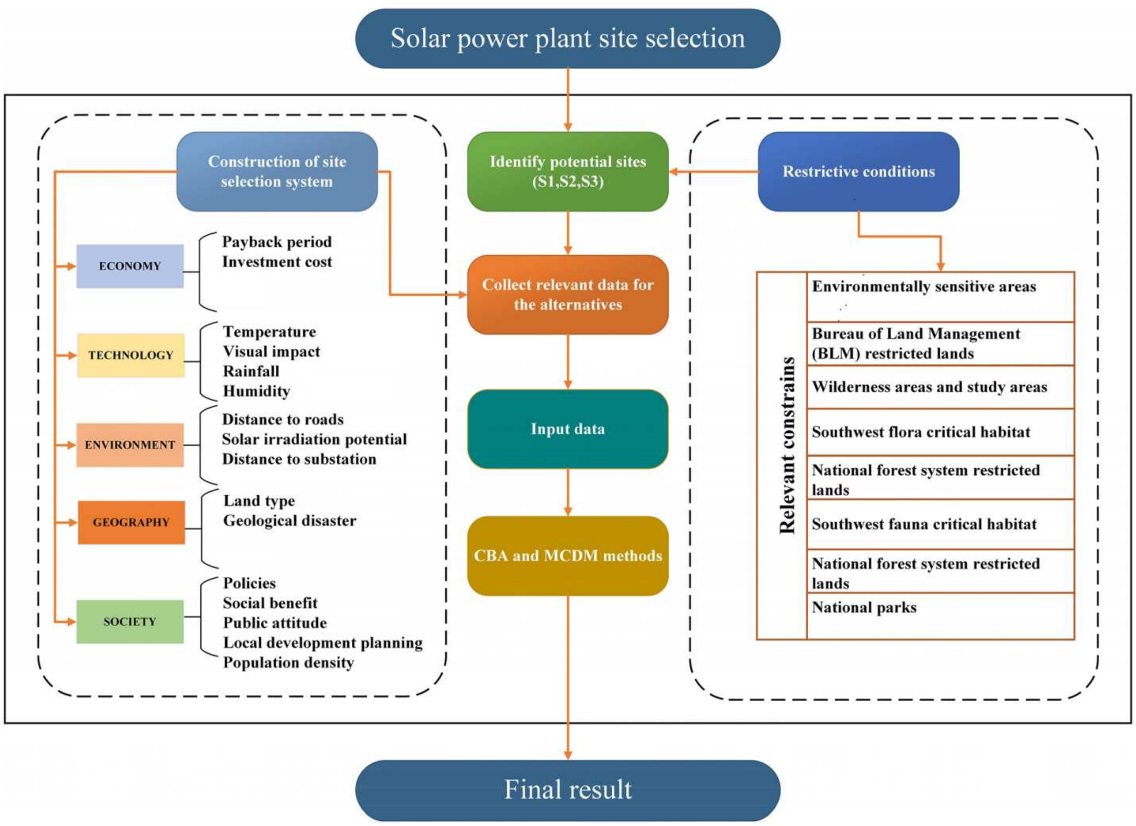
6. Solar Power Converter
Your solar panels generate DC power, and your home runs on mains AC power, the solar power converter converts the solar energy from the panels into usable energy in the home by providing the DC to AC conversion using electronic switching techniques. In practical terms, the converter allows us to run electric drills, computers, vacuum cleaners, mains lighting, and most other mains electrical appliances that can be plugged into the wall sockets of your solar panels. There are many square wave, sine wave modified wave converters on the market but a good quality 1200W converter likely won't cost you more than $100.

7. Backup Power

This for when the sun does not shine and the batteries are empty. Most systems will include some sort of backup power. In a stand alone installation this would generally be a diesel generator. In a grid-tied system the utility grid itself would provide the backup power through the converter. But a backup power source can also be a wind turbine or a water wheel as part of a small scale hydro system.

Once you have your 7 components installed, your solar power system gets wired into your normal home electrical panel and unless you are qualified, it may be necessary to get a qualified electrician to connect up the system. Now that you know what 7 components you will need to get your home solar energy system up and running the savings made on building your own panels and sourcing the materials will more than pay for the additional qualified help.
So whether you build your own solar panels from scratch or buy pre-made commercial panels, using solar energy to power your home can be easier than you think. With a grid connected system you can even sell excess electricity you do not use back to the utility company who have been selling it to you for all these years giving you an additional income.

Chapter 3: Evaluating Your Solar Potential



Depending on where you live geographically — and the orientation and exposure of your particular house or business — you get more or less usable sunshine. Even within small, localized regions, weather patterns vary due to topography and landscape details like trees and ponds. So two identical solar systems separated by a few miles, but otherwise built and operated identically, may yield different energy outputs averaged over a period of time.

In this chapter, I explain the factors that allow you to optimize the orientation and location of solar systems at your home, Rvs, Camper Vans, Boats and Cabins. This information can give you a head start in making important decisions, such as which type of system will work best for you, how big a system you will need, and how much potential, in relative terms, you can expect to achieve. Above all, this chapter gives you an idea how to evaluate the relative economics of a solar investment, the details of which I get into in Chapter 4, on payback analysis.

Weather is today’s phenomenon, but climate is a description of the general weather patterns over a long period of time. It may be cold and rainy in Los Angeles today, and that’s the weather, but the climate is warm and temperate. Good solar designers assess climate particulars to enhance system performance. Climate includes elements such as temperature, precipitation, and wind speed. Here’s a look at how climate can affect your solar system:

Sunlight: Climate dictates how much sunlight you can expect annually. The map below shows the average number of hours per day of sunshine in the United States and Canada. That the Southwest gets the most sunshine per day — and that Canada and the northern states get the least — should come as no surprise. The sun is higher in the sky in the southern states, so the days are longer.

Snowfall: You want to locate your panels so they avoid being inundated with heavy layers of snow. For example, some locations on your roof will experience very shallow snow build-ups as compared to other parts of your roof. Also, some parts of your roof may be warmer than others due to proximity to heaters, exhausts, chimneys, and so on.

Cloud cover: If you're living in a cloudy region, you still have solar energy, and it's generally diffused (spread out). As a result, collector panel orientation isn't so critical because light will be coming in at many different angles rather than just directly overhead from the sun. Smog: Air pollution and smog affect the amount of sunlight you can expect to receive. If you do live in an area with heavy air pollution, expect less system output over an extended period of time.

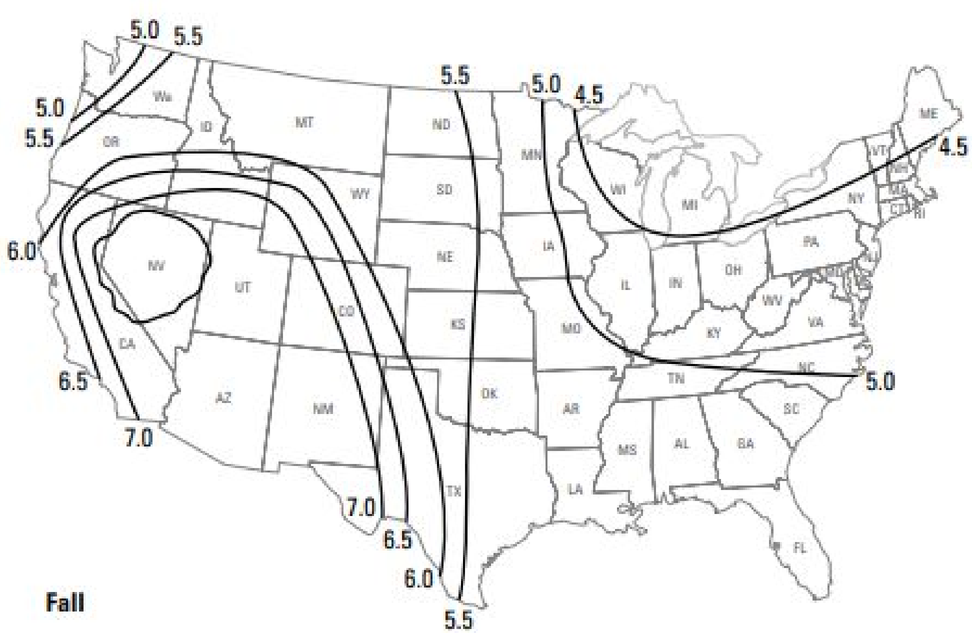
Air density: You get better solar exposure in the mountains than near sea level simply because the air is thinner and scatters less sunlight. You can make an approximate estimate of how clear your air is by simply observing how blue the sky is on a clear day. Thick air scatters more red lights, and so the appearance of the sky is less blue and whiter.

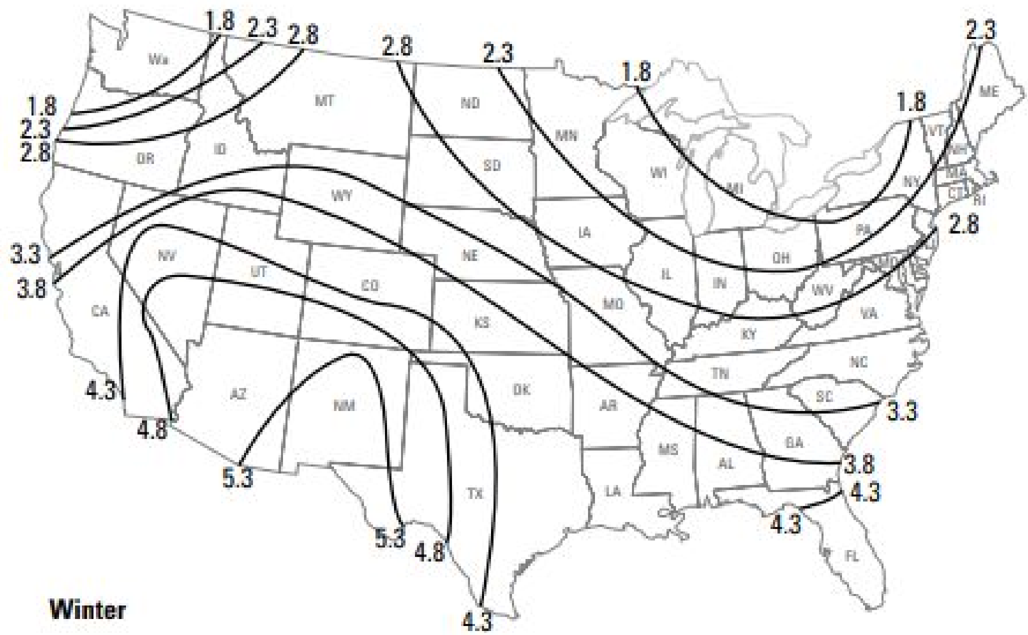
Temperature: With PV systems (not solar water heaters), the lower the temperature, the happier the semiconductors, and the greater the output. You can get more system output on a cold, clear day than a sunny day.

Frequent fog: If you're living in an area that's foggy and misty in the morning (in the San Francisco Bay Area, for example) but the mist burns off into a clear sky by noon, you want to orient your solar panels more westward to optimize the amount of sunlight you can achieve over the course of a day.

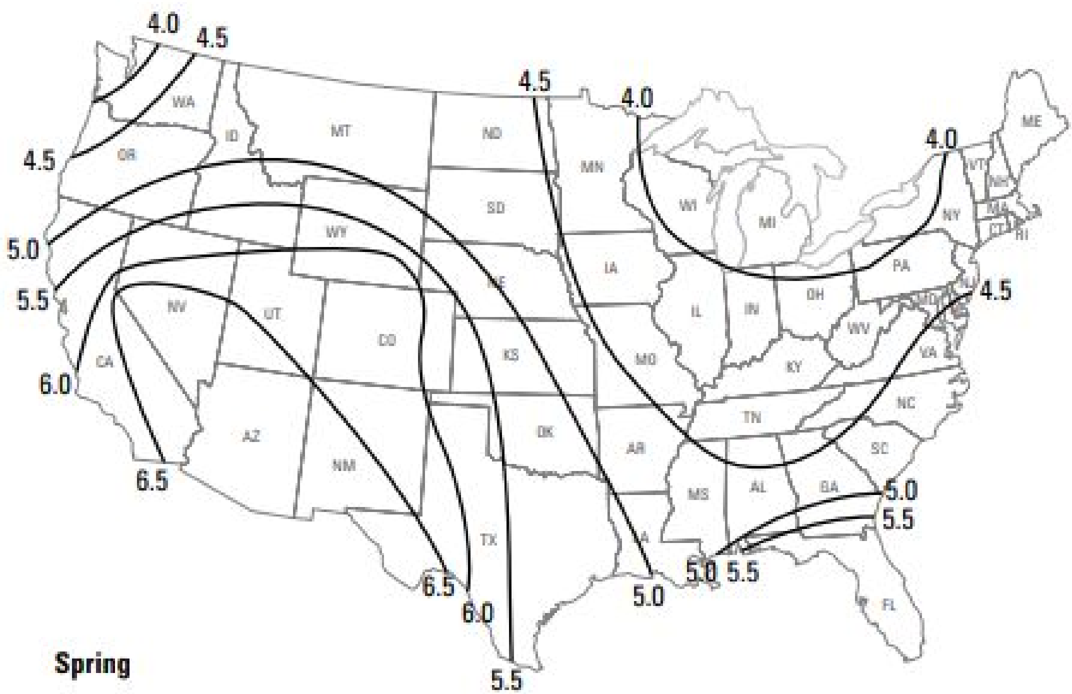
Wind: If you have a lot of wind, you need to consider where you mount your solar equipment for a couple of reasons:

- Wind can tear equipment off of its mounting hardware and result in expensive repairs, not to mention dangerous conditions. If you’re in a windy climate, you need to make sure that you specify heavy-duty mounting equipment. Mounting schemes all have wind speed specifications; pay close attention because mishaps are expensive.

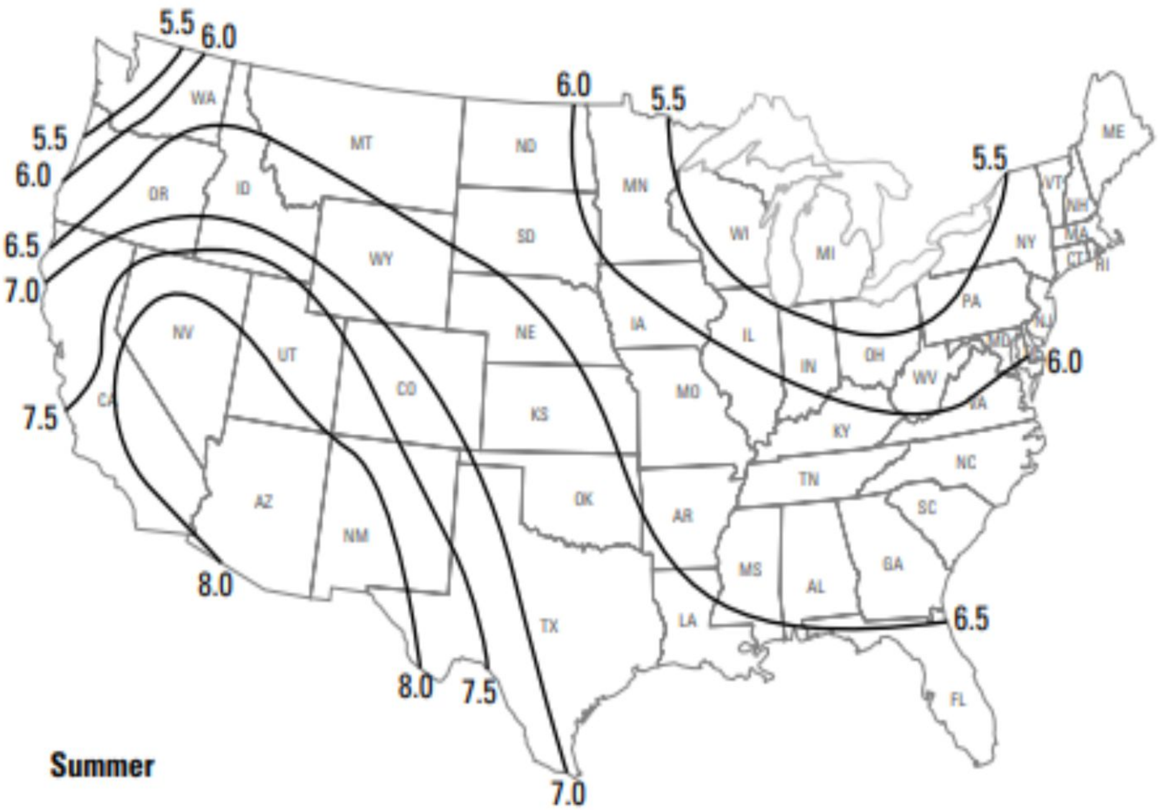




Winter



Spring



Considering Climate and Energy Use

Your climate dictates how much energy you need and when you need it. In temperate climates, the requirement for heating and cooling is generally lower. In northern climates, you don't need to worry about cooling your house at all. Your problem is how to heat your house in the winter.

Part of assessing climate is what you want your solar system to do for you. If you have a cabin in northern Minnesota, you probably won't be there much in the wintertime. And then you'll heat it using renewable wood. In the summer, you don't need to cool, and all you want to do is obtain some night time lighting and run a small, efficient refrigerator. In this case, a modest, off grid photovoltaic system with a battery backup can do the job. Even if you get only a few hours of sun each day, and it's low in the sky, you can still install a system that works for you.

Wind cools surfaces very efficiently. If you have a swimming pool, one of your best bets is to install landscaping that breaks the rush of wind that will cool the pool water much more than your intuition would indicate. Solar water heating panels may heat the water very effectively, but it doesn't make much sense to install expensive solar panels without addressing wind cooling first, because adding a few bushes and trees will be much cheaper than adding extra collector capacity. Plus it looks nicer and is better for the environment.

You can obtain generalized information and maps about the nation's solar resources from the following:

The National Renewable Energy Laboratory: Located in Golden, Colorado, the NREL (**www.nrel.gov**) has a solar resources section on its Web site; follow the prompts to obtain a data log for your city, or a nearby large city. You can get an estimate of the BTU's/square meter/day you can expect. This data is valuable because it averages out all of the factors that I explain in the previous bulleted list. National

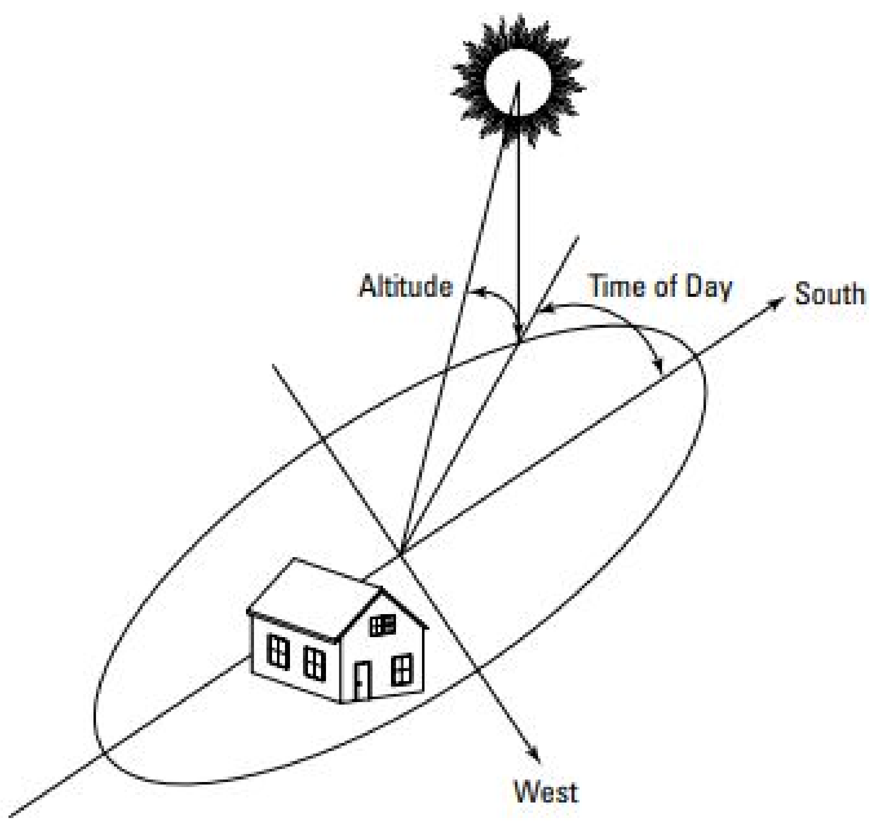
Climatic Data Center: The NCDC (**www.ncdc.noaa.gov**), in Asheville, North Carolina, claims to have the world's largest archive of climate data.

Plotting Your Sun Charts

Sun charts plot how much direct sunlight you can expect over the course of a day. They're an easy and intuitive way to visually display the movement of the sun across the sky. The following sections explain how to create your own sun charts and how to use them to evaluate the amount of sunshine you can expect to receive at your location.

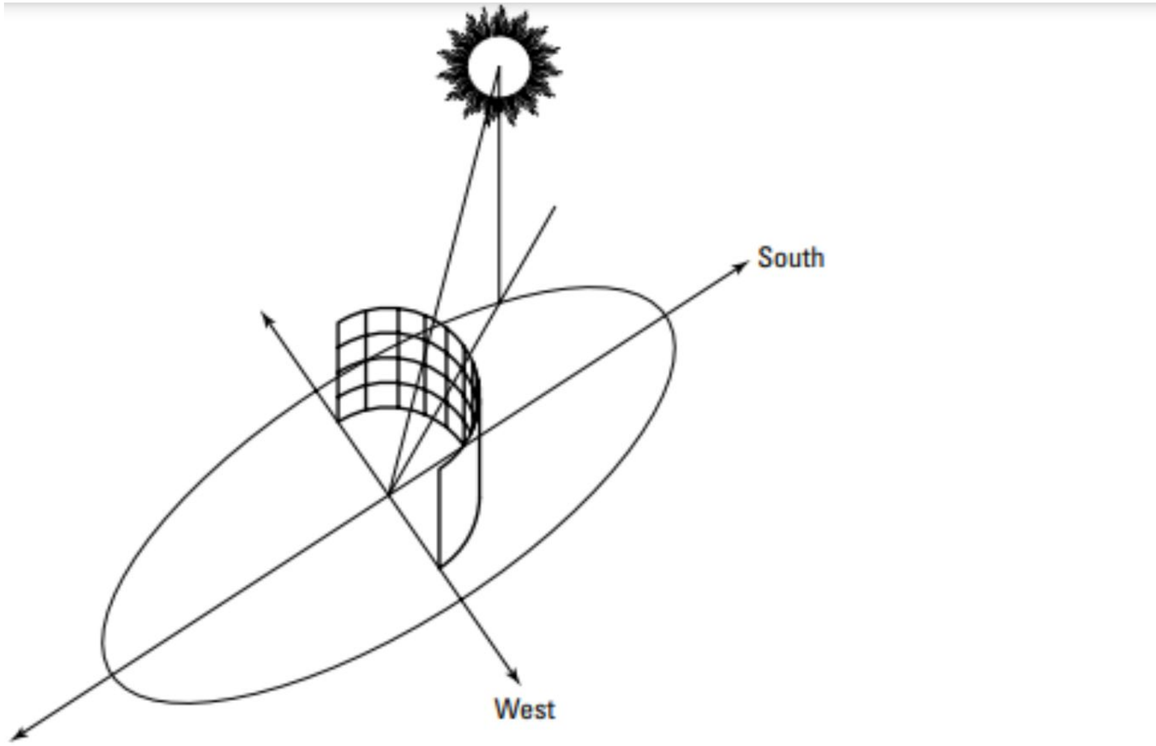
Charting out the Basic Path of the Sun

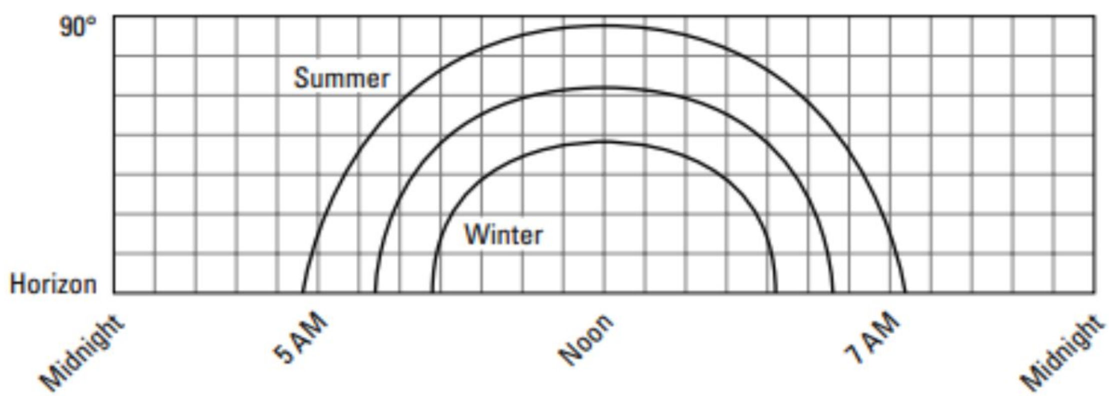
The position of the sun may be plotted with two angles (azimuth, which is the angle from true south, and elevation, which is the angle from level, or in most cases the horizon), as shown below.



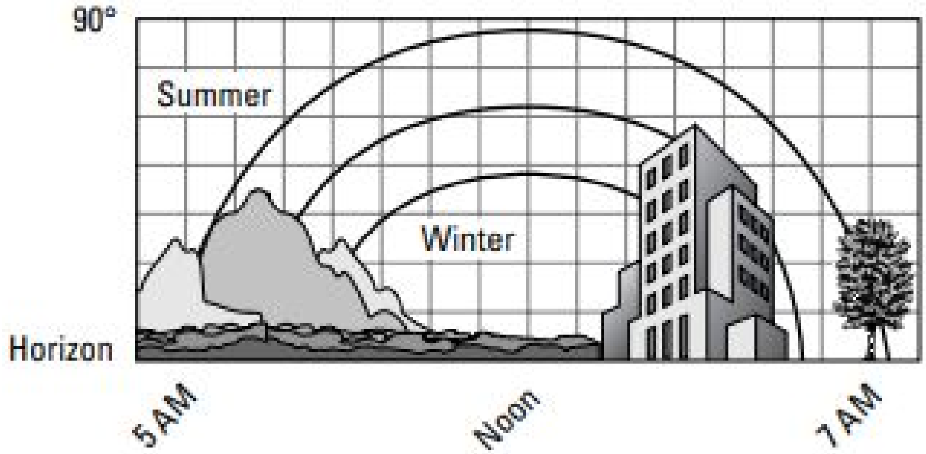
The next image shows you how to create a graph of the sun’s passage over the course of a day. Imagine a sheet of graph paper wrapped around your house.
The following image shows what your sun chart looks like if you plot the movement of the sun over the course of a day on your graph paper. The arc in the middle represents either spring or fall. All other paths lie somewhere between the two extremes, represented by summer and winter equinox, which are the longest and shortest days of the year.

Adding Skyline Effects
You can easily add a skyline (any impediments to direct sunlight, which includes horizon, buildings, trees, towers, and so on) to your sun charts. Trees, neighbouring roofs, tall buildings, mountains — you can easily include each of these.





When the sun goes behind a mountain or a tall building, you don't get any direct sunlight at all. If the sun goes behind a tree, you may get some direct sunlight, but mostly you get shading. The horizon changes the time of dawn and dusk. If your house has a big mountain to the direct west, dusk falls a lot earlier. If you go up on your roof, the whole skyline profile should change compared to that on the ground. Each location on your house has a different skyline.



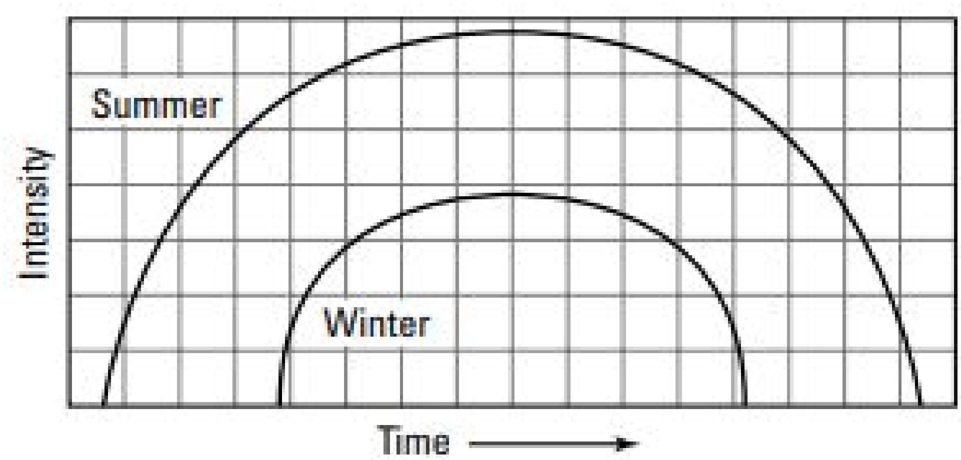
You can either buy (very expensive, and you only need it once) or rent ($25 per week) a Solar Pathfinder (**www.solarpathfinder.com**), which works as follows: You stand at the site you want to measure, aim the device south (it has a compass), level it (it has a bubble level), and then read the shade reflections on a domed indicator. A chart under the dome shows hours and months when any bit of shade will be a problem. These devices are rather complex, but they're interesting because you can see how they incorporate all the ideas in this chapter.

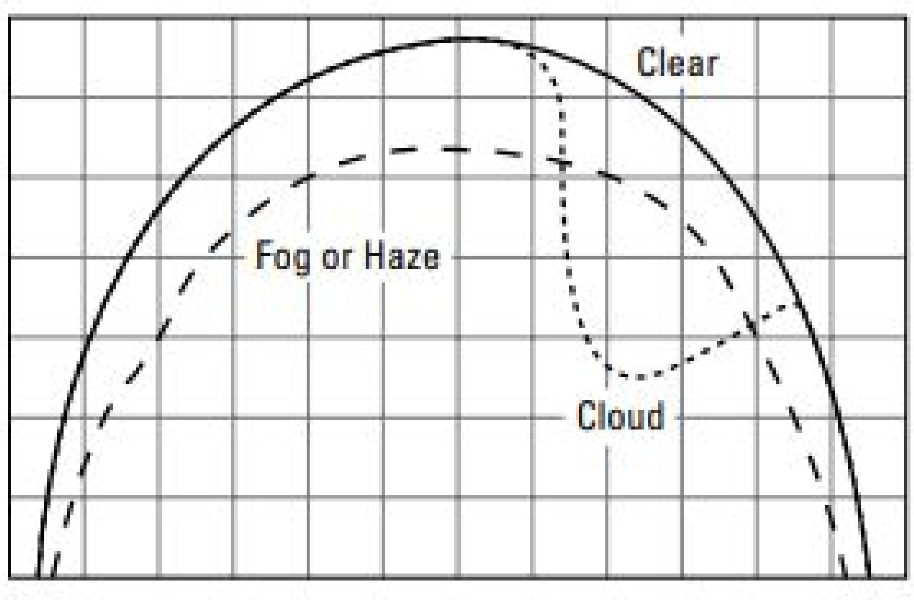
Noting Sunlight Intensity

In addition to how much direct sunlight you get, sunlight intensity is important. When the sun is lower in the sky, solar radiation must pass through more atmospheres, and it's therefore reduced by scattering and absorption. The next image, which is very similar in nature to a sun chart, shows how it works.

The sun is the most intense when it's directly overhead. And summer sunlight is much stronger than winter. You already know that — all you do now is make a plot to show what your intuition already understands.

Sunlight likewise changes along with the weather. The following image shows what happens when the weather’s cloudy or foggy. If your climate is often foggy or hazy in the morning, the charts show a very shallow curve on the left-hand side, and then when the fog burns off, the chart goes back up to normal.





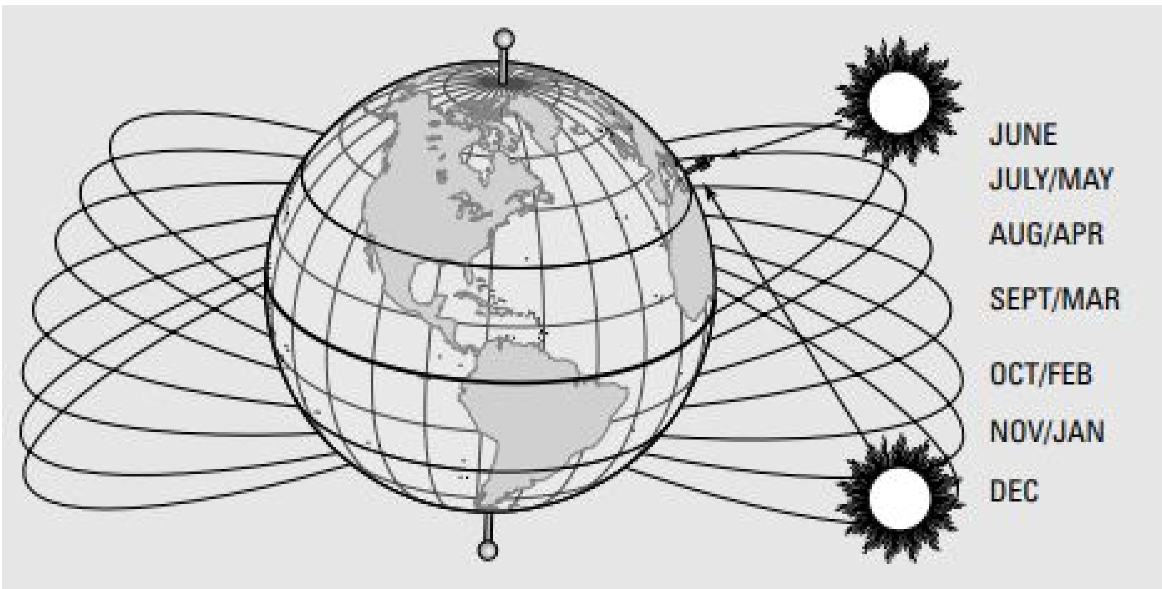
Collector Cross Sections

The final piece of the puzzle is collector cross section. Imagine a sheet of paper that you look at from different perspectives. If you set it on a table and look down, directly at it, it will look like a sheet of paper, nice and rectangular; you see the entire extent of the paper. If you look at it from the side, you will hardly see anything at all except a thin line. As you move your perspective around, the sheet grows bigger and smaller, and the rectangle becomes a parallelogram with odd angles. A fixed solar collector works on the same principle. The more surface area that is exposed to direct sunlight, the more output the collector is capable of.
How you orient your collectors with respect to the sun-chart angles is of critical importance. For example, if you mount your collectors facing north, you will obviously get more sunlight than if they're facing south, simply due to cross-section issues. If you mount your collector facing toward the west, you will get afternoon and evening system output. In this section, I explore some results of cross-section engineering that are of practical use.
Pretend you're the sun, looking down on your own house. The next image shows what a solar panel would look like from different vantages.

Earth: Going full tilt

The Earth is tilted on its axis 23.5°, and the following figure shows what happens to the position of the sun in the sky over the course of a year.
Regardless of where you live, the difference between the sun's peak angles in the sky from December to June is 46°. Regions closest to the poles experience seasons when the sun never shines, and six months later, seasons when the sun never goes below the horizon (known as white night).

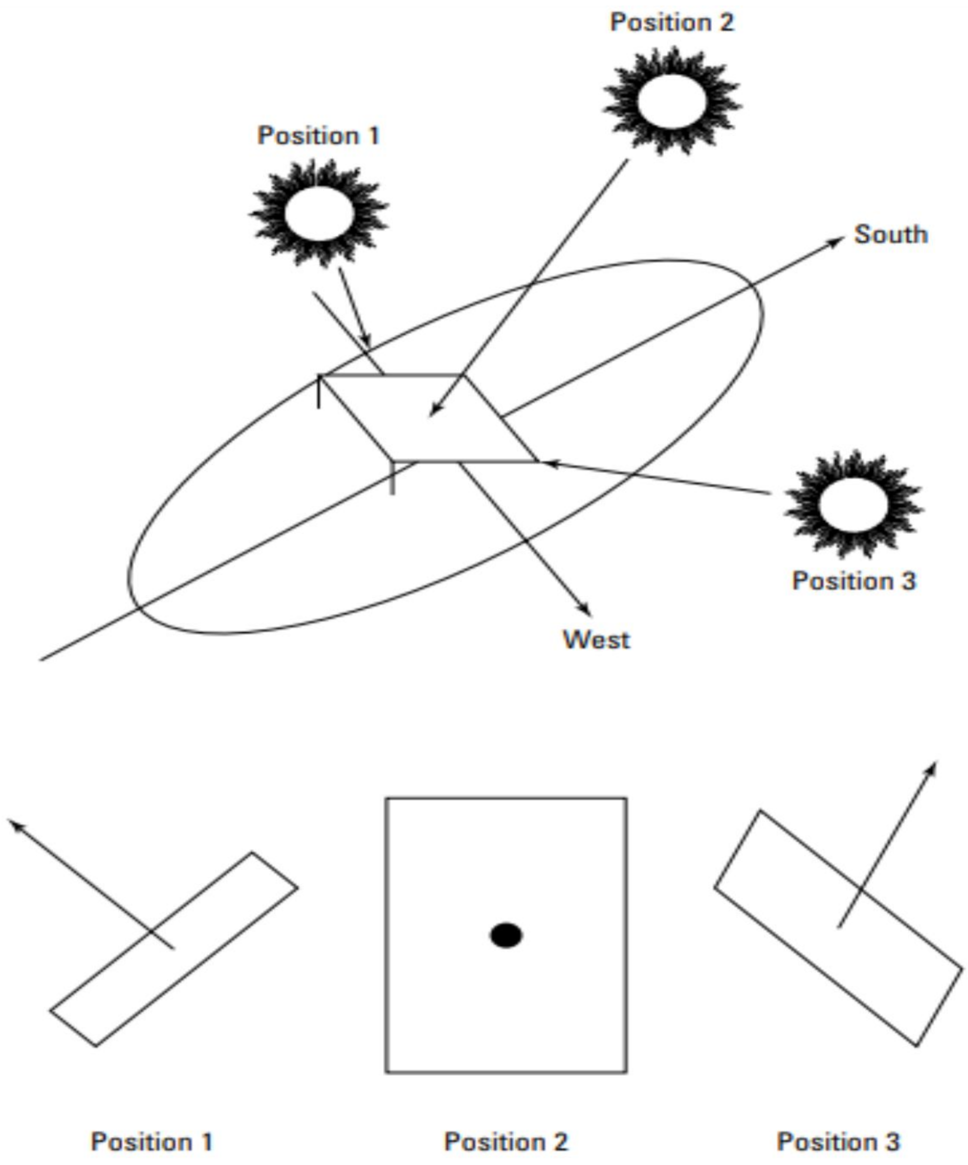
The optimum elevation angle for your solar system depends on your latitude. In general, the optimum tilt angle is equal to your latitude, for this will ensure the maximum amount of sunlight exposure over the course of a year. Even better would be to manually change the elevation of your solar collectors over the course of a year to “follow” the sun’s elevation in the sky.



To get a better understanding of the relationship of the angles, set a business card in a reclined, fixed position on a table top and then move around from side to side, and up and down (mimicking the way the sun moves over the sky during the course of a day and over the seasons), noting how much area of the card you can see from different vantage points.

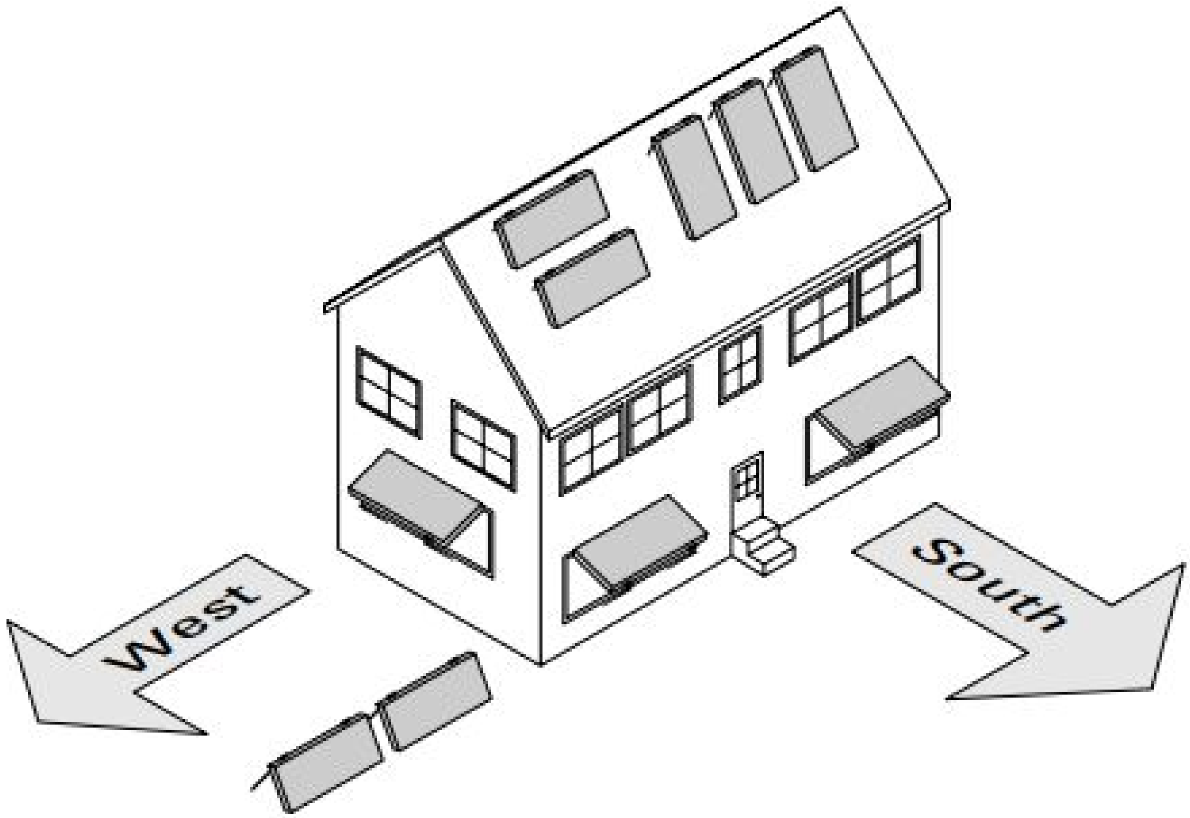
The difference in the sky between equinoxes (middle of winter and middle of summer) is 46°, which is considerable. Try it for yourself with the business card setup. If the angle is off by 25°, you still pick up 90 percent of available radiation (which means you see 90 percent of the full surface area). Off by 45°, and it goes down to 71 percent. Even at 80°, you still get 17 percent exposure.

Plus, there's a lot of scattering in the air. Even after the sun is set, some sunlight is still available.



Mounting Your Collectors Optimally

The next image shows the usual options for mounting collectors around your house. You always have a number of choices for mounting.

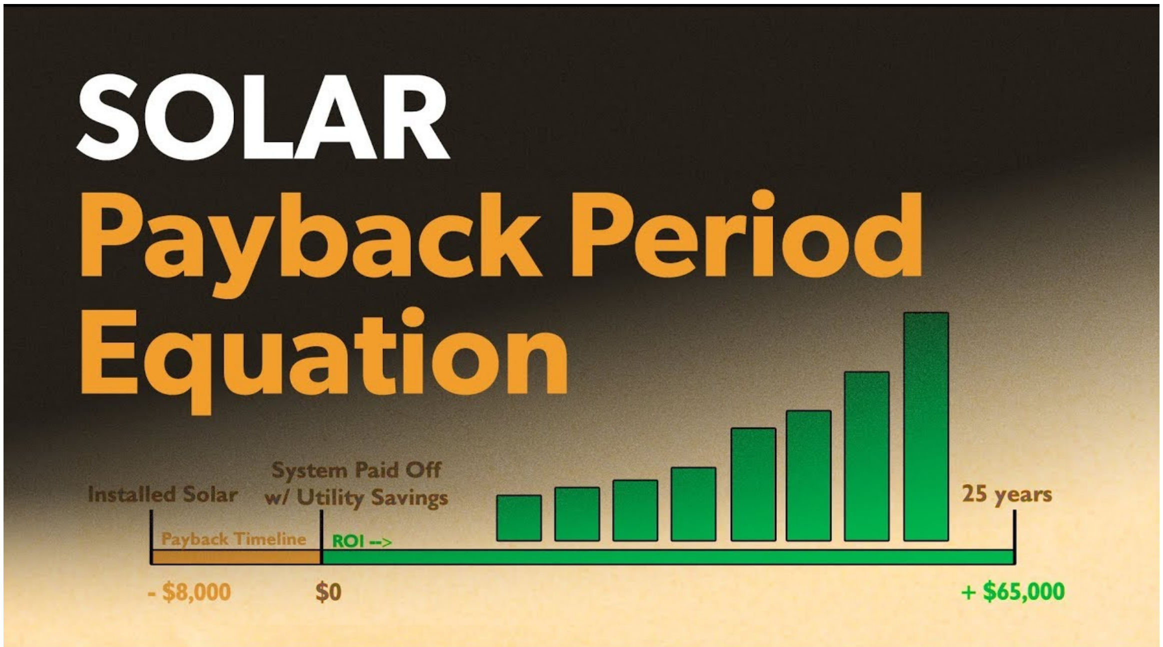


In most cases, you may not have much choice. If your roof faces southwest and its pitch is 45°, that's how you'll end up mounting, unless you want to get into some really odd-looking and expensive mounting racks.

The best orientations face due south. As for altitude, the best bet is to orient the panels to the altitude of the sun in the middle of the equinoxes, or around March 20 and September 20. This angle depends on your latitude.

If you need more power, simply install more surface area. It's cheaper and more reliable than installing moving mounts that track the sun. The idea is to maximize the cross section at all times. You clearly get more energy out of your system with moving mounts, so it's a calculation of cost versus gain; but moving trackers are expensive and have moving parts, so they fail and require maintenance. And experience has taught that moving mounts just aren't worth it for the vast majority of applications.

Chapter 4: Calculating Payback on Your Solar Investment



With every investment, you have options. You don’t need to invest in solar energy at all. You can just leave your house the way it is and instead put your riches toward life insurance, stocks and bonds, real estate, and so on. When something breaks, you don’t have to replace it with solar; you can just put the same thing back in. But as the financial pros say, you should assemble a mixture of investments to limit your risk, and solar power may be just the ticket to help balance your portfolio — and help the environment in the process.

Hedging is making investments that reduce risk. If you invest in solar, you shield your utility bill from energy price fluctuations. If you put a solar system on your roof that reduces your energy bills to zero, that’s exactly where they’ll stay, even if the cost of energy quadruples. That’s a powerful form of hedging.

In this chapter, I give you the big picture on calculating payback — the amount of time you have to wait to recoup your investment — and help you evaluate the costs, gains, and risks of solar power. I also help you analyse solar investments so you can see what kinds of returns you can expect. Finally, I take you through some real-life scenarios so you can see the numbers in action.

First Things First

While reading below about all the money solar will save you and your family, keep in mind that you'll also be actively helping the environment. Solar is a clean, healthy and renewable energy source, so you can start telling folks to thank you for helping improve air quality and thus quality of life for everyone.

Save a Lot of Money

Solar power costs about 80% less than your current utility bill. So if your electric bill now runs $150 per month, with solar power your electric bill would only cost $40.

Generating your own power at least pays you an extra $100 every month. And that's if you pay a modest $150 a month for your utilities - $400 or more is not an uncommon "normal" utility bill...

Sell Extra Energy you Generate to your Utility Companies

This is no joke. When you use solar energy your meter will actually spin backwards. Not to mention the joy you'll feel cashing a monthly check written out to you from the electric company - nothing could be finer.

Yearly Tax Deductions

Anyone using solar energy is automatically going to get federal and state tax credits. Any work made to your house involving the use of solar energy counts toward the credits and can easily cover the cost of over half of your new solar powered energy system.

Here's an example of the tax refunds that you will get for a year in which you bought a Residential Hot Water System in the state of Illinois:

Solar Unit and Installation Cost: $10,000
State of Illinois Rebate: -$3,000
Federal Solar Tax Credit: -$ 2,000
Cost of Solar Hot Water System: $5,000

Pricing Options

Every state has its own tax incentives, but most if not all states give rebates that will pay for at least part of your new solar energy system. A lot of cities will also help you out by lowering the cost of your property taxes, which is great.

But even if current government incentives cut our cost in half $5,000 is still a decent chunk of change where I come from, and sometimes it's hard to wrangle up that extra $5,000 looking in the couch cushions. Trust me, I've tried.

Luckily there are many other options that cost way less.

By itself an assembled solar panel will cost you up to $3000, but that's still a lot of money. What a lot of people are doing is just building their own solar power systems in the neighbourhood of $200. And it's not like fitting your house with a solar energy system is difficult.

You can easily make your own solar cell in under an hour using common stuff like copper, your electric stove and an electric current meter. Find it hard to believe? Solar technology isn't really very complex, which is why you'll find more and more people building their own solar units. You can find all the information you need online and be set up in no time.

Caution About Plan Accuracy

This book will teach you how to build solar energy systems. That's easy. The difference usually only occurs after it's too late: after spending a bunch of time and money you find out the plans you used were garbage. Take my word on this, please! Make sure you invest in quality blueprints or else you're going to be completely lost. There are a few really good solar energy plans that will also tell you where to get highest quality materials for the lowest price in your area.

Consider This Financial Trick

Another thing you may not have considered is financing for solar powered renovations. Even if you have a huge wad of cash in your eager little hand you should still consider getting a home equity loan or refinancing your home to pay for the solar improvements, and here's why: the government offers a mortgage interest tax deduction which means you get tax deductions for all home improvements that are included into your mortgage payment.

Even better, a lot of federal mortgage places are required to offer financing for people looking to improving their home with solar power systems. Even better than that? Most of the loans come with low interest rates, usually way below the current mortgage interest rates for everyone else not investing in solar energy.

Definitely talk to a lender and have them go over all the financing options. If you play your cards right you walk away with tax credits, rebates and property tax discounts, as well as a new extra income source when you start selling power to your utility company... you get all of this on top of the hundreds of dollars you'll save on your utility bill every month from now on... just for installing a solar energy system in your own home.

Bottom Line

Is solar energy practical to use? It's definitely at least worth looking into. More likely than not ditching the utility company is a decision you'll wish you had made a long time ago.

Now that most utility companies in each county are becoming monopolies without competition, and with all the big utilities pushing harder and harder every year to be allowed to set their own prices, no matter how outrageous they want them to be, I really don't know how much longer everyone can afford to be price gouged by our utility companies.

Can you really afford to not use solar energy in your homes, cabins and vehicles?

Part III: Solar Power System Design Methods

1. **The Quick Method:** sizing your system by a "rule of thumb"
2. **The Lazy Method:** Choose one of my precomputed systems
3. **Traditional Method:** Do some math and manually calculate your system size (recommended)

Smart Method: Check out the "fast method" and "lazy method" to understand everything, and then use the "traditional method" to calculate your personal system. Note: If you use the "Fast Method" or the "Lazy Method", you will still need to manually calculate the appropriate wire gauge and fuse sizes for your system.

Chapter 5: Quick Method

Fill up the roof with many solar panels as possible:
Vehicles have limited roof space for solar panels. Build your system around this limiting factor

Get a solar charge controller that can control the power generated by the solar panels:

-If you have limited roof space (100-250 solar watts) and don't plan to add more panels in the future, use a 20 amp MPPT solar charge controller.
-For most mobile systems (300-450 watt solar), use a 40 amp MPPT solar charge controller

-For large systems (450-700 solar watts), use a 60 amp MPPT solar charge controller
- For very large systems (700-950 watts of solar), use an 80 amp MPPT controller (80 amp controllers cost a lot, so it's economical to go for 2x40 amp controllers)

Determine the battery bank size:

- For every 100 watts of solar panels on your roof, you should have about 75-100 amp hours of sealed lead acid batteries. If you are using a lithium battery, buy the largest size that is affordable.

Find the "safe charge rate" for the battery pack in amperes and make sure it is greater than the total amperage produced by the solar panel array.

You can manually calculate this, or you can read the battery manual. Most solar battery specific manuals and data sheets will show you how many solar panels you can safely connect to one battery. If it is not on the manual, you can phone the manufacturer and ask them. Be sure to check this metric before purchasing your battery bank. Each battery has a different charge rate. If you plan to build a large system and need a high charge rate, put several smaller batteries together in parallel. This will increase the charging rate compared to buying a larger battery.

Buy the biggest inverter you can afford:

-If you only plan to power electronics like laptop and fan, buy a 750 watt inverter
-Most people do fine with a 1500 watt inverter
-If you want to use most household appliances, buy a 2000 watt inverter

-If you plan to use multiple large appliances then buy a 3000+ watt inverter

Chapter 6: Lazy Method

Want to design your own system without the hassle? You have 6 pre-computed options to select from:

- Minimalist (minivan or car)
- The Classic 400 watts (Large Van or RV)
- Off Grid King (Large RV or Bus)
- Ultra lightweight (Backpacker or Cyclist)
- Low Budget
- Dystopian Future

Minimalist

This configuration works well if:

- Plan for installation in a minivan/car
- Want easy setup
- Plan to use a small laptop, USB charger, fan, LED lights and other small accessories

Recommended components:

- 12 volt, 100-150 amp hour deep cycle battery
- 200 watts of solar panels and a 20 amp MPPT charge controller
- 750 watt inverter

The Classic 400 watts

This configuration works well if:

- Plan to install it in a full size van or RV
- Plan to use a TV, refrigerator, large laptop and more, every day

Recommended components:

- 400 watts of solar panels and a 40 amp MPPT charge controller
- 12 volt, 300 amp hour battery bank (note that this battery bank will weigh about 190 pounds or a single 100-200 amp hour lithium battery (this battery will weigh 30-60 pounds)
- 1500 watt inverter

The Classic 400W is my favorite size. Most people will love this setup!

Off-Grid King
This configuration works perfectly when:

- Plan to use an large RV or bus
- Want to power large appliances such as power tools and microwave ovens for a long time
- Weight and aerodynamics are not an important factor for your vehicle

Recommended components:

- 800 watt solar panel and one 80 amp MPPT solar charge controller (or 2x40 amp MPPT solar charge controller)
- 12V 350-500Ah lead acid battery or 300Ah Lithium battery (choose the largest battery you can afford and can safely carry in your car. These batteries are heavy and expensive!)
- 2000 watt inverter or larger

Ultra Lightweight
This configuration works perfectly when:

- You are backpacking and must travel by cars, trains, bikes and planes
- You live in a small vehicle and cannot carry a heavy battery pack
- You cannot permanently install solar panels

You need to charge your phone, laptop, camera and other travel gear

Recommended components:

Foldable solar panel that can generate 20-45 watts with USB cable socket

USB battery packs (2-4) with fast charging capability (4 amp input)

Quick Charge USB AC Adapter (to charge the battery when there is no sunlight)

USB rechargeable laptop/camera/phone. If you have a powerful laptop, use an external portable battery charger

Provide USB powered lights, fans, hand warmers, etc. online

Note: Use a foldable USB solar panel or a USB AC adapter to charge the USB battery pack. The entire setup fits easily into a backpack and can be used in a vehicle or in a backpack.

Low Budget

This configuration works perfectly when:

They are broke and now want a solar system!

Willingness to sacrifice efficiency and longevity

Recommended components:

Buy as many solar panels as possible. A 100-watt solar panel made in China can be purchased for $100.

Purchase a PWM (pulse width modulation) solar charge controller. A 30-amp PWM controller can be purchased online for $15.

Purchase refurbished forklift batteries. So I bought 2 225Ah, 6V fork batteries for $80. Search the internet for "refurbished batteries in San Jose" or wherever you live.

Buy auto jumper cables from the hardware store to connect them all. Make sure the jumper cable is 8 gauges for safety.

Buy cheap inverters online. An inverter of about 750 watts can be purchased for $40!

Note: this is surprisingly good. It probably won't last more than 2 years, but it will work.

Dystopian Future

This configuration works perfectly when:

You are fighting for your life and need electricity to increase your chances of survival

Recommended components:

Locate all 12 volt batteries (avoid those with visible damage) and connect them in parallel. It's usually not a smart thing to do (connect different types/ages of batteries), but if you're desperate, you'll do it. Store these batteries in an isolated place so they won't be harmed if they explode. Try to find a dry spot, such as a raised concrete slab with some kind of roof.

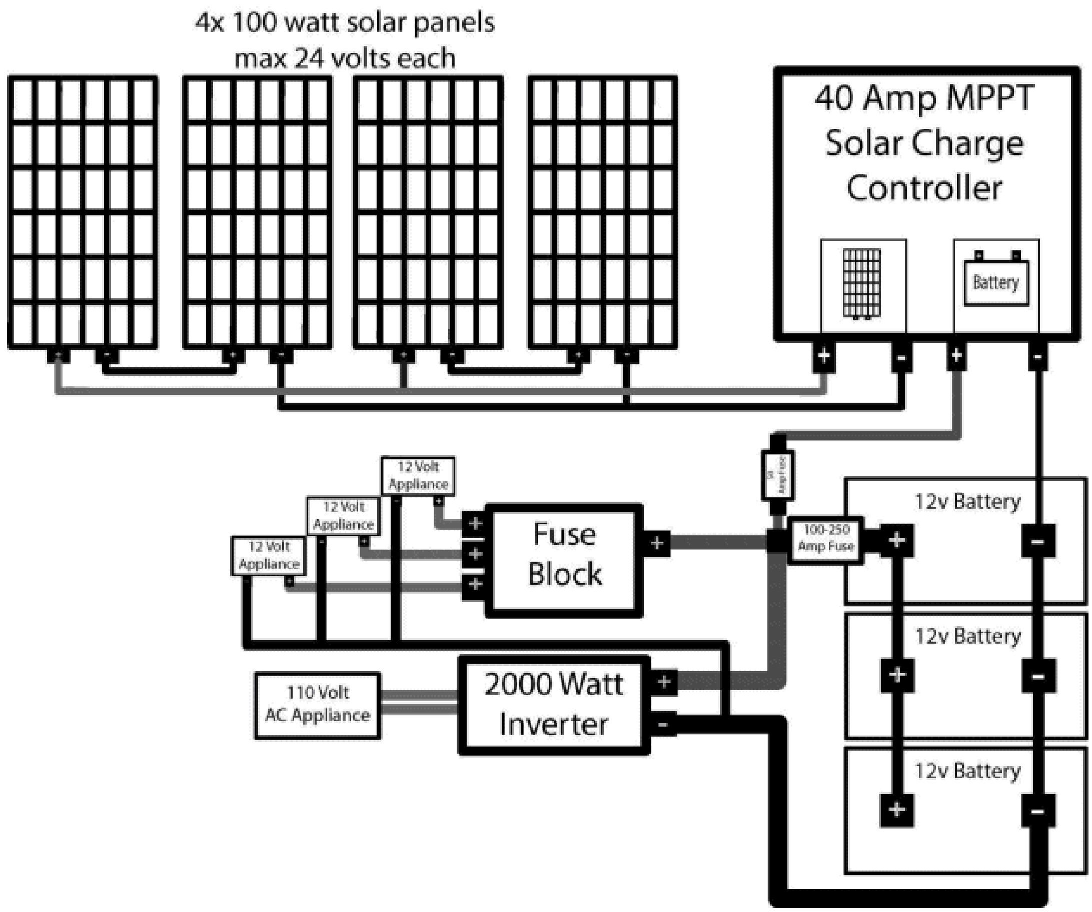
Find any solar panels. You can get them from phone booths, parking meters, and roadside construction lights.

Find a 12 volt regulator to use as a solar charge controller. Automotive alternator voltage regulators aren't ideal, but they work. A DC-DC converter can do the job. You can make your own with a microcontroller and some transistors, but it's a bit complicated. If you are able to save the solar panel from the phone case, use the included regulator.

Use alternators to build 12-volt hydroelectric dams, wind turbines, etc.

Connect the battery with any type of conductor you can find. If you can find metal foil, you can cut and seal it to the battery terminals.

This is all guesswork; I hope none of you need this setup! This is a good thought exercise. Before we dive into it, take a look at the schematic below a few times. This is the plan for a "classic 400 watt" system. This is the most common size I see in RVs and people love it!



Part IV: Traditional Method

1. Calculate the daily load (how much electricity your device will consume per 1 day)
2. Use the estimated daily load to calculate the battery pack size
3. Use the battery pack size to calculate how many solar panels you need
4. Calculate the size of the solar charge controller using the size of the solar panel array

Chapter 7: Calculating the Load

My Example Loads calculation in off grid solar 12volts system

4 ELECTRIC FAN	65 W X 4	260W X 6hrs	1560W
3 LIGHT BULB	15 W X 3	45W X 4hrs	180W
1 LED TV	40 W X 1	40W X 6hrs	240W
1 FRIDGE	75 W X 1	75W X 8hrs	600W
1 FLORESCENT	40 W X 1	40W x 4hrs	160W
1 WASHING	130 W X 1	130W x 1hr	130W
1 DRYER	120 W X 1	120W x 1hr	120W
		710W 30 hrs	2990W

To determine how much power you need, you need to work out the total watt-hour requirements for all the appliances you plan to use. Example:

1. If you use a 100 watt bulb for 1 hour, it has used 100 watt hours.

2. If you have a 30 watt bulb and it runs for 3 hours, it will use 90 watt hours.
3. If you run a 1000 watt microwave for 30 minutes, it will consume 500 watt hours.

Most appliances will show you the number of watts used. If you're not sure, look for the label on the back or bottom of the device, usually where the power cord connects to the device. It will show you voltage, amperage and wattage. If the device only shows volts and amps, you can determine the watt by multiplying volts and amps:

Amps x Volts = Watts

The phone charger outputs 5 volts at 2 amps, so it uses 10 watts.

The LED strip uses 12 volts at 5 amps, so it uses 60 watts.

An AC microwave uses 110 volts at 10 amps, so it uses 1100 watts.

Find the watt of the devices you plan to use every day. Calculate the amount of time you plan to use these appliances and calculate their watt-hour ratings:

Watt x Hours of Use = Watt-Hour Rating

60 watt LED strip for 4 hours of daily use = 240 watt hours

70 W refrigerator on for 24 hours but running for 4 hours (compressor on is intermittent) = 280 Wh

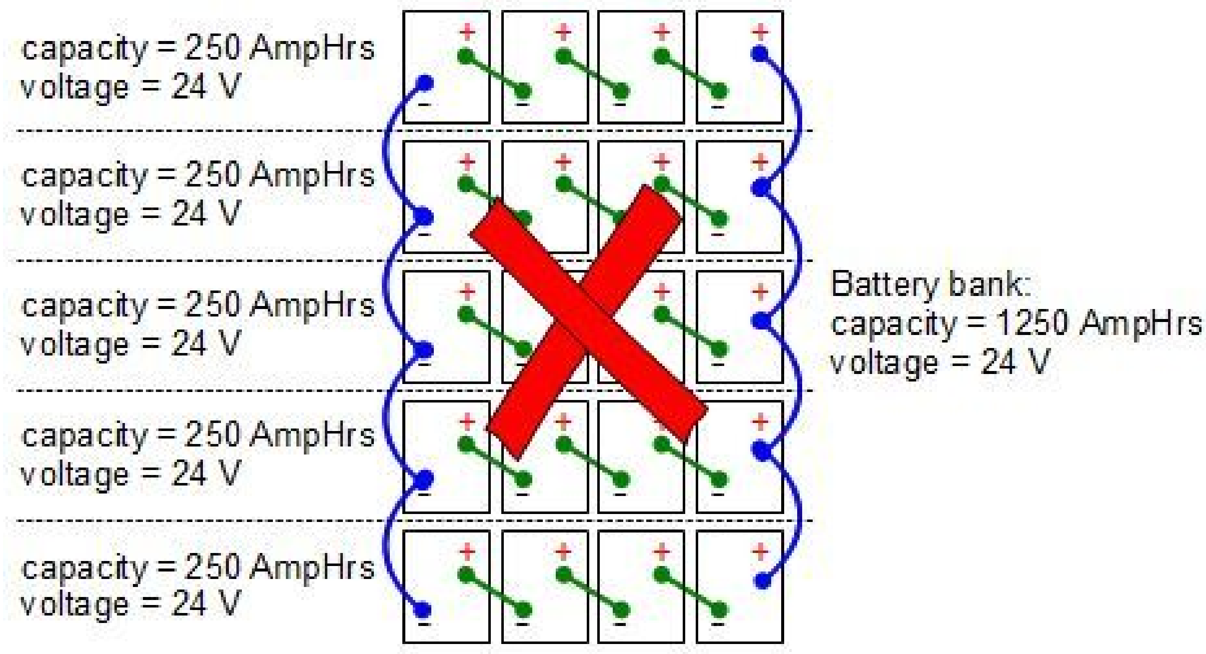
Using 60W laptop for 6 hours = 360Wh

1000W microwave for 15 minutes = 250Wh

Add together all the watt-hour ratings for your appliances. For this example, we'll add together the watt-hour ratings from the list above:

Total device load for one day: 1130 Wh

Chapter 8: Calculating Battery Bank Size



Now that we know how much power we need each day, we can calculate the size of the battery bank. First, add up our daily electricity requirement of 1130 watt-hours to 1200 watt-hours (to make the calculation easier).

Now we need to estimate how much reserve power we want to have. Winter, rainy days and shaded parking spaces can reduce the electricity produced by solar panels. The battery pack must be large enough to compensate for these times.

Ideally, you want the largest battery pack possible. But since this is a mobile system and weight is a factor, I recommend 2 days of power as a backup. If you need to use the battery pack for the cabin or other fixed structure, you will usually need 2-5 days of backup power.

Daily device load 1200 Wh x 2 (backup days) = 2400 Wh battery bank required

But here lies the problem! Lead acid batteries (the most common type of portable solar cell) can be safely discharged to only 50% capacity without damage. The lithium battery that will be mentioned later does not have this problem.

So, if you need a battery that can provide 2400 watt-hours of power, you will need:

4800 Wh lead acid battery
or 2400 Wh lithium battery

We will discuss the differences between these two batteries later. Now, we just need to calculate the size of the battery bank.

Chapter 9: Calculating Solar Array Size

Since most vehicles have limited roof space, having as many solar panels on the roof as possible is usually the best option.

But keep in mind that if you have too many solar panels, you may accidentally charge the battery pack too quickly, which will reduce the battery pack's lifespan. So if you're filling your roof with solar panels, make sure you build a battery pack big enough to handle it. This mostly applies to lead acid batteries (which have a lower charge rate compared to most lithium batteries).

Lead-acid batteries should also be fully charged after each use. They also like to be refill once a day. To keep your batteries healthy, you'll need a set of solar panels large enough to charge your lead-acid battery pack in one day (within six hours of full sunlight). Lithium batteries do not need to be charged every day after use, but only need to be fully charged every two months.

Solar array estimation (no calculation required):

For a single 1200 watt hour lead acid battery (i.e. a 100 amp hour, 12 volt sealed AGM battery with a maximum charge rate of 35 amps at 12 volts) use:

At least 200 watt solar panel

Solar panel up to 400 watts

For a single 1200Wh Lithium battery (i.e. 100Ah, 12V LiFePO4 battery with a maximum charge rate of 100A at 12V) use:

There is no minimum solar array size. Just make sure to fully charge every two months

Solar panel up to 1200 watts

The above suggestions are for reference only! Each battery pack will have a slightly different charge rate. Be sure to check the battery manual to see its recommendations. Most solar application batteries will recommend you the minimum and maximum size of the solar array.

You may have found that lithium batteries are suitable for mobile solar arrays of almost any size. This is usually true, but be sure to check the manual. The charging rate of a lithium battery depends on how the battery is designed. Most people can afford high tolls, but not always.

This is not the case with deep cycle lead acid batteries. They usually have flat rates.

But lead-acid battery charge rates may vary depending on the number of batteries you use. If you connect multiple small lead-acid batteries in parallel, the charge rate will usually be much higher than with a single large lead-acid battery (unless the large batteries are designed to handle fast charging. But generally, paralleling smaller batteries will be faster).

The above estimate will give you a rough idea of the size of your solar panel. Ultimately, the individual battery charge rate will determine how many solar panels you can install. If you're lazy or smart, call the manufacturer of the battery and ask them recommended solar panels.

How to calculate the maximum solar array size for batteries

If your batteries manual doesn't list the number of solar panels you can safely use, or if you want to do it manually, we can figure it out. You will need to read the batteries manual (or the data sheet you can find online) and find the "Maximum Safe Charge Rate" in amps. As long as the maximum power produced by the solar panel is less than the maximum charge rate of the battery pack, we can continue to use it.

Maximum solar power < Maximum charge rate of the battery pack

To find the maximum power produced by the solar array, we divide the total power rating of the solar panel by the battery pack voltage. Example:

> If we have 400 watt solar panels in a system, divide this number by the voltage of the battery it plans to charge, usually 12 volts.
>
> 400 watts divided by 12 volts = 33.3 amps

33.3 amps is the maximum current our 400 watt solar system can produce at 12 volts. A typical 100 amp hour, 12 volt lead acid should usually be able to handle a load rating of 35 amps.

35 amps is greater than 33.3 amps, so we're on the right track!

If you plan to connect several 12 volt lead acid batteries in parallel, you can add the maximum charge rates together. Say you have 3 batteries that can each handle 35 amps. If you connect them in parallel, they can handle a maximum charging speed of 105 amps!

How to calculate the minimum solar array size for batteries

For this calculation, we need to know how much solar energy is needed to charge the battery pack in 6 hours of full sunlight. This will keep the battery pack fully charged every day.
Divide the available watt-hours of the battery pack by 6:
Battery pack size (watt hours) / 6 = minimum solar array size

> The total usable capacity of your battery pack is 1200 Wh. Divide this number by 6 to get 200. Therefore, for this battery pack, the solar panel size must be at least 200 watts.
>
> The total usable capacity of your battery pack is 2000 Wh. dividing this number by 6 gives 333. So for this battery pack, the solar panel size must be at least 333 watts.

If you are using lead-acid batteries, it is important to determine the minimum size of the solar array because lead-acid batteries require a full daily charge cycle to extend battery life. If your solar array cannot charge the battery pack within 6 hours, it may shorten the life of the lead acid battery pack. If you have a lithium battery, this factor does not matter.

Additional tips for solar array sizing

We have to consider the actual production of the solar panel. Many solar panels rated at 100 watts typically produce about 70 watts in full sunlight. We still need to calculate a 100 watt solar panel system so that the system can handle the electricity that is ever produced.

If you have a budget, you can start with the smallest solar array size and work your way up. If I were to buy a 600 watt solar panel and still couldn't afford it, I would install a 400 watt solar panel first. You may find that a 400 watt solar array is more than enough for your needs! Be sure to buy a larger solar charge controller than you need so you can always add more solar panels or batteries if needed.

Solar production depends a lot on where you live. If you live near the equator, you obviously have more power. The angle of the panels, time of day and weather conditions will also determine how much electricity your solar panels will generate.

If you live far from the equator, your solar panels may never produce the power they are rated to produce, so you may have to try to "cover" your system. Overcharging allows you to connect 2 to 3 times the number of solar panels in the system without damaging the charge controller. This requires the use of a solar charge controller with this feature, or a fuse between the solar array and the solar charge controller.

Example: You live in Alaska and your 100 watt solar panel can only produce 40 watts in full sunlight. So instead of a 400 watt array of solar panels, you decide to use an 800 watt array and a solar charge controller with panel protection. This will allow you to get more energy from the available sunlight.

If you can't find a solar charge controller with on-panel protection, use a fuse to protect the charge controller. If you have a 40 amp MPPT controller and want to cover the panel with an 800 watt solar panel, you will need to calculate the fuse size for the voltage your panel will produce. This is for advanced users only! If the fuse is not the right size, you will damage the solar charge controller.

Part V: Calculating Solar Charge Controller Size

There are 2 variables that will determine the size of the controller:
1. The size of the solar array will determine the "amplifier rating" of the solar charge controller. Solar charge controllers are rated in "amps", which is how much current (in amperes) the controller can draw at the battery pack voltage. The more solar panels in the system, the bigger the controller needs to be. If you buy a 40 amp charge controller, it can provide a maximum load of 40 amps at 12 volts. The ampere rating does not refer to the ampere rating of the solar panel.
To calculate the amp rating of the controller, divide the total wattage of the solar array by the battery pack voltage. This will give you the minimum amp rating for the controller.
Solar Panel Array Power / Battery Pack Voltage = Minimum Ampere Rating of Solar Controller
Example: your solar array is 400 watts and your battery pack voltage is 12 volts. 400 (solar watts on roof) / 12 (battery pack voltage) = 33.3 amps (minimum solar charge controller amp rating)
Controllers are usually sold in amp rating increments of 10 and 20. If you go online, it's easy to find controllers 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 go with a 40 amp controller. Buying a larger controller than necessary is usually a good idea in case you want to add more solar panels in the future.

2. Maximum controller input voltage rating. If your array of solar panels produces more voltage than the controller can handle, the controller will be damaged. In general, if your system is not very large, or if you are installing panels in series and generating hundreds of volts, you don't need to worry about this number. For most mobile systems, the maximum voltage value will not be exceeded (you should still check your solar charge controller's manual to be sure).
A typical controller input voltage rating is 70-150 volts (but be sure to check your manual).

To summarize:

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

(80 amp controllers cost a lot so it's usually cheaper to buy two 40 amp controllers)

Chapter 10: Efficiency Considerations

The math above is great for estimating the size of battery packs and solar arrays, but it won't tell you the true output of your system. Without going into too much detail, consider:

- On average, you will have 2%-5% wire loss (they dissipate a small amount of heat)

Solar charge controller generates heat and generates 2%-30% loss.

A battery will lose 1%-15% of its charge (unless the battery is damaged or aged, it will be more)

When using inverter, there will be 10%-15% loss (sometimes more)

The devices are not completely efficient; they use various regulators and resistors that release heat. Another loss of 1-5% is expected.

If it is too hot, the efficiency of the solar panel will decrease. This can vary depending on the panel and how it's mounted and the materials used to make it, but it's another efficiency factor to keep in mind.

A bad connector can block the entire solar system. Losses can be huge! All connectors connecting the wires to the battery/charge controller must be properly made. To check them, feel them with your hand to see if they are getting hot. All connectors and wires should be cool to the touch (unless they carry a lot of power, such as in full sunlight or when the inverter is running).

So what I'm trying 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 poor connections, you will be completely out of power. I wouldn't be surprised to see a 100 watt panel producing only 20 watts in a poorly designed system.

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

When designing a system, do it right from the start and save months of frustration and hassle. A properly designed system is also safer, with little chance of an electrical fire.
Once the system is installed, you don't have to think about it! You've had free electricity for years, which is great. I'm currently working on this solar power book and it's awesome!

Chapter 11: Other Factors to Consider

Adding solar panels to any vehicle causes a change in the aerodynamic curve, which changes the efficiency (miles per gallon) of the vehicle. If you plan to travel a lot, you'll need a slightly different system than someone who stays still. Also keep in mind that system components can be heavy, especially the battery packs. The heavier your vehicle is by carrying a large battery, the harder it is for your vehicle to stop and the harder it is for the engine and transmission to work to move the vehicle.

After building your system, you may need more power. With proper planning, this is easy to do. You just add more solar panels and/or batteries. Try to design the system in a way that is easily scalable, such as buying a larger solar charge controller than you need, or using larger gauge wire. This will ensure that your system is scalable to some extent, or to its full potential.

Part VI: How to Select Solar Power System Components

Now is the time to order everything you need online. After calculating your system, you may have created a shopping list of small components and their ideal sizes:

3600 Wh battery pack
400 watt solar panel
40 Amp Solar Charge Controller
2000 watt inverter

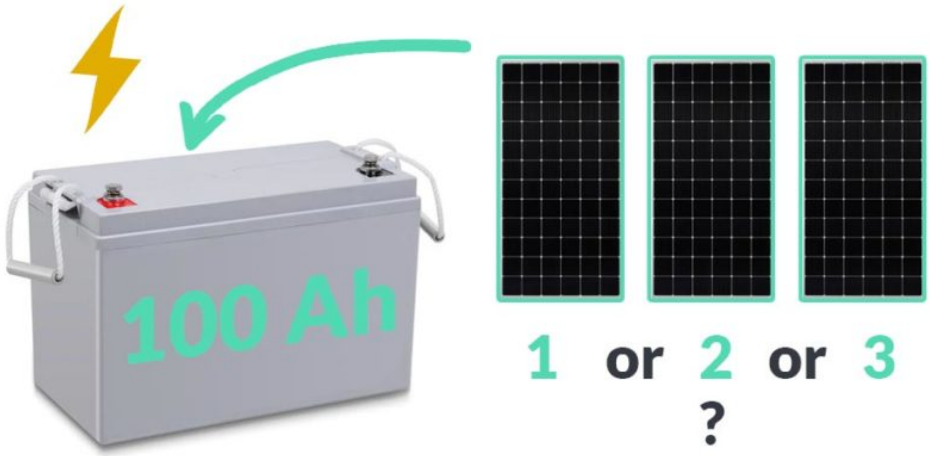
The components above require some computation when selected, but we must now add more to the list:

Wire
Fuse Box and Fuses
Battery Monitor
Tools
Other power sources

We will now discuss key factors to consider when selecting these components. Each component takes some time and research to select correctly for use with your system.

After selecting the battery pack, solar panel, charge controller and inverter, you can calculate the type and thickness of wires and the type and size of fuses to use with your system.

Chapter 12: Selecting a Battery



The world of battery chemistry is vast, and several books could be written on the subject alone. To avoid confusion, we will not discuss much on this topic. What you need to know is that most batteries are not suitable for solar power. Solar cells require:

- Long service life (7-25 years)
- Large estimate of deep discharge (how much charge is available in the battery)
- High cycle life (how many times you can discharge and charge the battery)

So what we need is a deep cycle battery. These are made with high capacity, high durability and long life. There are many different types of deep cycle batteries, but for most solar applications you should use an AGM sealed deep cycle battery or a lithium battery (lithium iron phosphate chemistry). These are the safest, most efficient and highest capacity batteries on the market designed for solar applications.

Many people mistakenly use car or marine batteries as solar cells. These cells were not designed for solar power and failed miserably. These batteries have a very low depth of discharge. This means that you can only use these batteries at 95% capacity and not lower. They are designed to generate large amounts of electricity in a short period of time, enabling them to power internal combustion engines. They are not designed to power loads for long periods of time.

To give you an idea:

- A 100Ah car battery has only 5Ah usable capacity (total battery capacity is 5Ah)
- 100Ah AGM deep cycle lead acid battery with 50Ah usable capacity (total battery capacity 50Ah)
- 100Ah lithium deep cycle battery has 100Ah usable capacity (total battery capacity 100Ah)

Lithium batteries have the best depth of discharge. They can be safely discharged to 0% (if the battery management system allows). If you want to increase the life of the lithium battery, discharge it to 20%.

So you have two options:

- AGM sealed deep cycle battery
- Lithium batteries (especially lithium iron phosphate)

The king of solar cells is lithium, without a doubt. But you may not be able to afford it. AGM batteries work well and are cheap.

Comparison of Lead Acid and Lithium Batteries

Keep in mind that the usable capacity of a 200Ah AGM sealed battery is comparable to a 100Ah lithium battery.

AGM sealed battery price rating and weight:

- A 100 amp hour battery costs about $170 and weighs 60 pounds
- About $290 for a 155 amp hour battery and weighs 90 pounds

A 200 amp hour battery costs about $400 and weighs 120 pounds

Estimated price and weight of lithium battery:

A 100 amp hour battery costs about $900 and weighs 35 pounds

A 200 amp hour battery costs about $1,800 and weighs 62 pounds

So initially, lithium capacity seems to cost a lot of money. But lithium is surprisingly cheap because it is rated for a longer life cycle than sealed AGM batteries:

If you discharge the sealed AGM battery to 50%, you will get about 500 charge cycles

If the AGM battery is discharged to 80%, you will get about 800 charge cycles

If you discharge the lithium battery to 0%, you will get about 5000 charge cycles

If the lithium battery is discharged to 30%, you will get about 8000 charge cycles

The average lifespan of lithium batteries is 4-10 times longer! And they have more usable capacity.

Other advantages of lithium batteries:

Weight decrease (usually 130-200%)

Reduction in size (usually about 50-70% smaller)

Higher discharge and charge rates and lower resistance. This means that all devices will run at higher performance (but it depends on the battery! Cheap lithium batteries have limited discharge and charge speeds)

Almost maintenance free

Better for the environment

Does not emit hazardous fumes (sealed lead-acid batteries technically emit fumes, but only if used improperly. All lead-acid batteries have the potential to produce gaseous fumes)

If you don't plan on using a lot of power and don't travel a lot, sealed AGM batteries will work and are the most common batteries used for portable solar power systems. If you plan to use the battery for many years and you need a product that will provide the best performance, then you need a lithium battery.

Sizing up a battery

When buying a battery, you should calculate its watt-hour rating to see if it will provide enough space for your needs. Unfortunately, batteries usually don't advertise their watt-hour rating, but they do advertise their amp-hour rating and voltage.

To determine the watt-hour capacity of a battery from its capacity and voltage rating in amperes, multiply them together:

- 12V, 250Ah battery stores 3000Wh (12V x 250Ah = 3000Wh)
- 12V, 100Ah battery stores 1200Wh (12V x 100Ah = 1200Wh)
- 6V, 225Ah battery stores 1350Wh (6V x 225Ah = 1350Wh)
- 24V, 100Ah battery stores 2400Wh (24V x 100Ah = 2400Wh)

Example of battery selection

Our solar example will require 2400 watt-hours of usable power. We need to find deep cycle batteries that can meet this requirement.

The total lead acid battery size required to meet the 2400 Wh requirement:

- A 12V, 400Ah lead acid battery pack will provide 2400Wh of usable power (but a total capacity of 6000Wh), perfect for our 2400Wh power needs

But guess what! A 400 amp hour lead acid battery weighs about 250 pounds! This is good if you have a large vehicle. But if you have a small vehicle, you may need to downsize the battery pack.

The total lithium battery size required to meet the 2400 Wh requirement:

200Ah lithium battery will provide 2400Wh usable power

Unlike lead acid battery packs, lithium battery packs will be smaller and provide more power. A 200 amp hour lithium battery weighs about 60-70 lbs, which is much lighter compared to a 270 lb lead acid battery.

Chapter 13: Selecting Solar Panels

This is the easiest part of the whole system! Here are the key factors:

Smaller solar panels are inherently stronger, so they are recommended if you are installing them on the roof of a moving vehicle. A 100 watt solar panel is the best size. They are sturdy, inexpensive, easy to find and easy to install. (Large solar panels are still safe to use, but I don't recommend using them. Use large solar panels instead of fixed solar panel arrays.)

The two types of solar panels that can be used for off-grid applications are monocrystalline and polycrystalline. monocrystalline is technically better due to higher efficiency, longer lifetime and the ability to handle higher temperatures. Both types of panels will work fine, so buy whatever works. If you have severely limited roof space, or plan to use solar panels for more than 20 years, buy monocrystalline panels.

The higher the efficiency of the solar panel, the better.

Purchase a solar panel with the MC-4 connector installed.

The best metrics I use to choose solar panels are customer reviews. If the panel is of low quality, you'll find it right away in the comments section. So to make your life easier, find the highest rated 100 watt solar panel and you are on your way! Buy solar panels in multiples of 2. This will allow you to connect them in pairs, they are connected in series. If you buy 100 watt solar panels, please buy 2/4/6/8 panels. This will make the process of connecting them together easier.

Flexible solar panels

If you care about vehicle aerodynamics and fuel consumption or total system weight, flexible solar panels will be better than glass solar panels:

A typical 100-watt glass panel weighs 16 pounds.

A typical 100 watt flexible solar panel will weigh about 3-6 pounds!

They are lightweight and aerodynamic, but have some drawbacks:

They easily get hot. This means a shorter lifetime and lower efficiency compared to glass panels. Some may fail in a few months! Be sure to buy one with a warranty.

They can bend, but not much. Usually they cannot be bent more than 30 degrees unless they are permanently damaged. But it depends on the panel.

If you buy an inexpensive flexible solar panel, it can overheat and cause a fire. There are quite a few online reviews mentioning this.

Also, flexible solar panels cost more:

A typical 100 watt glass panel will cost around $100-130

A typical 100-watt flexible solar panel will cost about $170

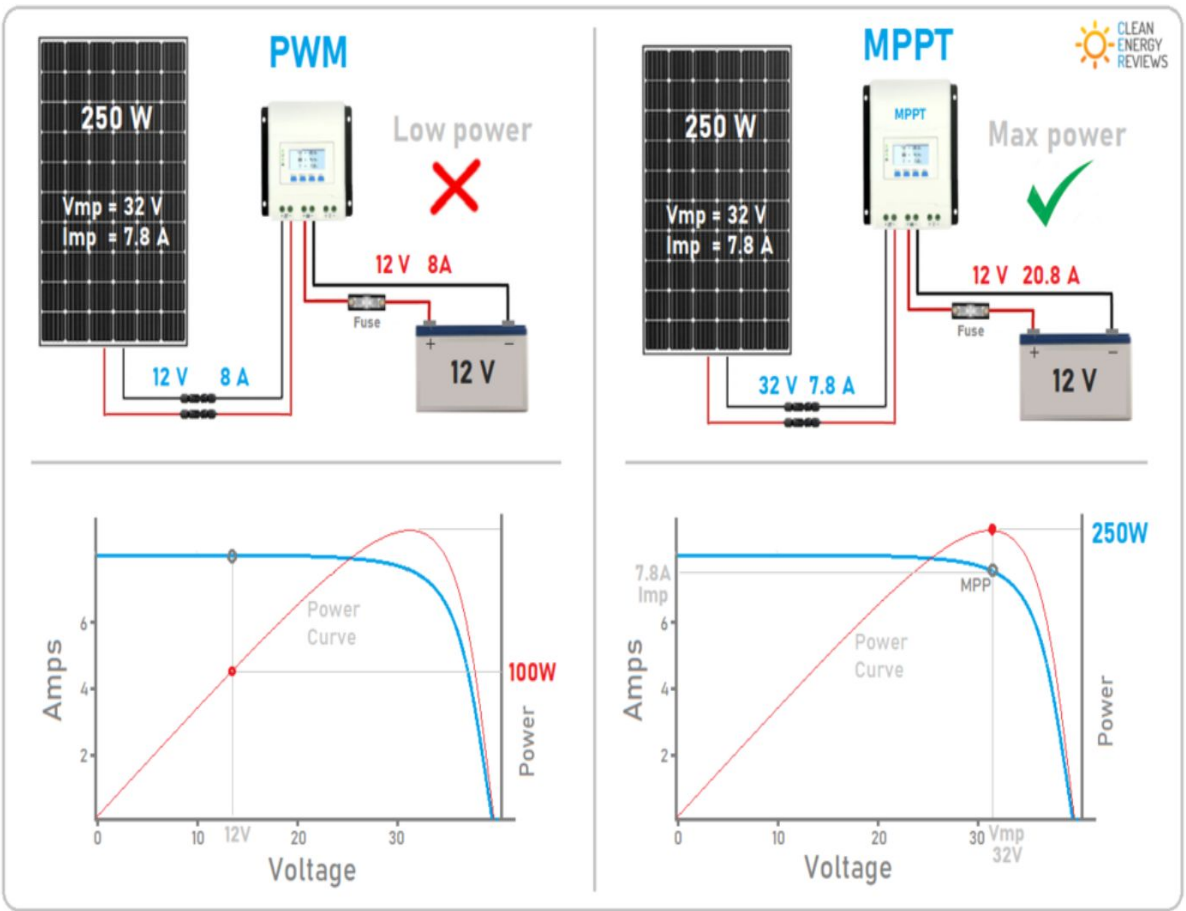
If your roof is curved or glass solar panels cannot be installed, you may prefer a flexible panel array. If you have a curved roof but want to install glass solar panels, you might consider adding a roof rack.

Most flexible solar panel manufacturers will tell you that you can flush mount your panels. This is never true. You need some kind of airflow under the panel. It's easy to do. I usually buy small, thin pins and slide them under the panel. This allows air to flow around the solar panels. Flexible panels don't need a lot of airflow, but they do need some.

I recently had to return a flexible solar panel because it overheated. It has good reviews online and I think it will last for years. Failed after only 6 months! This is why the warranty period for flexible solar panels is usually shorter than that for glass solar panels. I also have a few flexible solar panels, but they all come with a 25 year warranty so I should be happy.

Glass panel arrays are available to most people. They work well, are very safe to use, and are very cheap. They can handle the elements and high-speed winds. They might be heavier, but a full set of panels won't be as heavy. Most RVs and most pickup trucks can use a 400-watt glass panel solar array. It weighs about 60 pounds, which isn't a problem for most roofs and racks.

Chapter 14: Selecting a Solar Charge Controller



PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking) are the main types of charge controllers.

PWM controllers are cheaper than MPPT controllers. Compared to MPPT charge controllers, PWM controllers prevent battery overcharging and overdischarging, resulting in longer battery life, but are less efficient (20% on average).
The PWM controller achieves extended battery life due to the application of a complex switching algorithm and a combination of pulse width modulation and pulse charging. Pulse charging prevents sulfation of the battery's lead plates.

A PWM charge controller is the best choice if:

- The solar array consists of only a few modules and the installed solar power does not exceed 1.5-2kWp (1,500-2,000Wp).
- The nominal voltage of a single module is close to the battery voltage.
- The solar system operates in warm climates.

The average efficiency of the PWM controller is about (75-80)% compared to the (92-95)% efficiency of the MPPT controller.
The MPPT controller prevents overcharging and overdischarging of the battery while transferring more power (up to 20-30% more) from the solar module to the battery pack or load. It doesn't extend battery life as effectively as a PWM controller.
Some MPPT controllers have a "voltage step-down’ " function. This feature allows connecting higher voltage solar arrays to lower voltage battery packs – for example, connecting a 48 V array to a 24 V battery pack. If the step-down’ function is not provided, the total voltage of the array must be equal to the battery pack voltage.
The voltage step-down feature provides the following benefits:

- Higher solar array voltages – they allow for smaller cross-section cables between the array and the controller, reducing wiring costs. Therefore, more solar modules can be connected in series and fewer modules can be connected in parallel compared to the case without the step-down function.

Opportunity for solar array expansion without increasing the size of the cables.

The MPPT charge controller is designed to fast track the maximum power point of a solar panel/array under variable atmospheric conditions with maximum accuracy. Depending on how successful the MPPT controller is, it can show up to 10% better performance by compressing more power than its inferior MPPT controller.

The ultra-fast MPPT controller is 30% more efficient than the PWM controller and 10% more efficient than the slow MPPT controller in cloudy weather and changing insolation intensity.

PWM and MPPT Controllers – A Detailed Comparison

PWM Controller Advantages:

Prevents battery overcharging and overdischarging by extending battery life more efficiently than MPPT controllers.

Cheaper than MPPT controllers - prices range from $25 to $250, depending on the power required.

Best for systems with solar power up to 1.5kWp (1,500Wp). For installed solar power above 1.5kWp, MPPT controller is recommended. In this case, up to 30% of the energy production will compensate for the higher price of the MPPT controller in the long run. This works especially well in cooler climates.

PWM Controller Disadvantages:

Not optimized to ensure optimal loading of solar panels, which means an average loss of up to 20% in solar power generation. To compensate for this efficiency loss, you should add more panels to your solar array.

The system voltage must exactly match the nominal voltage of the solar panel, that is, you must use a solar panel with a nominal voltage of 12 V, a charge controller with a nominal voltage of 12 V, and a battery pack with a nominal voltage of 12 V.

For this reason, low-cost 60-cell modules from the grid market may not function properly with PWM controllers. Due to their lower maximum power tracking voltage at higher ambient temperatures (about 15V instead of about 18V for 72-cell modules), 60-cell modules may not charge the battery pack.

The solar array voltage should be slightly higher than the battery pack voltage. Otherwise, you will lose some of the power that might be generated from the solar array because the PWM controller does not convert the excess voltage into current to increase the power output like the MPPT controller does. The PWM controller simply reduces the voltage of the solar array to a low but high enough value to allow the current from the array to charge the battery pack. This is the main reason why PWM controllers are inefficient at lower temperatures. The lower the temperature, the higher the voltage of the solar array, and the more energy is lost to adjust this higher voltage to a lower voltage.

The PWM controller may generate audible or radio frequency noise due to the use of pulse width modulation.

Not ideal for scaling your system. You can get PWM controllers rated up to 120 amps. However, the most common ratings are as high as 60A.

Advantages of MPPT controller:

Prevent overcharging and overdischarging of the battery.

“Squeezes” more power (up to 20% on average) by ensuring optimal loading of the solar array. The colder the climate, the higher the compression power, as the operating voltage of the solar panel is at its maximum.

Maximum efficiency (up to 30%-40% increase) in cold climates.

The nominal voltage of the solar panel can be higher than the system voltage, i.e. a solar panel with a nominal voltage of 48 V can be connected to a charge controller to charge a 12V battery pack.

You can get MPPT controllers rated up to 200A. However, the most common ratings are as high as 80 amps.

For MPPT controllers, the warranty period is usually longer than for PWM controllers.

MPPT controllers offer better opportunities for system growth than PWM controllers.

Some MPPT controllers (provided by MorningStar Corporation) may operate with very large solar arrays with installed power several times higher than the maximum input power supported by the controller. These controllers simply limit the output charge current to its maximum supported value without shutting down the controller, as some of their counterparts do when overloaded. This can be useful when you want to use a cost-effective high power panel instead of a low power one or you want to get more energy on average. In the case of an oversized solar panel, the energy gain during periods of reduced sunlight may exceed the energy loss during periods of full sunlight due to solar panel charging current limitations.

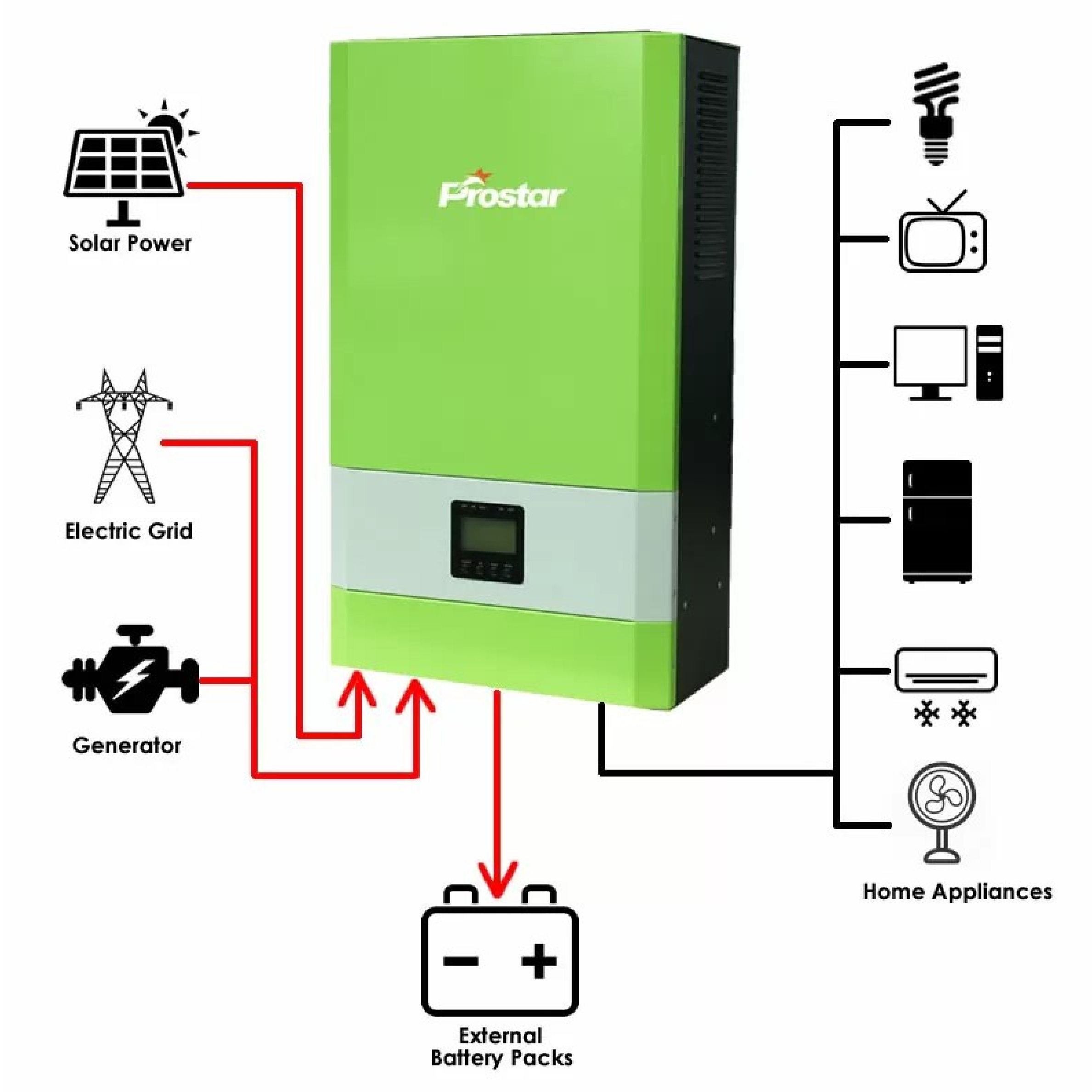
As we all know, 60-cell solar panels are not suitable for PWM controller. However, low-cost high-voltage 60-cell solar panels for grid-tied systems can be used with MPPT controllers in off-grid systems.

Disadvantages of MPPT controller:

More expensive – a good one ranges from $500 to $1,000.

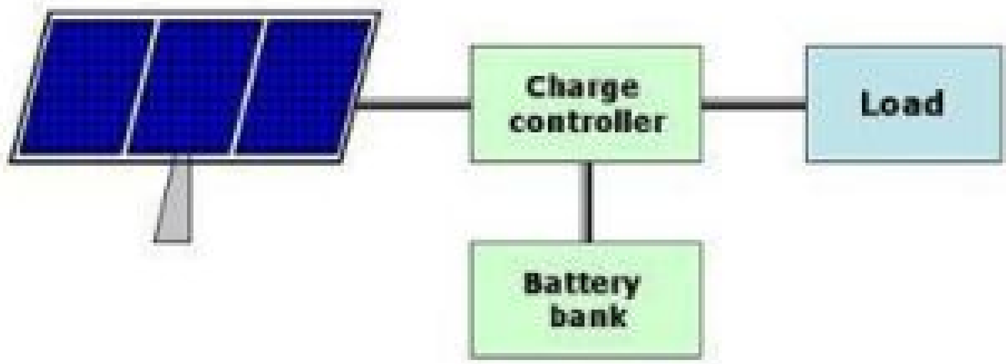
In hot climates, MPPT controllers lose their main advantage – high efficiency. In hot climates, the efficiency of MPPT controllers is reduced to only 10% higher (on average) compared to PWM controllers, while in cold climates, the solar energy squeezed out of MPPT controllers may be Increase by up to 40%.

Chapter 15: Selecting an Inverter

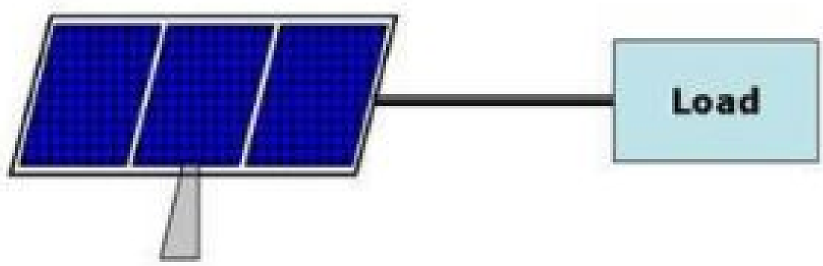


The main function of an off-grid inverter is to convert the output voltage of the battery pack to AC voltage. Not every off-grid solar system needs an inverter. If you are supplying only DC loads, you don't need an inverter:

a) Inverter-less off-grid PV systems with battery packs:



b) Non-inverting off-grid photovoltaic system without battery pack:

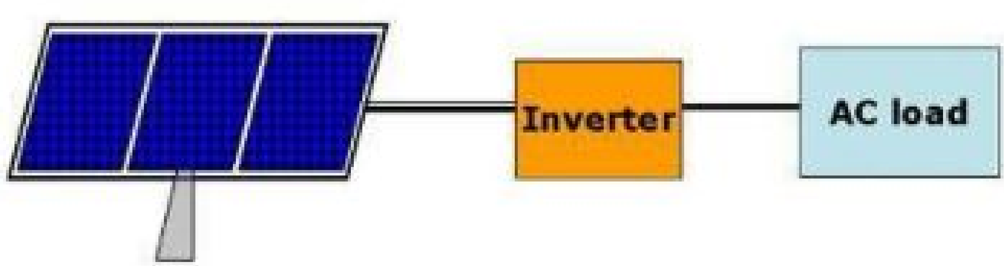


Note:

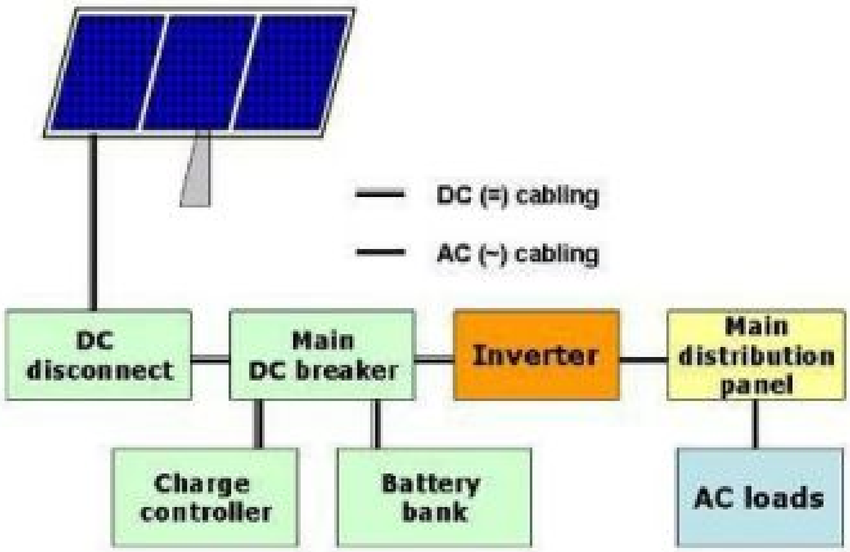
Grid-tied and off-grid PV systems use different types of inverters.

There are two types of off-grid inverters.

The first is an off-grid inverter connected directly to the solar panel, thus directly powering the AC load:



The second is a battery backup inverter connected to the battery via a DC circuit breaker:



To efficiently convert DC to AC, the input voltage range of the inverter must match the voltage range of the battery pack. The battery pack voltage reaches a minimum value when the battery is discharged and a maximum value when the battery is fully charged.

Additionally, off-grid inverters are often equipped with a low-voltage audible alarm to warn you that the battery voltage is about to drop below the critical discharge point. Once this point is reached, the inverter starts to shut down to avoid any further discharge that would be dangerous to the battery.

There are three different types of stand-alone inverters on the market today, in terms of the type of voltage wave they generate - sine wave, quasi (modified) sine wave and square wave ones.

Although the most expensive, sine wave inverters are the best choice because they are suitable for any application and best meet regulatory requirements.

Keep in mind that certain electronic devices, such as cell phones, microwave ovens, computers, vacuum cleaners, etc., may have problems with quasi-sine wave inverters. Additionally, quasi-sine wave inverters may generate additional noise for audio and television equipment.
Inductive loads, such as refrigerators, water pumps, electric drills, etc., must be powered by pure sine wave inverters. In addition, the inverter must be able to supply such loads with a starting current that is typically 2 to 3 times higher than its nominal operating current.
The quality of square-wave inverters is worse than that of quasi-sine wave inverters.

The most important features of an off-grid inverter:

- Produces a sufficiently stable sinusoidal AC voltage.
- Capable of supplying sufficient power to all connected electrical equipment.
- Able to withstand surges caused by loads containing motors.
- Low power consumption in standby mode.
- Tolerances with respect to battery voltage.
- Alerts when the battery is low.
- Battery Charging - Converts AC voltage produced by an external backup generator (optional) to DC voltage to charge the battery pack.
- Overcurrent protection.

With the idea of protection, off-grid inverters are designed to automatically shut down when the battery voltage falls below a certain level. Therefore, in systems based on off-grid batteries, the battery charge level should be checked regularly.

Off-grid inverters and charge controllers are usually combined into one device. This results in lower costs for building solar panel systems. However, such a concept has a distinct disadvantage. Because several devices are integrated into one device, the system designer has less freedom in sizing and selecting components.

Part of the direct current generated by the solar array is used to charge the battery, and if the battery has sufficient capacity, the other part of the direct current is converted to alternating current to power household equipment and other loads.

When the battery capacity reaches a certain minimum allowable level, the inverter can alert the system operator to turn on additional generators (using wind, diesel, fuel, etc.) or automatically start itself as generators to prevent over-discharging of the battery pack.

Depending on the type and size of the solar panel system, off-grid inverters are available in a variety of power outputs. There are 100 W inverters for small stand-alone systems and 5 kW inverters designed to power all possible loads in a residential solar system.

Another essential feature of battery-based inverters is that their DC inputs are only suitable for a limited number of DC voltages (12V, 24V, and 48V), since the inverter input is usually also the battery output voltage in these DCs.

Off-Grid Inverter Specifications

Rated Input Power – Typically chosen to be 20% lower than the solar array peak power due to solar module losses.

Rated output power – should be sufficient for the inverter to handle all loads operating simultaneously.

DC input voltage from battery pack – voltage values are standard, most typically 12V, 24V and 48V.

Output Voltage – Typically 120 VAC or 230 VAC for most residential buildings.

Output frequency – 50Hz in Europe, 60Hz in the United States.

Surge Capacity – Allows the inverter to provide more output power than its rated value for a short period of time, providing high starting current for motors (refrigerators, water pumps, etc.).

Chapter 16: Selecting Cables

	2% Voltage Drop Chart					
AWG =	14	12	10	8	6	4
Capacity(AMPS)	15	20	30	40	55	70
ARRARY AMPS	FEET ONE WAY FOR A PAIR OF WIRES					
1	45	70	115	180	290	456
2	22.5	35	57.5	90	145	228
4	10	17.5	27.5	45	72.5	114
6	7.5	12	17.5	30	47.5	75
8	5.5	8.5	11.5	22.5	35.5	57
10	4.5	7	9.5	18	28.5	45.5
15	3	4.5	7	12	19	30
20	2	3.5	5.5	9	14.5	22.5
25	1.8	2.8	4.5	7	11.5	18
30	1.5	2.4	3.5	6	9.5	15
40			2.8	4.5	7	11.5
50			2.3	3.6	5.5	9
100					2.9	4.6

Cables are used to connect the various components of an off-grid solar panel system. Cables are wires placed inside conduits or pipes for protection.

A clear distinction should be made between DC cables and AC cables in solar panel systems.

The DC part of the wiring consists of the cables laid outdoors and the wiring between the modules (collected in the junction box, if the solar array includes a pair of strings), the wiring between the strings (collected in the combiner box) and connection to the inverter. To prevent ground faults and short circuits, the positive and negative terminals of the cables should always be separated from each other. In addition, DC cables should be jacketed against adverse weather conditions, shielded from lightning strikes and mechanically protected.

The AC cable connects the inverter to the load. AC cables do not need to be designed for outdoor conditions.
Note: Higher system voltage results in lower current, which means lower voltage drop in the cable and therefore lower cable losses. Higher currents require larger cross-section cables, which mean more expensive systems.
Therefore, try to keep the cables between the solar array and the controller/battery as short as possible.
Compared to AC cables, DC cables should have the following additional features:

- Double insulation
- UV and waterproof
- Designed for wide temperature range (-40 to +120°C)
- Designed for high voltage (over 2 kV) operation
- Easy to install, lightweight and flexible
- Fire resistant and low toxicity
- Dimensioned for low pressure drop.

• All DC cables should be UV resistant and suitable for outdoor use.
• DC cable losses (i.e. voltage drop across the cable) should be kept to a minimum as follows:

- Less than 3% between solar array and battery.
- Less than 5% between battery and DC load.

If the cross-section of the DC cable that spans between the solar panel and the battery is not large enough, battery life can be significantly reduced, especially at high ambient temperatures. The reason is that the maximum voltage drop allowed on the cable is exceeded and the battery will not be fully charged.
When more than two solar panels are required, a DC circuit breaker should be installed between the solar panels and the charge controller so that the system can disconnect itself from the solar panels during maintenance work or during a thunderstorm.

The most important electrical safety element in an off-grid system is the battery main fuse. It is designed to protect the battery from short circuits and must be installed as close as possible to the positive side of the battery. The battery main fuse should also be appropriately sized to protect all components that may be affected by short circuits and overloads.

A short circuit between the poles of a battery is extremely dangerous. In the case of a short circuit, a very high current starts to flow (due to the battery's very low internal resistance), which can cause a voltage arc - the cable can melt, the battery can explode and emit sulfuric acid approx. Sulfuric acid is very harmful to human health and can cause blindness, severe skin burns and lung damage. So make sure you have an appropriately sized fuse or automatic circuit breaker for each element connected to the battery.

Note:

1) The cable must be sized to carry the maximum current of the circuit or short-circuit current for at least 3 hours.

2) The selection of the cable size must consider the operating temperature, that is, the current carrying capacity of the cable must be derated according to the operating temperature. Cable ampacity is rated at a given operating temperature. The higher the operating temperature than the rated temperature, the lower the cable ampacity due to the increased thermal resistance of the cable. For example, copper cables may conduct up to 50A at 60°C (140F) and only 41A at 75°C (167F). Therefore, if the ampacity of the desired circuit is 45A at an operating temperature of 75°C (167F), a larger diameter cable type should be selected.

3) The rated ampacity of circuit breakers and fuses should not exceed the rated ampacity of the cables, but should always be close to the relevant short-circuit current. Expect circuit breakers and fuss to protect cables and components, not the other way around!

4) The fuse size in amperes must not exceed the cable ampacity.

Part VII: Battery Bank Voltage Monitors

One of the most useful devices available for solar power is a battery monitor. This is usually an available feature of the charge controller. The charge controller includes a battery voltage that provides the user with a reference to the state of charge of the battery pack.

Each lead-acid battery is made up of batteries. Each battery is about 2 volts. So a 12 volt battery has 6 separate cells. A fully charged battery is around 2.15 volts, while a discharged battery is around 1.9 volts.

If you choose a 12-volt battery size, you may see voltage values ranging from 12.73V to 13.5V (depending on the stage of the charging process). This will give you an indication that the battery pack is fully charged or the charging process is complete. If you find that the voltage is lower than 11.4V, the battery will be fully discharged.

For a 24V system, the full charge voltage may be between 25.8V and 28V, while the discharge voltage may be less than 23V.

Finally, for a 48V system, a fully charged battery pack will be between 51.6V and 56V, while an uncharged voltage may be less than 46V.

All of these voltages are temperature and model/technology dependent; therefore, they can only provide a general reference.

The best way to verify this is to check the manufacturer's data sheet, where you can find a graph of voltage (V) versus state of charge (%).

Remember that lead-acid batteries should not discharge more than 2V or 50% per cell. Failure to do so may cause permanent damage to the battery.

For reference, the chart below shows the percent charge for different lead-acid models.
Lithium batteries are different from lead-acid batteries. Each battery has a voltage of 3.2 volts. Four separate batteries make up a 12V battery.
You can purchase a battery monitor, which will tell you the current voltage level of your battery. This only applies to open circuits, meaning there is no load or power connected.
The additional load will temporarily reduce the voltage at the battery terminals, while the power source (PV panel) will temporarily increase the voltage.
To accurately measure the health of a battery, using voltage alone is not ideal. We will use a shunt to measure the battery capacity.

Chapter 17: How Low can you Safely Discharge your Battery?

This can be a difficult question to answer. If you have a sealed lead acid battery, the typical answer is 50%, which means 12.1 volts when all appliances are off. If you want to use the battery for a long time, you need to discharge it to 70%, which is around 12.3 – 12.4 volts. If you use a deep cycle battery full depth of discharge, which means discharging to 20% of its capacity or 11.7 volts, your battery will degrade faster.
If you have a lithium battery, the BMS (Battery Management System) usually allows you to discharge the battery to 0 – 20% and nothing more.
Also, if you don't use the battery or discharge it only a little, say 98% of full capacity, other problems can arise. You will need to discharge at least 90% weekly to keep the battery charged.
Long story short:

If you have a sealed AGM battery, discharge to 12.2 volts, never less than 12.1 volts.

If you have lithium battery, check how the BMS works and try to reduce the load to 20%

Part VIII: Fuses and Fuse Holders

The fuse is the "weakest link in the chain" of the solar system. If something in the system draws too much power, such as a short circuit (which happens when the positive and negative wires touch), the fuse will get hot and "blow". This will instantly disconnect the battery from the appliances and cables.

If there is no fuse installed in the system and something goes wrong, the wires or appliances will get very hot until they are destroyed. This can cause a fire.

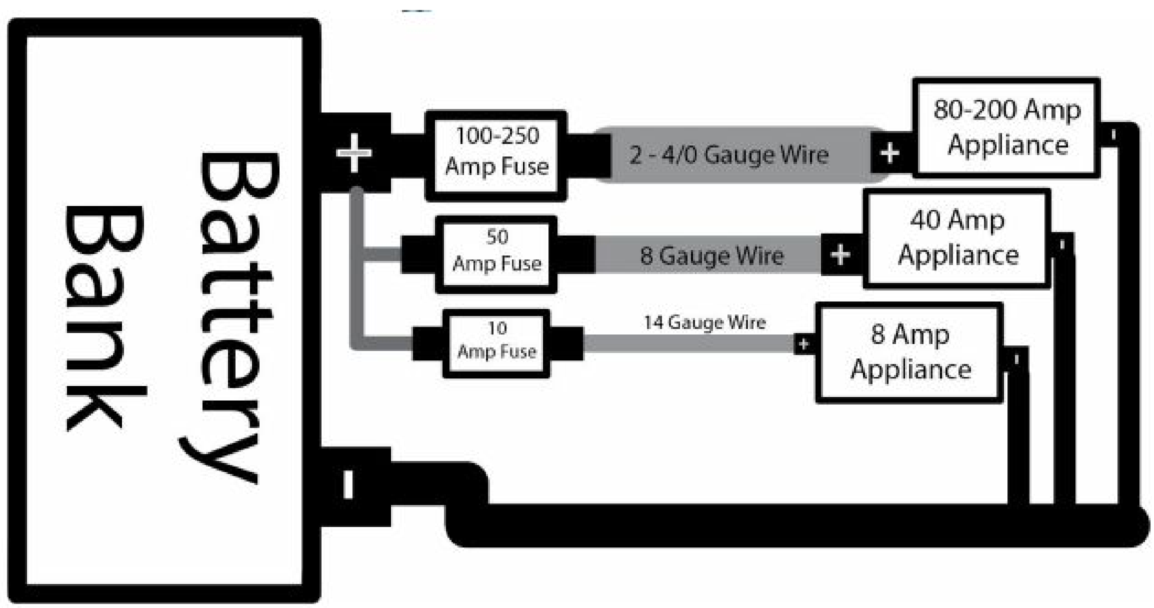
Strategically placed properly rated fuses will prevent most problems from occurring.

But a fuse will only work if it's connected to a wire big enough to carry enough current to "blow" the fuse. If the wire is too small or the fuse is too big for the wire, the fuse will not blow. The fuse is no longer the "weakest link in the chain" in your system. The fuse will not blow, the system wires will be the fuse. Because the wires don't burn like a fuse, they get very hot until something breaks.

If you are connecting your device with an 18 gauge wire (very thin and small) and you connect it to a 50 amp fuse and there is a short in the circuit, the fuse may not have blown and the wire may overheat. This is because the wire itself is becoming a fuse.

Large Appliances = Large Wires = Large Fuses

Smaller Device = Smaller Wire = Smaller Fuse



Choosing the proper wire gauge and fuse size is a fairly simple task. Fuses are measured in amps, and if you know how many amps a wire can carry, you'll know what type of fuse you need. If you follow some simple rules, you will be on the right track.

Before discussing which fuse ratings to use, we need to understand the types of fuse holders currently available. Before you install a fuse in your system, you'll usually install some type of fuse holder.

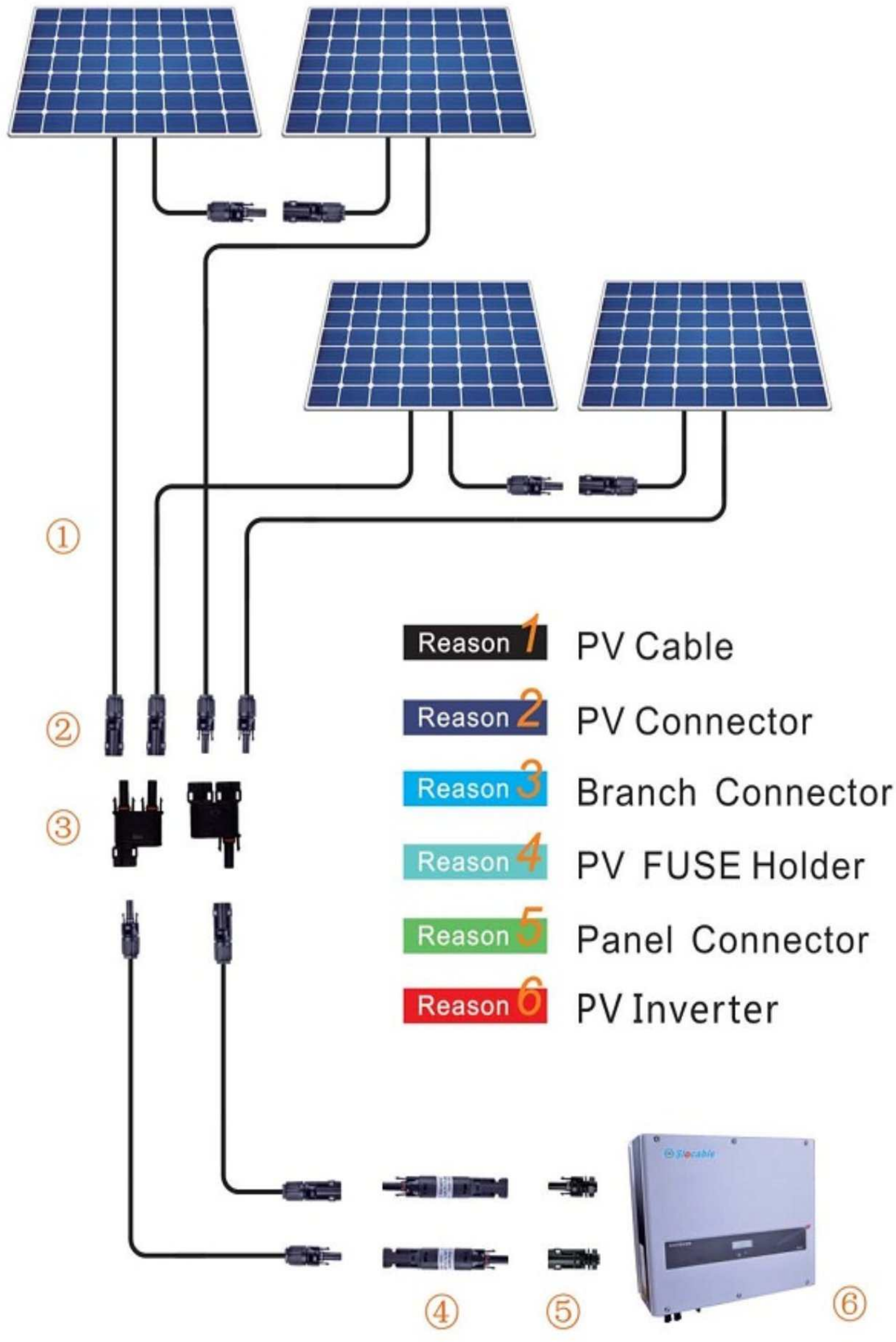
There are three main types of fuse holders:

Bolt-on Fuse Holders and Fuses – Connect directly to the battery pack terminals. Typical sizes are 50 amps to 250 amps.

Fuse Box – A fuse panel where several small fuses power the appliances. Typical sizes are 10 amp, 15 amp, 20 amp, and 30 amp. Each fuse box can contain from 3 to 10+ fuses.

Inline Fuses – A fuse that is spliced into a wire. These fuses can be installed anywhere, but are generally used in small appliances with smaller power cords. You can splice these in-line fuses on large cables, but it is not recommended. A common size of in-line fuses for solar system applications is 5-15 amps, but you can purchase sizes larger than 30-100 amps (but not recommended. bolt-on fuses are better).

Chapter 18: How to Calculate the Fuse Size



Appliance amp draw x 1.25 = fuse amp rating

If the device draws 20 amps, use a 25 amp fuse (20 x 1.25 = 25)

If you need to power an appliance that requires 12 volts 5 amps, using a fuse box, you will need a 6.25 amp fuse. This is not a standard size so a 7 amp fuse will work just fine. If the wire feeding the LED strip is thick enough to carry 10 amps, use a 10 amp fuse.

If you need to power a refrigerator that requires 12 volts and 8 amps, insert a 10 amp fuse into the fuse box where you will connect the refrigerator's positive lead. Then connect the negative or ground cable to the negative terminal of the battery.

Let's say you have a small device that only needs 10 amps at 12 volts. Suppose this little device has a thick wire attached to it that can carry 25 amps (for example, 10 feet of 12-gauge wire). In this case, a 15 – 20 amp fuse would work just fine. The size of the fuse depends more on the thickness of the wire. If you use a heavier gauge wire, you can safely use a large fuse. (Unless the device is poorly designed)

You might think that a smaller fuse would be safer. In most cases it is, but it can cause some problems. The fuse provides a lot of resistance to the system, which means that some of its electricity will be converted to heat. The fuse will continue to heat up. This is the energy loss. Using properly sized fuses and cables will be the safest and most efficient solution.

Chapter 19: Important Locations and Ratings for fuses

1. There should be a large bolt-on fuse on the positive lead of the battery pack, which connects to the inverter and fuse box, as well as any other large appliances you plan to connect to the battery pack. This is the main "safety fuse" that will only blow if there is a large short circuit near the battery. This fuse must be rated to match your inverter:

- The 500 watt inverter must be equipped with a 50 amp fuse
- The 1000 watt inverter must be equipped with a 100 amp fuse
- The 2000 watt inverter must be equipped with a 210 amp fuse
- The 3000 watt inverter must be equipped with a 315 amp fuse

2. With the large bolt-on fuse connected to the battery pack, you can now add the fuse that powers the solar charge controller. You can mount this fuse directly to a bolt-on fuse. This fuse should be rated slightly higher than the amp rating of your solar charge controller:

- 20 amp charge controller cord requires a 25 amp fuse
- 30 amp charge controller cord requires a 35-40 amp fuse
- 40 amp charge controller cord requires a 50 amp fuse
- 60 amp charge controller cord requires a 75 amp fuse

3. Now we can connect the last fuse to the battery pack, which is the fuse box. This will hold multiple fuses so you can power your device. If you want to connect the fuse box directly to the large bolt-on fuse located in the battery pack, you will need to use thick wire. This wire must be at least 6 gauges. This should be enough to trip the large bolt-on battery fuse if it were to short.

If your fuse box is small and can't handle 6 gauge wires, you'll need to blow out the wires that feed the fuse box. 50 to 100 amp fuses is ideal, but check your fuse box instructions for recommended values.

Part IX: Other Power Sources

Solar energy is an ideal way to generate electricity, but not the only way. Depending on your location, you may wish to supplement your system with other power sources.

Chapter 20: Shore Charging (plug in chargers)

Ground charging means using an AC outlet to charge the battery pack while parked. If you're stationary and have an AC outlet nearby, you can use a plug-in charger to design a fairly robust system that uses fewer solar panels. But it will depend on whether there is an AC outlet nearby.
There are many battery chargers to choose from today, but the biggest deciding factor is how many amps the charger can draw. Common amplifier sockets are 15/30/45/100 amps. Many battery chargers come with alligator clips. This is fine for emergencies, but if you plan to use it a lot, you'll need to cut off the alligator clips and crimp the connector so it's permanently attached to the battery pack.
High current output chargers should be connected to the battery pack via a large bolt-on fuse. If you are using a very small battery charger, you can connect it to the fuse box. Example: If your battery charger only draws 15 amps, connect it to the 20 amp fuse on the fuse box. Be sure to buy a 12 volt charger! 24 and 6 volt chargers are also available. Make sure your charger is designed for the battery you are using.

Chapter 21: Generators

A lot of people, me included, are tired of generators. They smell, make noise, consume petroleum derivatives, and require moderate maintenance. But they work! If you plan to run large loads, such as power tools, electric furnaces, or large water pumps, you may need to supplement your system with a generator.

Most generators cannot be connected directly to the battery pack. You're going to need some kind of charger, like the grounded charger mentioned a second ago. Connect your battery pack charger to the generator and you're good to go!

Most large motorhomes will have a dedicated generator storage compartment. If not, you may need to add generator brackets to the bumper. If you have a scooter/motorcycle rack, you can mount the generator there. Make sure you screw it down and chain it to the frame so no one can steal it. Do not install the generator on the ceiling or near the living room. Be sure to operate in an open area to avoid inhalation of vapors.

Chapter 22: Wind Turbines

These work fine, but usually don't work with vehicles. They must be folded while driving. If your vehicle is parked in a windy place, install a turbine! They can produce a lot of power and are easy to set up. Usually you just screw it into something secure and plug it into the system. Some turbines have voltage regulators that you can connect directly to the battery pack.

Part X: How to Install a Solar Power System

First, install the:

1. Battery
2. Solar charge controller
3. Solar panels

Chapter 23: How to Install a Battery Bank

Take a look around your vehicle and think of a place to install the battery pack. RVs and some pickup trucks will have a compartment for the battery pack. Some vehicles will require you to build your own compartment. Battery packs generally tend to:

- A dry place sheltered from the rain.
- A location that protects the battery terminals from tampering.
- A position that prevents the battery from tipping over while driving.
- An isolated place to avoid large temperature fluctuations. You may need to insulate the battery pack compartment.
- Ideally, the compartment should be made of insulators to prevent accidental short circuits. Plastic battery boxes are perfect for this purpose.
- If you have sealed batteries, the location does not require ventilation. But ventilation is always good. Sealed batteries do not smoke if used correctly, so this is usually not a cause for concern. If your battery

is vented then your battery compartment will need venting.

The battery pack is heavy. You have to store the battery somewhere between the front and rear tires. If you charge the passenger side of the vehicle with a battery pack, you must do the same for the driver's side. Use the tire location to draw an imaginary "X" on your vehicle and try to place the battery in that location.

If you have very tall batteries, you may want to secure them with straps so they don't tip over. Most deep cycle batteries are large and heavy enough to function on their own without any special installation methods.

Once you find the location, drop them there. As long as it's a relatively safe place, you shouldn't have any problems.

Chapter 24: How to Install a Solar Charge Controller

Most solar charge controllers are designed to be wall mounted. This is because the controller has heat sinks, which require some form of convection ventilation to cool it down. When installing it on the wall, make sure the space above and below is clear for air to pass through.

The hardest part of choosing a charge controller location is finding a location on the wall near the battery. The closer the controller is to the battery, the better.

You can screw the charge controller to the wall, or you can use mounting tape (if the charge controller is relatively light). Either way works, so use the easiest way. If you have a large charge controller, such as a 40+ amp MPPT charge controller, you'll need to brace the wall it's mounted on or mount it to a piece of wood, then mount the piece of wood to the wall.

Chapter 25: How to Install the Solar Panels

Solar panel requirements:

- Airflow under panel
- Strong waterproof connection to the roof

Here are your options:

Option 1: Bolt the solar panel directly to the roof rack using a standard solar panel mounting kit. If you can fit a roof rack on your vehicle, this is your best option!

Option 2: Use a set of "no-drill corner mount solar panel brackets" and some VHB tape or weather resistant construction adhesive to mount your solar panels. Where you put these brackets should be a flat roof.

Option 3 (not recommended): Use a solar panel mounting kit to attach the panels directly to the roof. Secure the solar panel mount bracket L to the roof with long bolts and lock washers. Next, seal all the holes with putty.

Punching holes in the roof of any vehicle is a bad idea. Also, the studs on either side of the roof don't look as pretty. Most people will buy the mounting kit recommended by the manufacturer. These kits usually come with special L-brackets that allow the solar panels to be attached to the roof with large screws. These L-brackets are usually very strong, but the ceiling they are attached to can be weak. Many RV roofs are made of relatively weak materials, such as fiberglass and foam, and are not designed to have solar panels on them. Most solar panel mounting L-brackets are designed to attach to bare wood or screw to metal. If your vehicle has a metal roof, you can get in, but you probably don't want to.

Option 4: If you have a curved roof made of fiberglass and you don't want to burrow in and can't add a roof rack to your vehicle, then you may want flexible solar panels. You can still use 3M-VHB mounting tape or whatever the solar panel manufacturer recommends, but it's probably your only option.

Solar Panel Safety Line

Placing heavy glass solar panels on the roof of a moving vehicle is usually a bad idea. To reduce the chance of a solar panel flying away and killing someone, you need to add a safety line.

How to add safety lines:

1. Drill a hole in the frame of each solar panel in the array. Make sure you don't damage the solar panel while drilling. Most 100 watt solar panels come with tiny holes that work well for this purpose.
2. Find a weatherproof- and UV-resistant rope or cable to attach the solar panel to. Thin stainless steel cable is ideal, but marine grade rope can also be used.

3. Secure the solar panels to each other with a safety wire. You can connect them individually or together like a spider web. Really don't care. Just make sure that if a solar panel flies, it's connected to another solar panel.
4. Attach the safety line to a sturdy object on the roof. This could be a luggage rack, RV roof ladder, air conditioner, or even an unused TV antenna.

Now that you have the solar panel safety wire, you need to be very careful not to trip over it while walking on the roof. This can be done by loosely securing the safety rope to the roof with roof sealing tape. If you have a lot of solar panels on your roof, try installing them around the perimeter of your roof so you're less likely to trip over safety lanyards or solar panel cables.

This safety line saves lives, so it has to be perfect. Spend the extra money on better supplies and make sure your safety line is working in case your solar panel installation fails.

Should you tilt your solar panels?

Usually not. It is best to install them so that they are parallel to the roof.

If you live far from the equator, you may need to tilt your solar panels. In this case, you may want to consider mounting them on the side of the vehicle. You can also use some flexible solar panels to make a large panel that you can attach to the side of your vehicle if needed.

Tilting the panels improves overall performance when the sun is low, but is difficult to do in a moving vehicle. If you're using a tiltable solar panel stand, you'll need to fold it every time you drive.

You can always connect a linear actuator to the power circuit so that the panel tilts when you park and folds when you drive. However, you have to hook up the motor control and light detection circuits to indicate where the panel should be tilted. If any of these parts fail, there's a chance the solar panel will fly off your roof and kill someone.

Therefore, to avoid problems, install the panels parallel to the roof.

Part XI: DIY Solar Power Setup

The procedure for a solar energy system is very simple and can be done with the following steps:

1. Calculations and schematic diagrams

Before you order components or even consider building a solar system, you need to do the math. Refer to the chapter ‘Part 4: Traditional Method’ for more information.

Drawing your solar system will make it easier to assemble the components later. It will also give you an estimate of the space you need.

2. Order and prepare components

Once the load analysis is complete, it's time to order the components. Be sure to read all the chapters in this book before purchasing components to avoid unnecessary frustration.

Remove the components from the box and place them roughly where you want them. Using a wooden back plate to mount the components makes installation easy. Be sure to place them as close together as possible to reduce cable loss and save on cable costs (especially thicker cables). Make sure these connections are available for future upgrades or maintenance.

3. Design

Find a space in one of the RV's compartments to put lead-acid or lithium-ion batteries and put them there. Make sure the battery is at room temperature.

Ideally, place the inverter and charge controller close to the battery pack. This reduces voltage and ohmic losses and allows for easier installation.

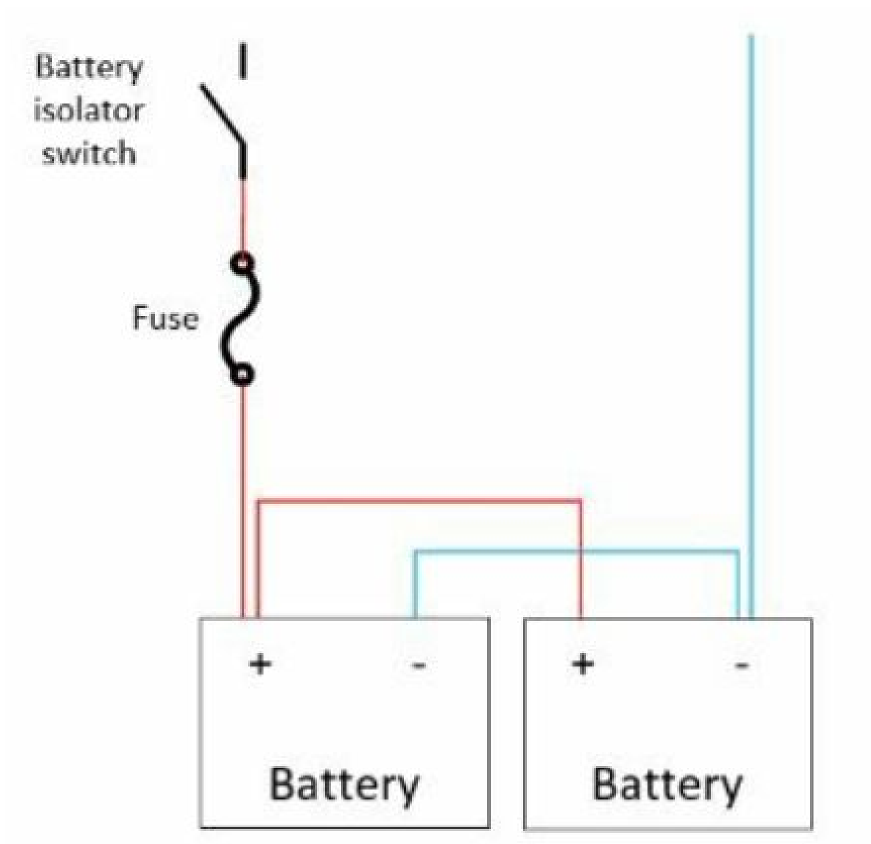
4. Connect the battery

Before wiring a battery, remember to review the sections related to series and parallel connections in the battery section of this book.

Choose the wire gauge size wisely to handle the current flowing from the charge controller to the battery.

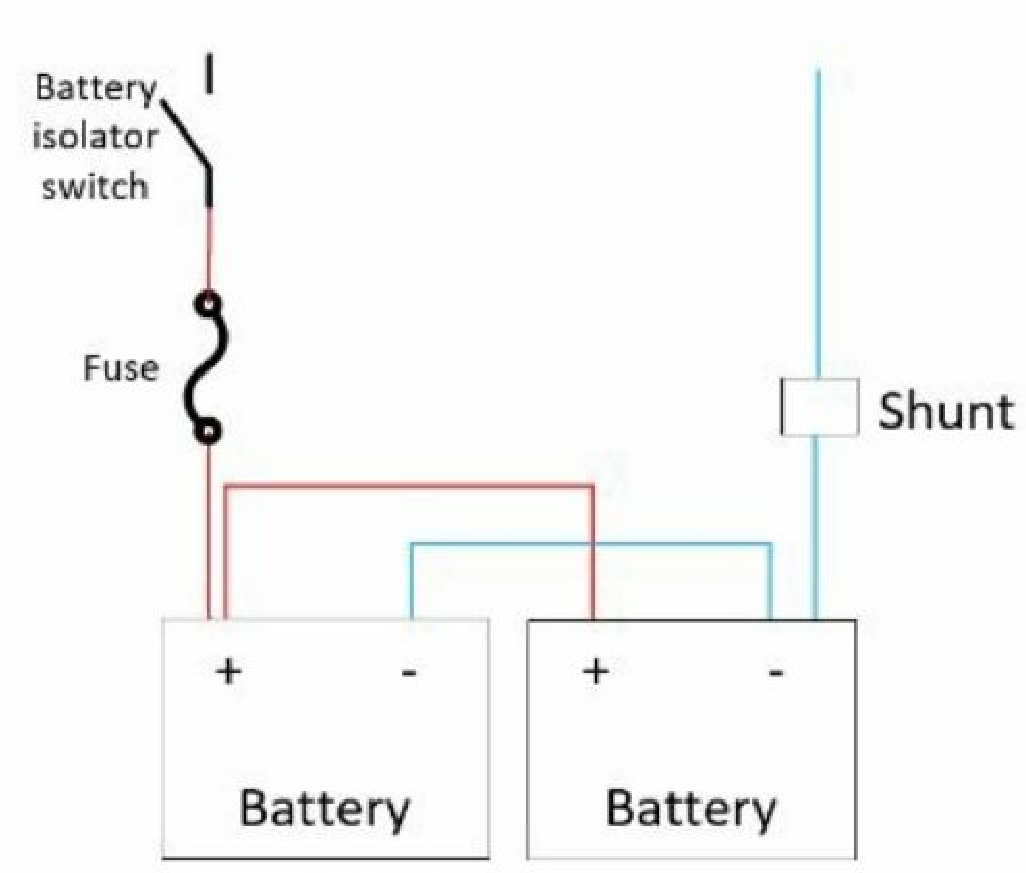
Remember the maximum wire size for the input terminals on the charge controller. Added in-line fuse and battery pack disconnect switch. The series fuse should be as close as possible to the positive terminal of the battery.

Your charge controller will have the maximum charging current. Use this temperature compensated number to find the correct wire gauge. Choose a fuse size that protects the wire diameter. This should be close to 125% of the charge controller's charging current.



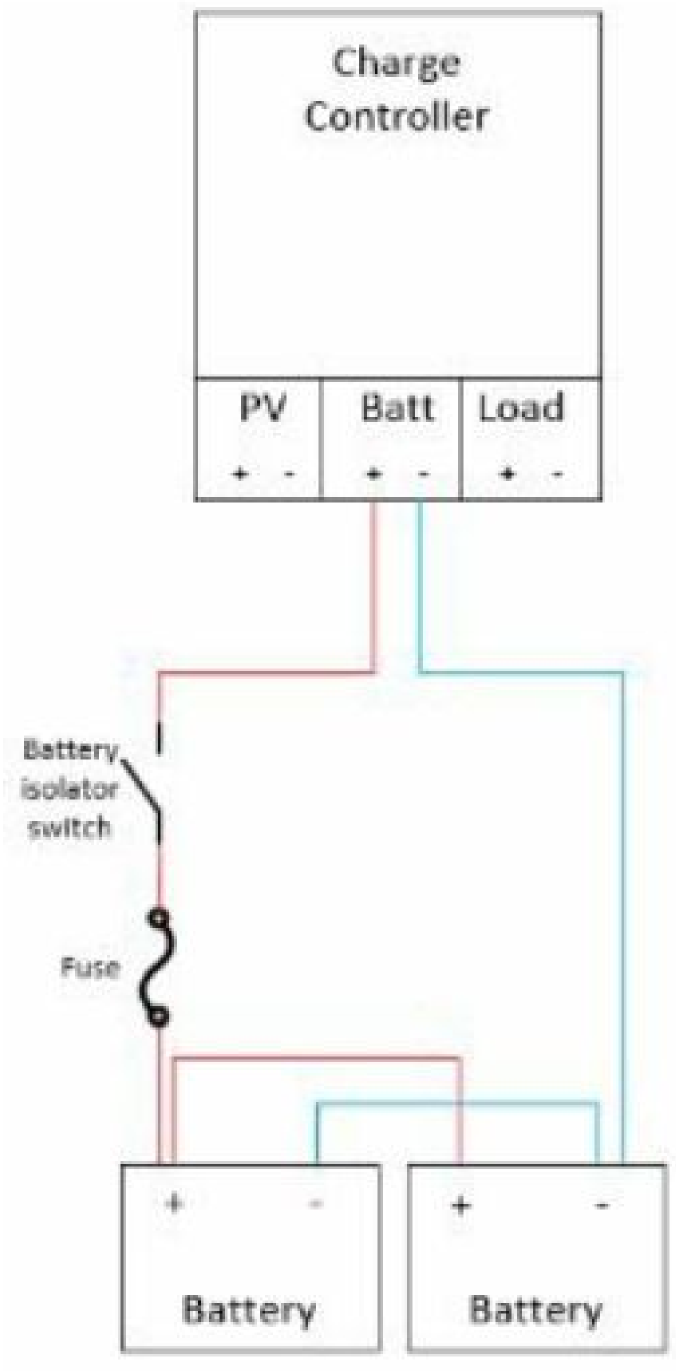
Two batteries in parallel with fuse and switch

If you choose to use a shunt, now is the time to connect it. The negative terminal of the shunt will act as the negative terminal of the battery. Shunt on negative battery terminal



Shunt at the negative battery terminal

5. Connect the battery to the charge controller



Wiring the batteries to the charge controller

After wiring, the charge controller display will light up. Select the type of battery you are using. Follow the instructions in the manufacturer's manual.

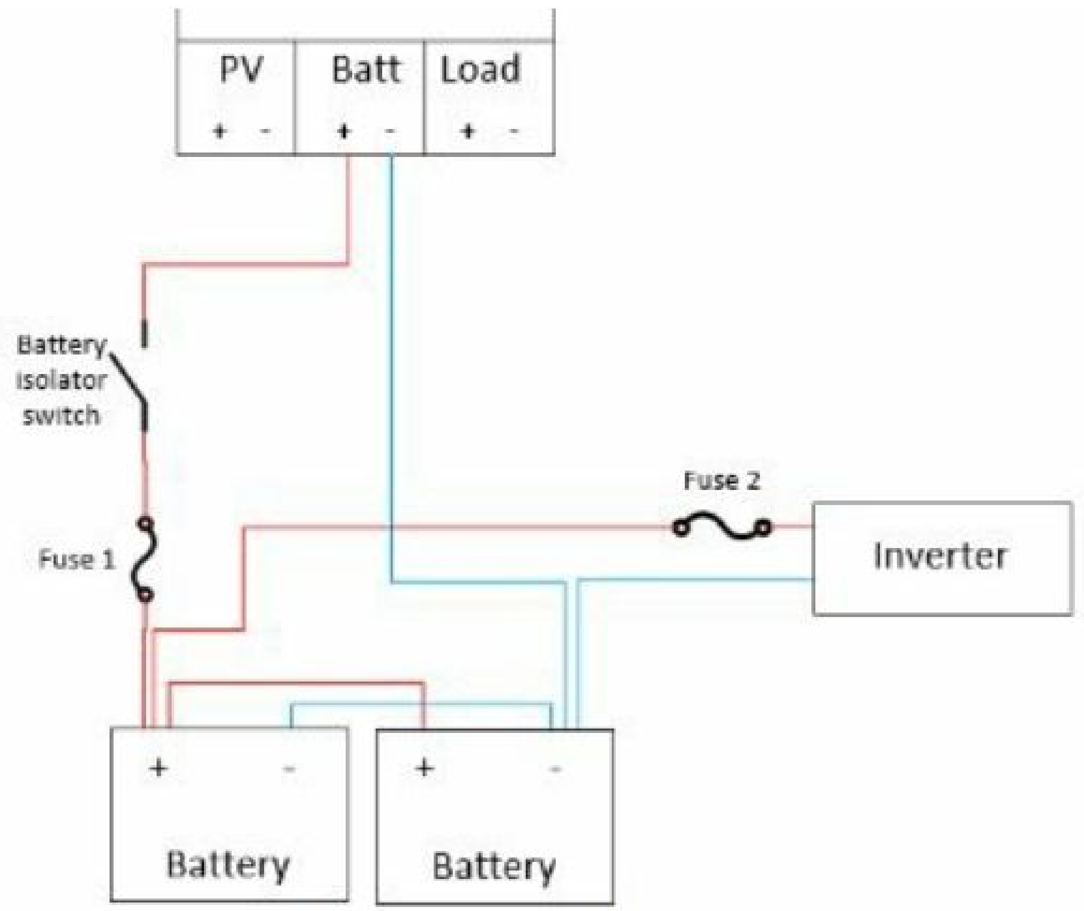
6. Install the inverter

There are two options when installing the inverter:

Connect directly to the battery terminals.
Cable from bus bar.

Wiring from battery terminals:

This option is a bit easier than wiring from the busbar because it requires fewer fuses. The disadvantage of this configuration is that it is more difficult to extend the configuration later.

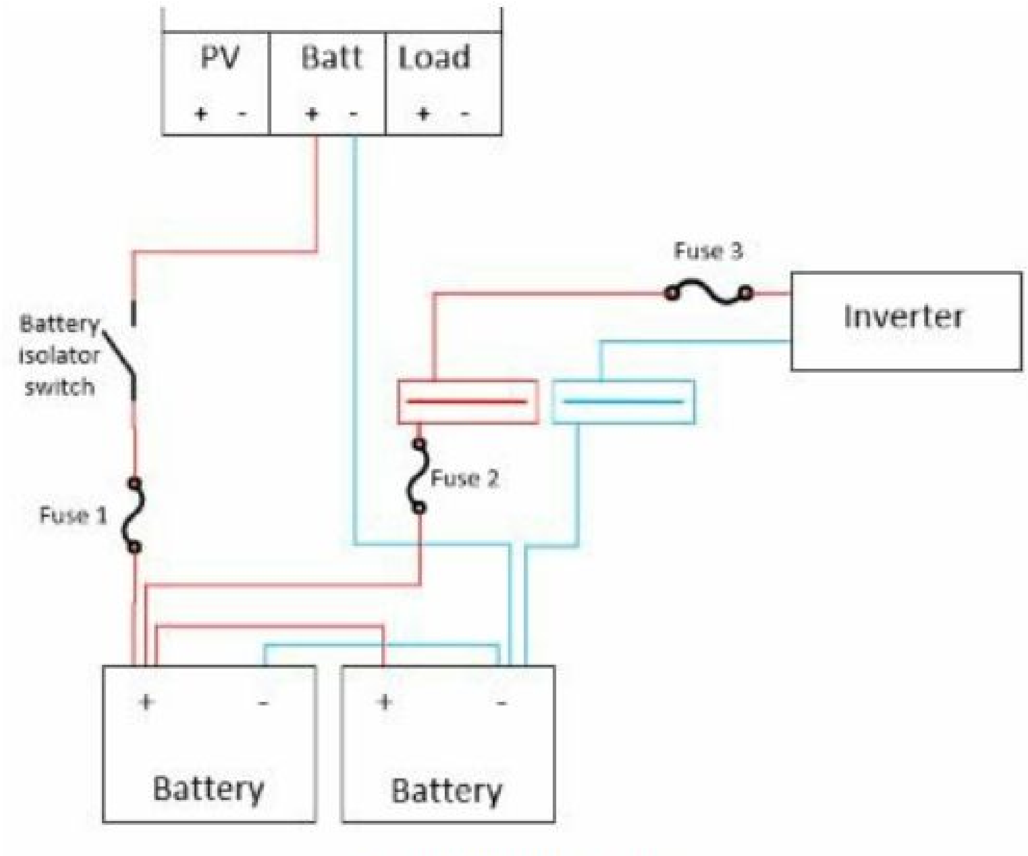


Wiring the inverter or inverter/charger to the batteries

The fuse must be able to handle the current drawn by the inverter. If the inverter is rated at 2000 watts, you need to know the amount of current flowing through the wires. For 12 volt systems:

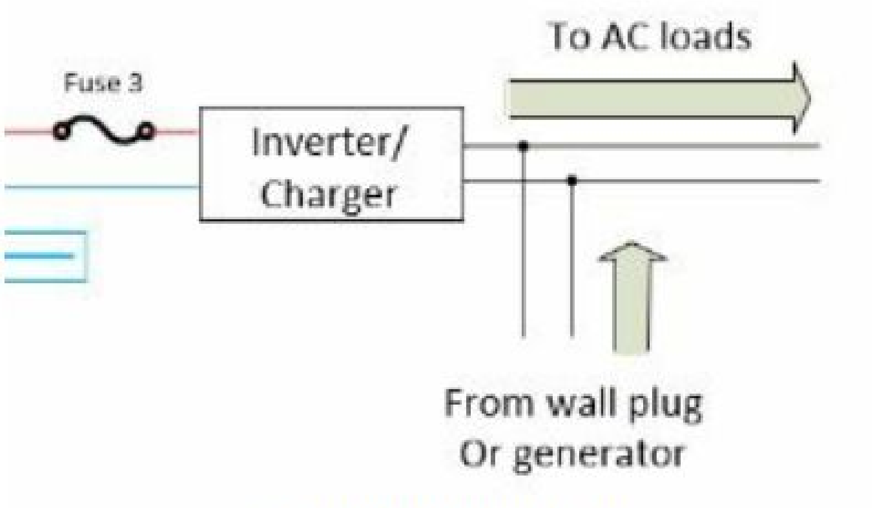
Current = 2,000W/12V = 166.6 Amps

If the inverter uses 2,000 watts of power, the maximum current through the cable is 166.6 amps. Select the wire size and choose the correct fuse that matches the wire size.
If you don't want to connect directly from the battery, I recommend installing a busbar. The following diagram shows how to wire the busbars.



Wiring the inverter to a busbar

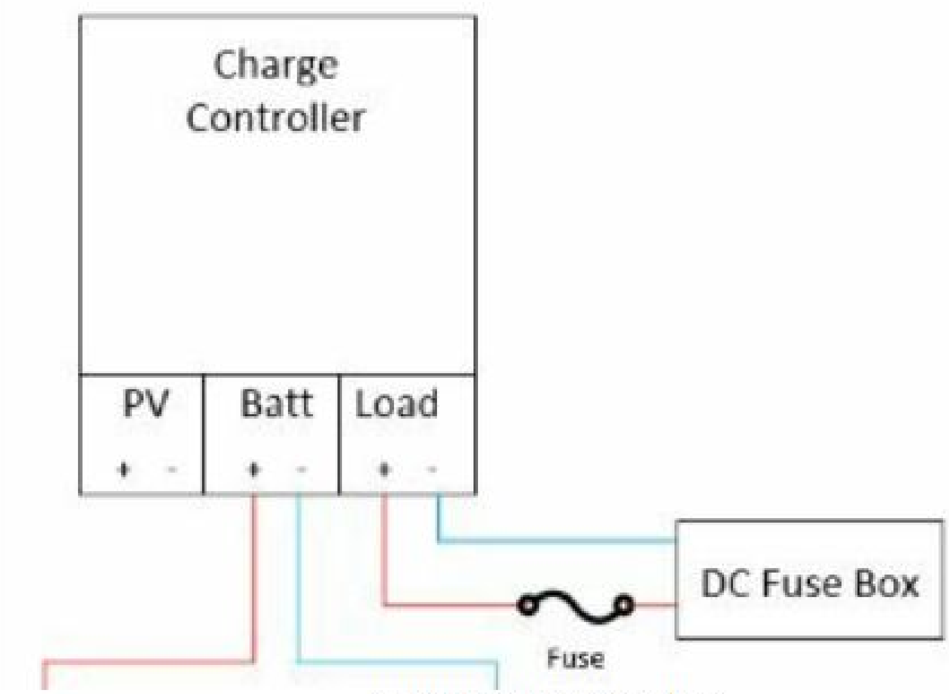
In this case, fuses two and three will be the same size. If no other loads are connected, only fuse 2 is sufficient. However, if you are upgrading your system with a DC fuse box, fuses 2 and 3 will not be the same size.
If you choose an inverter/charger, install an AC input plug that can accept power from the shore or generator.



Installation of inverter/charger

7. DC fuse box

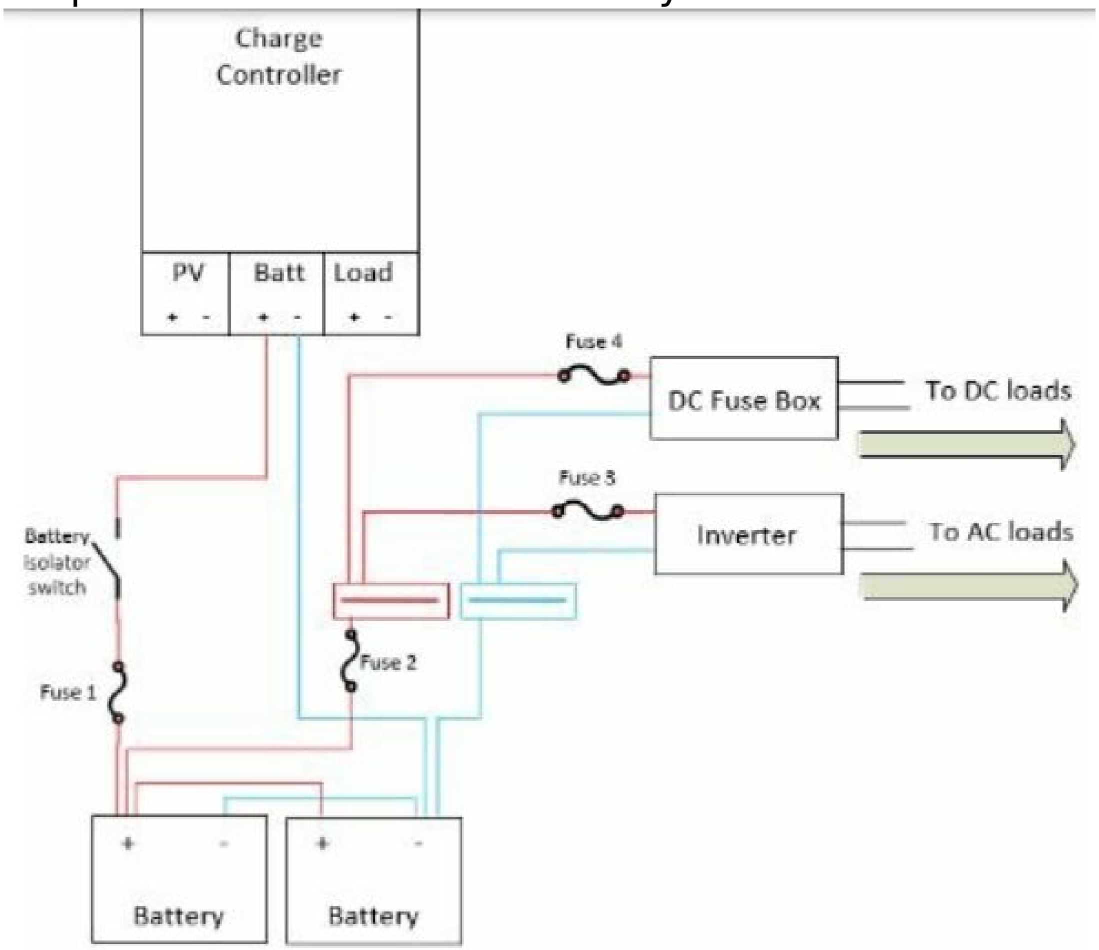
You can connect the DC fuse box using the charge terminal of the charge controller.



Connecting the DC fuse box

However, if the output terminals can only deliver 20 amps, you will be limited to 12 volts X 20 amps = 240 watts.

This can be a problem, especially if you have a lot of DC loads. Therefore, I recommend connecting the DC fuse box to the pre-installed busbar or battery terminals.



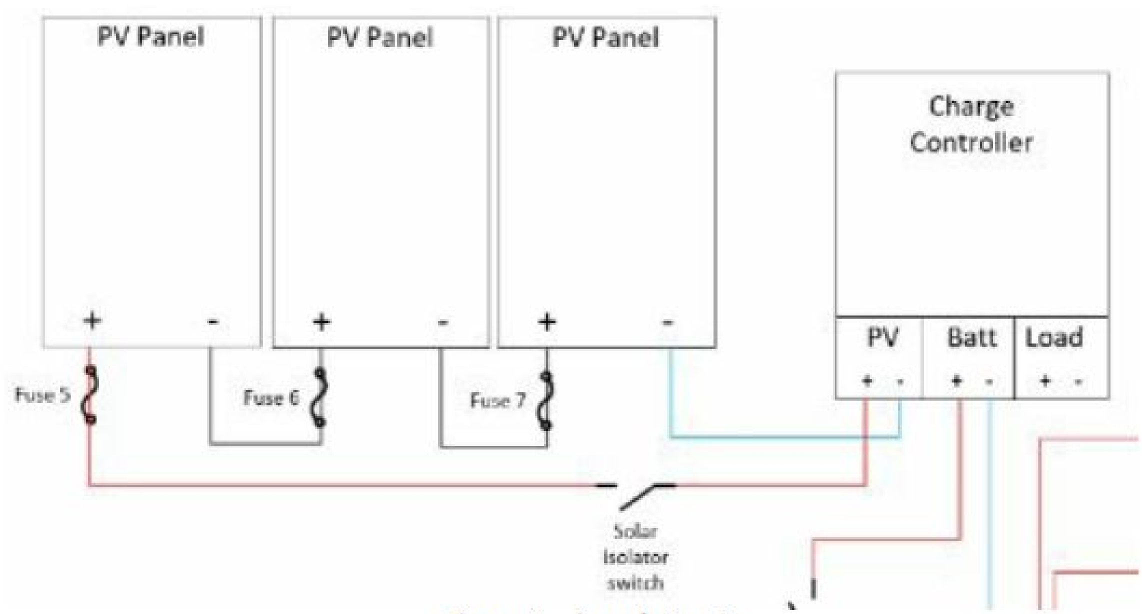
Connecting the DC fuse box to the busbar

In this case, fuses two and three will not be the same. You must use load estimation to calculate the maximum AC load and DC load and choose the correct fuse for each. Add fuses 3 and 4 to get the value of fuse 2.

8. Install solar panels

Whether you decide to install rigid or flexible solar panels, you will need to mount them on the roof. If they are rigid solar panels, use the available holes in the rear frame to drill through the roof and drive in screws and bolts to secure the panels. If you use flexible modules, you can use adhesive material.

9. Connect the module



Connecting 3 panels in series

In this example, the panel is fused using inline MC-4 series fuses (fuses 5, 6 and 7). If maintenance is required, the string of solar cells can be disconnected using a solar disconnect switch. Try to place the switch within easy reach, preferably near the charge controller.
A cable entry plate is a device that allows you to securely connect your solar panel outlet from the outside to the inside of your RV. Be sure to use enough caulking to protect your roof from leaking when it rains.

Solar cable entry plate

10. Install B2B charger

If you want to use the car battery to charge the solar battery, please install the battery to the battery charger.

11. Test

Congratulations, you have completed the installation of the solar system. Now you can run some tests. Tests include:

Check for loose wires.
Check for any sharp edges that could cut the cable.
Monitor the temperature of the components.
Check the temperature of the cables.

Check the battery voltage when fully charged.
Load test.

Conclusion

The sole purpose of this book is to provide you with information on how to build an off grid solar power system.
I hope this book has accomplished that.
Never forget that your safety and that of those around you should be the number one priority. Be very careful when using non-insulated tools. Dropping a key on a battery pack will short the terminals, creating a large spark that can injure you and those around you.
Having said that, enjoy making your own solar system from scratch. If you are unsure about anything, contact a licensed electrician for more information.
Thank you and good luck!