Table of Contents

Choosing Your (Solar) Path In Life

If you're new to the whole 'solar thing' and are looking to get started, there are two important decisions that you need to make before investing in any solar technology. These choices will set the course of your solar life, so choose wisely.

I want to point out here that this eBook will focus on solar electric panels and not solar thermal panels. Solar thermal panels are used to heat water and use completely different technology. Other than using the sun as their source of energy, **they** don't have much in common with solar electric panels.

So what are those two important decisions? They are these:

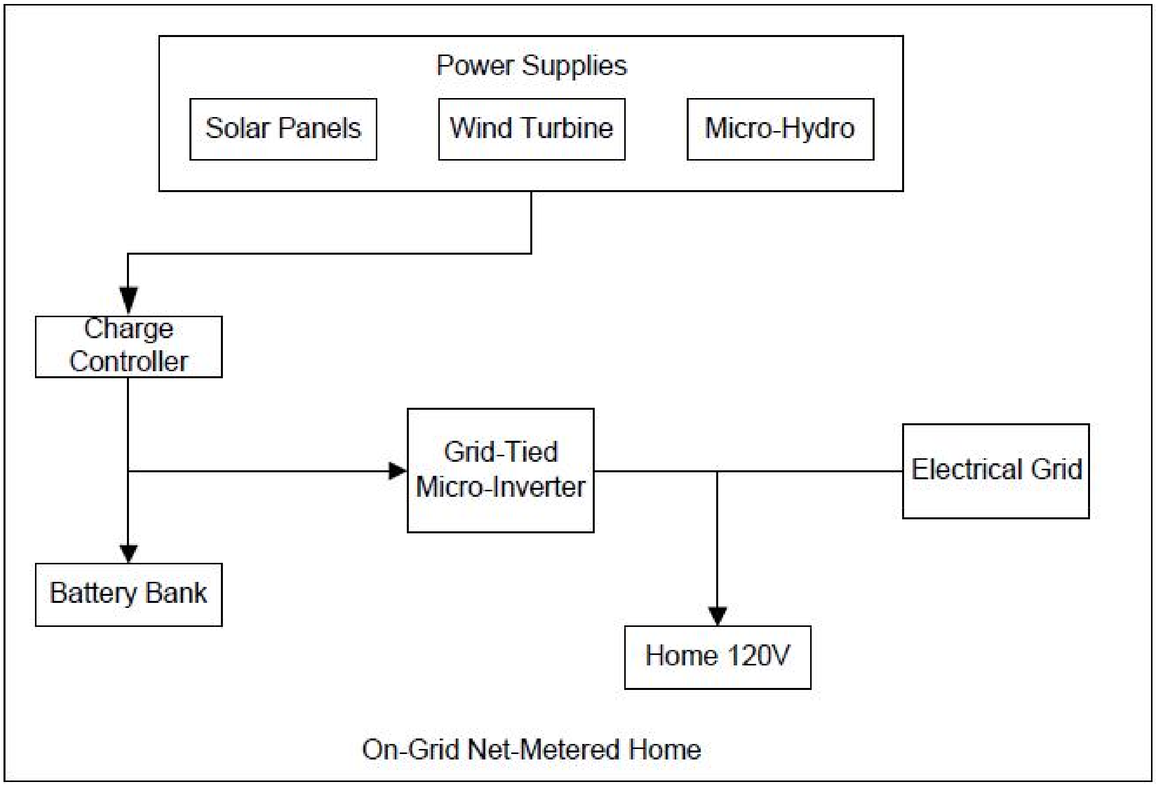
- To implement a grid-tie system or an off-grid system.
- To use 12 volt panels or a system that uses higher voltages.

Grid Tie vs Off Grid Systems

The term grid-tie means that your solar system is attached to the power grid through a grid-tie inverter. The purpose of a grid-tie system is to sell unused electricity back to the power grid. It's very popular right now and most appropriate for people who live in a home tied to the power grid, which would include most people.

The term off-grid is the opposite of grid-tie. It means the energy from your solar system is stored in batteries, to be used only by your home when needed. This setup is most appropriate for remote buildings and cabins where grid power is not available or over expensive to install.

While it may seem like a no-brainer to implement a grid-tie system rather than an off-grid system, there are pros and cons to each. For example, off-grid systems do not need to meet any building or electrical codes. They are considered a hobby/custom installation. You are the designer and the buck stops with you because the electrical grid is not involved (other than maybe a battery charger). Conversely, you'll need to get an electrical permit (at a minimum) and probably need to hire a professional to install a grid-tie system. If you don't have thousands of dollars to invest in the beginning to install a complete system, you may need to hire someone or get a permit every time you want to add more capacity to your system.



Schematic For A Domestic Solar Power House Using Net-Metering

There is a middle ground. Using a grid-tie micro-inverter you can install a simple and basic system, powered from a small battery bank. You can use the batteries to isolate the solar panels from the inverter. From the panels to the batteries you have a basic off-grid system. The micro-inverter and a low voltage disconnect is used to upload stored energy in the batteries to the grid.

The point is that you need to be aware of the difference between grid-tie and off-grid architectures before starting in your own venture with solar power for homes. Many people opt for complete grid-tie kits and don’t realize that they may be pigeon-holing themselves into a corner if the system is not designed for adding additional solar panels later.

12 Volt vs Other Voltages

When solar panels weren't as popular (10+ years ago), most solar panels were designed to operate with 12 volt systems. The reason for this is that grid-tie systems didn't exist and neither did the concept of net-metering. Solar electricity was almost exclusively used in an off-grid architecture. With the advent of these new ideas, the majority of solar panels produced today generate electricity at voltages far higher than 12 volts.

The advantages of using higher voltages is a reduction in current for a given power rating. This reduces transmission loss, sometimes referred to as I2R losses. To figure it out for yourself, play with the power equation and ohms law until you get this equation:

$$P = I^2 * R$$

Higher voltages mean smaller wires can be used and the system is more efficient. This saves money and energy. What could be wrong with that?

The disadvantage is that there is no standard for solar panel voltages. Panels from one manufacturer probably won't be compatible with those from another manufacturer. Also, equipment like charge controllers and grid-tie inverters have their own voltage requirements, which differ from manufacturer to manufacturer.

In contrast to this, 12 volt systems are well understood, standardized, and the equipment is widely available and cost effective. If the solar panels are mounted far from the load, the transmission losses can be eliminated by stepping the voltage up to 120V AC with an inexpensive inverter. At the load, this voltage can then be converted back to 12 volts with a standard power supply.

Additionally, solar panels are made from several solar cells strung in series. It takes approximately 36 cells to create a 12 volt panel. Panels using higher voltages need hundreds of cells. Since cells in a panel are in series, it means that if one cell gets shaded it will block power from all the rest of the cells in the series. Running multiple panels in parallel is more robust than running panels in series, so there are significant reasons to prefer 12 volt panels over high voltages from the perspective of shading effects.

DIY Solar vs Consumer Solar

Deciding on a grid-tie vs an off-grid architecture and weather to use 12 volt panels vs other voltages leads up to one important question: Are you a DIY solar enthusiast? If the answer is ‘yes’, or ‘I want to be’, then I strongly recommend installing a system that is modeled after an off-grid architecture (but may utilize a grid-tie inverter for uploading power to the grid) and operates at 12 volts (nominal). This is the best system for the do it yourself minded person. The system will be scalable, which means you’ll be able to add more panels and grid-tie inverters later on. Most components like wires, fuses, disconnect switches, and inverters will be available from local hardware or auto parts stores.

Basic Electrical Concepts

In previous project posts, I've tried to pass on hands-on knowledge of how to build solar circuits. However, I rely on a common foundation of electrical concepts such as voltage, current, resistance, etc. I assume that my readers are familiar with these concepts, but this is not always a valid assumption. This post covers some basic electrical concepts that need to be understood by anyone wanting to work with electrical solar circuits. Each definition below includes links you can follow to get more information on that topic.

Electrical Charge

Charge, abbreviated 'Q' is a specific quantity of electrons. Specifically, Q = 6.25 x 10^18 electrons, which is one Coulomb. This measurement does not rely on time. For instance, one cubic centimeter of copper contains 13,622 Coulombs or 13,622 Q of free electrons.

More Info:

- Charge & Coulomb's Law
- Electric Charge
- Speed of Electricity

Electrical Current

Current is a measure of the flow of electrons. It *does* depend on time and is expressed as Amps, abbreviated as 'I'. Specifically, one amp is equal to a flow of one Coulomb of electrons per second.

Mathematically:

$$I = \frac{Q}{t}$$

(Coulombs / seconds)

More Info:

- Voltage, Current, and Power

Amp-Hours

Closely related to the concept of Charge and Current is Amp-Hours, which is a common way of rating batteries.

If you're good with math, you might note an interesting detail. If you multiply amps (Q/t) by time (t), the 't's cancel and you left with Q, or Charge. So, mathematically, amp-hour and charge are the same thing. Why use two different terms to describe the same thing?

Mathematically, Charge and Amp-Hours work out to be the same quantity, but in reality, a batteries ability to deliver charge is time dependent. You get many more Coulombs of charge out of a battery over a long period than then you'll be able to get over a short period. This is because the battery needs time for it to change potential chemical energy to electrical energy. This is one reason why amp-hours are used to describe battery capacity rather than charge.

In reality, a batteries actual charge capacity (in Amp-Hours) is always less than its theoretical charge capacity (in Coulombs). The theoretical charge capacity never changes, while the amp-hour capacity of a battery will decrease as it ages. This is another reason why the term Amp-Hours is used instead of Charge when talking about the capacity of a battery.

More Info:
- Understanding Battery Ratings
- Ampere-hour
- What is an Amp Hour

Voltage

The simplest analogy to describe voltage is water pressure. If you imagine that the electrons are like water, then voltage is the analogous to water pressure. If there is no pressure, then there is no flow, and hence no current. Charge may still exist, but no amperage exists because those electrons aren't moving.

More Info:
- Voltage
- Voltage, Current, and Power

Resistance

Extending the water analogy, resistance would be similar to the size of the hose. More water can flow through a large hose than a small one. Similarly, current can flow more easily through a bigger wire than a smaller one. Small hoses and small wires both have more resistance.

More Info:

- Electronics/Resistors
- Circuit Theory/Resistors
- Resistive Circuit Analysis

Measuring Voltage, Resistance, and Current

In a nutshell, electricity comes down to three things: Voltage, Current, and Resistance. Things like 'charge' and 'amp-hours' are different ways of expressing these three basic concepts. In real world practice, you can measure all three elements of an electrical circuit with a digital multimeter (DMM). These devices go by other names such as multifunction meters, volt meters, amp-meters, ohm-meters, etc. The last three are actually different meters, but a multimeter can perform all three functions.

A multimeter is a bit like a swiss army knife for electronics. It's the first tool anyone should turn to when trying to troubleshoot an electrical circuit. The good news is that they are widely available and easy to obtain.

The Two Most Useful Equations in Electronics

There are two important equations that are used in every electrical project. A person can usually debug an electrical circuit using only these two equations, so long as they are good with logic or algebra. However, before we can discuss them, we need to cover two more definitions.

Electrical Energy

Energy is measured in units of joules. Energy is a way of measuring work, and is abbreviated in equations as ‘W’. Like charge, energy is not dependent on time, and also like charge, it is rarely measured directly.

More info:

- Circuit Theory: Energy
- Electronics: Energy

Power

Power is the use of energy with respect to time. It is much more practical to measure power than energy directly because time is always moving. Power is abbreviated as ‘P’ in mathematical equations and is measured in units of watts. In equation form, the relationship of power to energy is written like this:

$$P = \frac{W}{t}$$

Stated as “power is equal to joules per second”.

Horsepower is also a measure of power. Specifically, 1 horsepower is equal to 746 watts:

$$1HP = 746watts$$

More info:

- Electronics: Power
- Electric Power
- Horsepower

Ohm’s Law

The first equation, which is hands down the most important equation in electronics, is Ohm’s Law. It is mathematically expressed as:

$$V = I * R$$

In english, this would be stated as voltage equals current times resistance. Voltage here is measured in volts (V), current in amps (I), and resistance in Ohms (Ω).

Ohm’s Law is so powerful because it governs all electric circuits. If you know two of the above variables – in any circuit – you can figure out the third. Consequently, you can arrange the equation to solve for current or resistance:

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

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

The Power Equation

Everything comes back to power. Think about it. Your engine puts out a certain amount of horsepower, an electric motor puts out certain amount of watts, your lights are have a certain wattage rating; so does your electric heater. Power is the tangible product of electrical energy in motion. For this reason, the power equation is arguably the second most important equation in electronics:

$$P = V * I$$

Stated in english: power equals voltage times current. It can also be rearranged to solve for the other variables:

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

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

One of the most practical uses of this equation is to measure the current draw of a device. Here is an example:

Example

Here is an example: This Rule Marine Bilge Pumpdraws 2.1 amps:

How much power does it use?

Using the Power equation, 12 volts times 2.1 amps equals 25.2 watts!

$$12 * 2.1 = 25.2$$

Let’s say we didn’t know the current draw but we read the box and saw the pump was rated for 25 watts at 12 volts. We can determine the current draw because 25 watts divided by 12 volts equals 2.1 amps (approximately):

$$\frac{25}{12} = 2.1$$

Now, if we wanted to build a solar pond pump with this pump, we know our solar panels would have to generate 25 watts (or 2.1 amps at 12 volts) in order to power our system. That’s pretty useful information!

Understanding Battery Ratings

A battery rating is a measure of how much energy is stored in the battery. Measuring the capacity of a battery is a difficult thing to do because batteries are usually built for a specific application and the amount of charge they hold varies drastically with temperature and age. A batteries capacity decreases as it gets colder and increases as it gets warmer.

Battery Rating Basics

The most basic way of describing a batteries capacity is with the following equation:

$$\frac{Capacity}{CycleTime} = BatteryRating$$

Where Battery Rating is in amps, Capacity (abbreviated 'C') is in amp-hours, and Cycle Time is in hours.

<u>Here is an example:</u>

A battery with 100 amp-hours of Capacity can deliver 1 amp (Battery Rating) for 100 hours (Cycle Time). This would also be known as the C/100 rate. Likewise, the same battery should be able to deliver 100 amps (Battery Rating) for 1 hour (Cycle Time), which could be described as the C/1 rate.

While this works out to be a nice mathematical formula, it's not entirely accurate. Batteries are able deliver current for longer if they are discharged at a lower rate (less amperage). Likewise, they deliver less current than the formula calculates for high discharge rates. To model this 'non-linearity', engineers use Peukert's equation. However, the above equation is a good-enough rule of thumb for every-day use.

Amp-Hour Rating

All batteries are rated with an 'Amp-Hour' capacity. This is closely related with the above equation, but is not exactly the same thing. The Amp-Hour (AH) rating labeled on batteries is actually its C/20 rate or 20-hour discharge rate. As long as the battery is discharged over a 20 hour (or longer) period, it will delivery 100% of its rated capacity. If it is discharged in less time (at higher currents), it will deliver less capacity.

Continuing our example above, a battery rated for 100 amp-hours can deliver 5 amps over a 20-hour period.

Cold-Crank Amps

Another very common rating, especially for starting batteries, is the Cold-Crank Amps or CCA rating. I feel obligated to point out that starting batteries are not the type of battery that you want to use for a solar system, but I'll cover this rating to be thorough.
The CCA rating is the amount of current that a starting battery can discharge for 30-seconds at a voltage greater than 7.2 volts. Note that this assumes the battery is fully charged and at 0°F (-17.8°C).

There are other forms of this rating such as Cranking Amps (CA), Marine Cranking Amps (MCA), and Hot Cranking Amps (HCA). These are all slightly different variations of the CCA rating. Here is the conversion:

Rating	Amp Rating at °F (°C)	Conversion to CCA
Cranking Amps (CA)	32 (0)	CCA = CA * 0.8
Marine Cranking Amps (MCA)	32 (0)	CCA = MCA * 0.8
Hot Cranking Amps (HCA)	80 (26.7)	CCA = HCA * 0.69

Reserve Capacity

Most deep-cycle batteries are rated at a reserve capacity, measured in minutes. Deep-cycle batteries are the best for solar applications and this rating is the most informative for solar powered home applications. The reserve capacity is the amount of time that a fully charged battery at 80°F (26.7°C) can deliver 25 amps until the voltage falls below 10.5 volts.

When looking for a deep cycle battery for your solar application, sometimes a manufacturer will rate the batteries in amp-hours and sometimes they'll rate them in reserve capacity. Here is an example to help you convert between the two:

Using the equation at the top of the page, we know that a 100 AH rated discharged at 25 amps should last 4 hours or 240 minutes:

$$\frac{100AH}{25A} = 4H$$

Thus, it’s reserve capacity is 240 minutes. However, since 25 amps is quite a bit higher than the 20-hour rating (of 5 amps), we know that we’ll actually get less than 4 hours.

Amp-hour, Cold Cranking Amps, and Reserve Capacity are the most common battery rating that you’ll see. There is a plethora of other standardized ratings out there for special applications, but for solar applications, you’ll want to pay the most attention to the amp-hour and reserve capacity ratings. These will give you the best estimate as to how long you’ll be able to power a load with a battery.

Read This Before Buying A 12v Solar Panel

Many people who decide to purchase a 12 volt solar panel do so in order to charge a 12 volt automotive battery. They want to use a solar panel outputting 12 volts to charge a 12v battery – makes sense right? Unfortunately, it's not that simple.

Panel Voltage Should Be 1.5x Higher

Automotive, 12v batteries are only *nominally* 12 volts. During operation they will vary from 13.5 volts down to 10.5 volts. Additionally, a solar panels 12v output will undergo some loss before it actually reaches the battery. These losses come from the internal resistance of the panel, the voltage drop across a protection diode, the resistance of the connecting wires, and finally the internal resistance of the battery.

For this reason, solar power experts recommend that solar panels be rated for an output voltage that is 1.5 times greater than the battery to be charged. In this case, that would be 18 volts (nominal). This gives room for voltage drops between the panel and the battery so that by the time the energy reaches the battery it still has enough voltage to charge it.

Use a Protection Diode

If you are purchasing a 12v solar panel for use in a battery powered system or for charging batteries, be sure the panel either comes with a protection diode or you know how to install one. The best option is to purchase a charge controller to sit between the battery and panel in order to ensure they 'play nice' together.

Electrical current is often analogized to water flow. A diode acts just like a one-way valve, allowing electrical current to flow one way. In this case, we want the current to flow from the panel to the battery. At night, the voltage of your 12v solar panel will decrease far enough that the battery will be able to discharge into the cells. This will fry your panel! A simple $0.10 diode will prevent this from happening.

Ensure The Proper Power Rating

In the event you want to use a solar panels 12v output to drive a system directly (no batteries involved), then the situation changes. You do in fact want a 12v solar panel for this system and no diode is needed so long as there is no way for energy from somewhere else in the system to discharge into the panel at night. In this case be very wary of the power rating of the 12v solar panel.

If you are trying to run a 15 watt pump with a 12v solar panel, you would want the solar panel to be rated for 15 watts, right? Wrong.

A pump or other load is typically rated at the power required for operation. The power rating for a solar panel is the maximum power output in full sunlight. If it’s a cloudy day or the panel is partially shaded, you won’t get anywhere near the rated power. For this reason, solar power experts recommend that the power rating of a solar panel be two (and preferably three) times greater than the load you desire to power with it. In this example, you’d want a 45 watt, 12v solar panel in order to power a 15 watt pump.

Since the pump won’t take more than 15 watts at 12 volts, it’s OK to connect a solar panel with a high rating to it. Just make sure the voltages match.