A Short Treatise on Practical Solar Power

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The allure of long term free power from the Sun is strong, and with the recent drop in the price of solar panels, it is becoming more affordable.

Although the physics of generating solar power is the same in all cases, the practical approach to solar is radically different depending on whether you are simply trying to power a station for Field Day or other portable work, your shack, or your entire house.

Even here in the Pacific Northwest on the West side of the Cascades, it is possible to effectively use photovoltaic power.

For everything to work right, the first step of the process is to make sure you have a spot where there is an uninterrupted path between the Sun and where your panels are going to be mounted or deployed.

The second step is to properly size the system: You need to figure out how much power your system will have to supply, if you are going to store it, and how much storage is required.

Let’s look at the basics: Solar panels provide DC power to a controller, which regulates or converts the DC voltage for system use and battery charging. Larger systems are more complicated, and typically use inverters to convert the low voltage DC to standard AC.

Due to current losses in low voltage wiring, 12 volt systems are typically limited to 500 watts. If you need to supply more instantaneous or steady power than that, you should go to a minimum of a 24 volt battery.

The least complicated system is the portable or Field Day station, where solar panels and batteries are temporarily set up, the system used, and then packed away again in a few days’ time.

Let’s assume this will be a 12 volt system, and it is used to power two 12 volt transceivers: A 100 watt HF rig, and a 50 watt VHF or UHF of some type.

The standard unit of measure of power is the Ampere/Hour, or how many Amps a load draws over a period of hours. Typical 24 hour power requirements would be along the line of 36 Ampere/Hours (A/H) for the HF rig, and 24 A/H for the VHF/UHF.

The math is based on 1 amp receive and ½ amp standby for both, 20 A transmit for the HF rig, and 10 amps transmit for the VHF or UHF. This assumes a duty cycle of 5% transmit, 5% receive, and 90% standby (value may go up a bit due to skewing of use during FD conditions).

Now a word about batteries: Forget using a standard car battery. They are classified as ignition cells, and do not like being below 75% charge state, ever!

You can ruin a car battery by repeatedly drawing it down to a low charge state, then recharging it.

The proper battery to use would be a marine, golf cart, or other true deep discharge battery that is designed to be cycled to a low charge state and then charged up again. More on site batteries later…

The standard car battery sized 12 Volt lead acid deep discharge cell has about 80 A/H charge available. That means that over a specified period (usually 20 hours), you can pull so much accumulated current from the battery. At a 20 hour rate, an 80 A/H battery fully charged will deliver approximately 4 amps per hour (80 A/H divided by 20 hours). The faster you pull the current, the less you get. The slower the discharge, the more overall power you get before having to recharge.

So, for our example, if we need 60 A/h in a 24 hour period, a single standard deep discharge battery should work. For two days, two 12 volt batteries in parallel should work without needing to be recharged at all.

To figure out recharging the batteries, we need 60 A/H per day of current, plus about 10% (Lead acid batteries are about 90% efficient at converting charging current into the chemical power stored in the plates).

So, we need about 66 A/H per day to charge the batteries. And with a 90% efficiency for an MPPT controller, maybe another 6 Amps, for a grand total of 72 A/H.

Now we come to the concept of Insolation, or the amount of sun you can depend on averaged over time in a particular area. If you use the charts at http://www.ecy.wa.gov/climatechange/greenenergy_maps.htm , you'll see that for year round use, you can depend on an average of about 4 hours a day of usable sunlight in this area. The winter and rain seasons will be worst, but during the summer, we can have ten or more hours of good sunlight. Please be aware that when the sun is hidden by clouds, panel output can go down to as little as 5% of normal, full sun output!

For FD conditions with sun, you'll get more than 4 hours.

But, if we do the math like this is going to be a home installation, 72A/H divided by 4 hours = 18 Amps charge current per hour needed. Standard 150 watt "12 Volt" panels run about 7-8 amps, so this is about half way between two and three panels needed for operation. For extended operation, you'll want to build the system much more robust. We will discuss the calculation of safety factors in such buildouts later.

Warning! Solar panels put out more voltage than one would think: A typical "12 volt" panel will put out about 21 volts open circuit! Don't connect your equipment or battery directly to a solar panel!

All of this power needs to go through a controller: This is a device that in simplest terms that limits charging voltage so that the battery doesn’t over charge, and keeps the load (your radio equipment!) at a steady, safe voltage.

As a quick rule of thumb, at 77 degrees F, if the charging voltage goes over 14.2 volts, your battery will begin gassing. At this point, the voltage is high enough to break apart the electrolyte into Hydrogen and Oxygen. This is really, really bad, especially if you have a sealed cell like an Absolyte glass mat battery! Hydrogen is also a fire and explosion hazard.

Controllers vary in performance: The best “bang for the buck” is an MPPT (Maximum Power Point Tracking) controller: They act as a giant DC-DC converter, and instead of just chopping off and wasting the voltage above what is needed, it sets the panel voltage to the maximum power transfer point and converts better than 90% of your panel output to usable power. That’s about 20-25% better than a non-MPPT controller.

The downside is that MPPT devices sometimes go into an oscillation mode and pump power at a high pitched audio frequency into the line, which may need to be filtered out. The devices themselves can also cause MF/HF RFI that may need to be mitigated.

For where we live, panels should be pointed South.

Most panels are fixed due South, at about a 60 degree angle away from horizontal. If the panel is not movable, set it so that it is broadside to the winter Sun, as you’ll want to maximize collection at that time of year, as that’s when everything counts most. You’ll have plenty of excess power in the summer.

I’ve monitored the receipt of energy from the Sun, and it’s about half in winter as compared to summer (approximately 400 Watts/Square Meter vs. 1000 W/M squared).

There is an additional amount of energy to be generated by tracking the Sun, but this also adds greatly to the complexity of a fixed installation.

For proper operation, it is vital that none of the panel is shaded. Any cell that is not directly illuminated acts as an open circuit, and keeps any cells in that series string from delivering power.

For truly remote installations requiring 100% reliability, use panels that have long, narrow strips instead of the normal round cells. If a part of the strip is covered, the rest of it still conducts, and power continues to be generated.

Foldable panels will work well, but don’t have the longevity or mechanical stability of fixed panels.

Let’s take the scenario of a solar powered shack at home next.

This can vary from a simple installation to run one or two radios, all the way to fully powering a large shack.

It's assumed that either install will require storage batteries, and an inverter for a fully solar powered shack.

Again, you will need to figure out how much power you need. If you can't figure out power on AC operated equipment, you can always install a Kill-A-Watt power monitor (http://www.p3international.com/products/p4400.html), and use that to see how much power equipment uses in standby and operating modes. Then figure how many hours a day you use the equipment in each mode, and you can calculate the amount of watts used. You can divide this by your battery voltage, add ten percent for conversion inefficiencies, and come out pretty close with an A/H reading.

Don't forget phantom loads like transformers or wall-warts!

Let's run a sample calculation: You're running a Kenwood 820-S for 8 hours, 2 of it transmitting (680 Watt/Hours), 200 watts of lighting for 8 hours (1600 W/H), a 50 watt 2M rig (24 hours, 5/5/90 duty cycle, 288 W/H), and various other loads for a grand total of 2568 watts… Because this is a big system, you're feeding it with a nominal 24 volts (really about 28). 2568 W/H divided by 28 volts = 91.7 A/H per day. Add 20% for losses in the inverter, controller, and battery, and you need about 110 A/H. Plugging in 4 hours for Insolation, you need 27.5 A/H at 28 volts nominal from your panels. Again, a 150 watt, 12 volt panel delivers about 7-8A, so you need 4 x 2 or 8 panels (4 parallel arrays of 2 12 Volt panels in series).

Bear in mind, that this is an absolute minimum, with no safety factor!

Before we address a solar safety factor, we need to discuss batteries some more.

This is easily going to be the place where you spend the most amount of money, unless you luck into a site that's being decommissioned and you can get the batteries for free.

We spent $12,000 (and this was a discount!) for a 3000 A/H, 24 volt stack of Absolyte glass mat batteries at one site!

Buy the best quality batteries that you can. I will say it again: Buy the best quality batteries that you can.

Remember that ignition cells are out! Verify that a battery is truly a deep discharge battery, and not an ignition cell being mis-marketed. Look up the specifications, and see how may charge/discharge cycles they are rated for.

For optimum performance, it's best to buy all of your batteries at once, and ensure that they are from the same production run.

If you don't have many thousands of dollars up front, you can settle on a particular type of battery that you can buy every so often and add to your stack in series/parallel to boost your capacity. Don't mix battery types!

The Absolyte batteries we use are rated for 20 years. Your mileage will vary widely according to the batteries you buy, and how you deploy them!

The two most important things after battery quality are storage temperature, and charging voltage. Batteries are rated at 77 degrees Fahrenheit. When you go above that temperature, their lifetime begins to drop rapidly. Heat is your enemy!

Also, remember the gassing issue if you have the charging voltage too high.

Two more things to consider are battery placement, and temperature compensation. If the temperature in your batteries differs by more than 5 degrees F, some will over charge, while others under charge. Keep this in mind if you stack them in racks above one another.

Also, a controller with a temperature compensation lead that can be attached to the battery is preferable to one without.

The charging voltage and gassing points change with temperature.

It is necessary to reduce charging voltage at higher temperatures, and increase them at lower temps. The controllers with compensation do this automatically.

We have had 12 volt batteries safely charge at almost 15 volts in the winter, which would have quickly gassed and killed the same battery in summer!

Lead acid cells can give off sulfuric acid gas and other corrosive fumes, as well as highly flammable Hydrogen gas.

The batteries should be located in their own shed or building outside the shack, and be well ventilated.

Wiring between the batteries, controller, and inverter should be as large in size and short in length as possible to reduce resistance losses.

Another area where MPPT controllers really shine is that they can frequently take solar inputs at up to 100 volts DC. This will allow you to wire multiple panels in series so that you can use smaller diameter wire.

At one site, we wired up the panels in series so that four panels were supplying 80 volts at 14-16 amps to the controller, with a second stack doing the same.

The current loss with this series arrangement was only $1/16^{th}$ that of running the panels in parallel.

Of course, safety must be addressed, and panel frames need to be grounded to protect against lightning, batteries need to be fused and have disconnects, and all wiring done to state and national standards.

In designing a system, you have to figure out how deep you want to discharge the batteries. As a general rule, even with deep discharge batteries, you don't want to pull them very low. Limiting the discharge to 2/3 of full charge, or even 50% is wise.

The number of charge/discharge cycles they will withstand usually goes down the deeper you pull them. Check the specifications on prospective batteries for service life vs. repeated depth of discharge!

Again, you can pull the better ones down further, but do you really want to do that on a daily basis? That large system only dropped to 66% charge state after three days at rated load, leaving 2/3 of the battery in reserve.

Another thing to consider is prolonged loss of sunlight: It's not uncommon to have several days in a row where the sun doesn't shine. How much of a safety factor do you want to include? With the earlier example, it would take almost ten days for the site battery to be depleted due to lack of sunlight. So far, we've never had to start the backup generator other than for its weekly routine run!

A quick word on inverters: Buy only true sine wave inverters! Square wave or modified sine wave inverters are to be avoided.

Getting back to our real world shack example needing about 110 A/H at 24 volts: To work in a proper safety factor, you will need from 1000-1200 A/H at 24 volts.

The Trojan T105RE supplies 6 volts at 225 A/H, so you'll need 5 parallel strings of 4 batteries in series, or 20 of them at about $220 each, for $4400…

Powering an entire house is a matter of scaling up a shack. Unless you are a Microsoft Millionaire, you will need to change the way you heat and cool, and buy energy efficient appliances: The secret to a successful solar house is to shed huge heating and cooling loads: Shift heating, cooking, and water heaters to gas, and substitute fans for conventional air conditioning. Buy refrigerators and freezers that are super insulated, so they won't run as long as conventional ones.

By cutting down unnecessary loads where you can, you can make solar much more economical, and have performance that rivals commercial power.