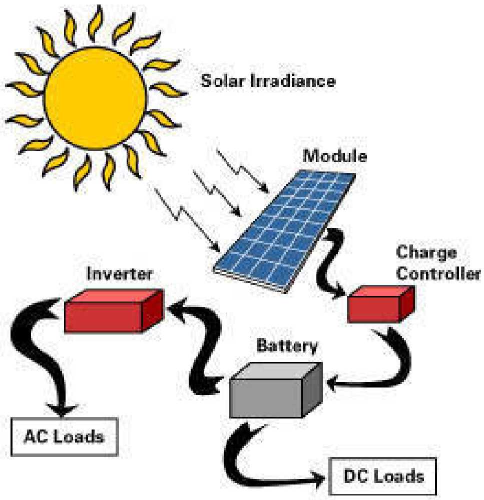
Windy Dankoff's Home Solar System - Part 1

by Windy Dankoff



My wife and I found our perfect home in the woods, except for one thing -- it already had electricity from the grid. Half of the staff at Dankoff Solar lives with photovoltaic power, so the Dankoffs certainly should! We just installed a PV system to pump our water and to power some of the circuits in our house. It also gives me a way to test new products and ideas. I will describe the power and water supply systems now, so you can learn from my experience. In Part 2, I will describe the how I am tying power into the house, and reducing the lighting load.

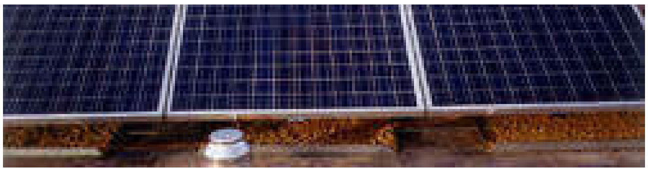
DESIGN GOALS. I wanted my system to pump all of our water, to supplement the house, and to keep some of our circuits going during power failures. I wanted a PV array that wouldn't cost a fortune or be visible from a mile away. Therefore, energy efficiency would be a priority. I also wanted a battery bank to carry us through a power failure of several winter days.

SYSTEM LOCATION. I installed the PV array and power system near the water well, 140 feet from the house. Our wellhead is located at the bottom of a covered pit that also contains the pressure tank and water filters. The pit is 6 feet deep and 7 feet in diameter. It is made of galvanized steel culvert material. I called the well driller and had him install a similar pit to contain the power center, batteries and inverter. Many of our dealers have used this "power pit" concept. It gives protection from temperature extremes, it's unobtrusive, and it's cheap (as long as the location doesn't have a high water table). I also put in some shelves for storing food. The PV array is installed nearby, on a pole-top tracker.

PV ARRAY AND TRACKER. To size the PV array, I did a load calculation for summer drought conditions, to supply 500 gallons per day. Working from the pump specifications, I determined the daily watt-hours to be about 1000. I chose our 85-watt, BP Solar BP-585 modules, because their extra quality and embedded-grid cell construction makes them more efficient, and thus more compact, than others (see "BP Solar Modules: Independent Lab Test"). I figured on a 9-hour peak solar day, assuming the use of a solar tracker during the driest summer weather. Calculation indicated that only two 85-watt modules would produce more than enough energy for water lift and pressurizing -- Surprising, isn't it?

I decided to go with four of the BP modules. This will give us enough surplus energy to run my home office and some compact fluorescent and LED lights in the house. In case of a long power failure, the battery bank would have good capacity to run our Conserv refrigerator, our gas heating system, and the blower that distributes heat from our wood stove, for about four winter days.

The solar tracker gives the array a 40% average energy gain during the warm half of the year, when we need the most water. I chose the Zomeworks Track Racktm because it is simple and cost-effective. The only moving parts are the rack axis, a shock absorber, and the refrigerant fluid that flows from one side to the other to tip the balance. I used the new "universal" tracker that accommodates various sizes and brands of PV module. It took about two extra hours to measure and place the parts to fit my modules, but it worked out fine. The tracker requires a 3" pipe for its pole but that is not strong enough to handle the extra height, so I had 5 feet of 3" pipe welded to a 4" pipe. After we did the assembly and wiring on the ground, a neighbor came over with his backhoe to lift the finished array onto the pole. It tracks beautifully, even on windy days.



SYSTEM VOLTAGE

DC voltage standards are 12, 24 and 48V. 24V is a happy medium and is most common for a system of this size. A 12V system would require four times the wire size in all DC circuits, and would necessitate wiring battery sets in parallel, which is not ideal (see Batteries: How to Keep Them Alive). A 48V system was not an option because 48V charge controllers and inverters are only available in sizes much larger than we need.

CHARGE CONTROLLER

I'm testing a new Solar Boosttm 50 charge controller with MAXIMUM POWER POINT TRACKING. I have observed over 20% gain in charge current, compared to a traditional controller. (See "Solar Boosttm MPPT Charge Controllers")

STORAGE BATTERY

I selected a battery bank of 970 amp-hours capacity. This is relatively large for the array and the load on the system. I wanted a large set because it allows future expansion and gives us a good reserve during power failures. I chose batteries of the conventional wet cell lead-acid variety, made by Surrette/Rollstm. They have a high reputation for quality and reliability. I expect these batteries to last for at least 15 years of our relatively light service. Lowering the batteries into the pit was easy. Rolls dual container batteries allow you to unbolt and remove individual 2V cells. It is then safe to suspend them by their terminals. We used a 4:1 rope and pulley system suspended from a step-ladder, to lower each of the 12, 95-pound cells down one at a time.

WATER WELL PUMP AND STORAGE TANK

I installed the most energy-efficient pumping system that I could, using two DC pumps and a storage tank. This system uses less than half of the energy (watt-hours per gallon) of a conventional AC pump powered by inverter (see Inverter Sizing for Submersible Pump Applications). By utilizing a storage tank, the well pump could be set to run only during daylight hours to eliminates some battery loss. The tank provides a safety buffer in case of pump failure. The additional cost of DC pumps and a storage tank is compensated by savings in the power system, which would have been doubled in size to run our original AC pump. The storage tank is made of drinking water-grade polyethylene, designed for burial. It stores 1200 gallons, which is sufficient for 4 to 8 day's supply, depending on the season.

Our water well is 285 feet deep. It had a 230V, 1HP submersible pump. After I got the power system, storage tank and pressure pump working, I used the AC pump one last time to fill the tank before our well driller pulled it out. Discoloration on the drop pipe indicated our static water level to be around 125 feet, so I chose to set a SunRisetm Submersible pump at 150 feet. Five days later (still with a half-full tank of water) Paul and I lowered the SunRise pump by hand, using 3/4" flexible polyethylene pipe.

Lead-acid batteries are often considered to be the "weak link" in renewable energy systems. However, todays renewable energy batteries are better than ever, and so are the devices that regulate and protect them. Battery failures are rarely the fault of the batteries themselves! Follow these guidelines to avoid the vast majority of all battery problems. **Size a battery bank and PV array properly**

A battery bank should be sized (as a minimum) to a capacity of 5 days of load. Energy use in most home power systems increases over time, so consider sizing larger than that. Why? After 1 year of service, it is NOT advisable to enlarge a battery bank by adding new batteries to it, because batteries' voltage response changes with age. Stray currents flow, causing losses and failure to equalize. A PV array, if it is the primary energy source, should be sized to produce (on average) 30% more energy than the load requires. This compensates for battery losses and for less-than-average charging conditions. Luckily, a PV array can be expanded at any time. **Buy high-quality batteries, selected for your needs**

You get what you pay for! Good deep-cycle batteries can be expected to last for 5 to 15 years, and sometimes more. Cheap batteries can give you trouble in half that time. Buy from a reputable source. **Avoid multiple parallel strings**

The ideal battery bank is the simplest, consisting of a single series of cells that are sized for the job. Higher capacity batteries tend to have thicker plates, and therefore greater longevity. Having fewer cells will reduce the chance of randomly occurring defects, and reduces maintenance. Suppose for example, that you require a 700 Amp-Hour bank. You can approximate that by using 3 parallel strings of golf-cart batteries (220 AH), or 2 strings of the larger L-16 style batteries (350 AH) or a single string of larger, industrial batteries.

Under no circumstances is it advisable to install more than three parallel battery strings. The resulting bank will tend to lose its equalization, resulting in

equalization, resulting in accellerated failure of any weak cells. Weak cells will be difficult to detect because they will "steal" from the surrounding cells, and the system will suffer as a whole and will cost you more in the long run.

Here are some precautions to take when wiring two or more strings of batteries in series-parallel. The goal is to maintain all of the cells at an equal state of charge. Cells that tend to receive less charge are likely to fail prematurely. This can take years off of the effective life of the battery bank. A fraction of an ohm of added resistance in one battery string can reduce the life of the entire string.

(1) Connect the two main cables to opposite corners of the battery bank, and maintain symmetry in wire size and lengths. This will help to distribute current evenly through the bank.

(2) Arrange batteries to maintain even temperature distribution throughout the bank. Avoid uneven exposure to heat sources. Leave at least 1/2 inch of air space around each battery, to promote even cooling.

(3) Apply a finish charge at least every 3 weeks (bring every cell to 100% charge). **Prevent corrosion**

In flooded battery installations, corrosion of terminals and cables is an ugly nuisance that causes resistance and potential hazards. Once corrosion gets hold, it is hard to stop. The good news -- it is easy to prevent! Apply a non-hardening sealant to all of the metal parts of the terminals BEFORE ASSEMBLY. Completely coat the battery terminals, the wire lugs, and the nuts and bolts individually. A sealant applied after assembly will not reach all around every junction. Voids will remain, acid spatter will enter, and corrosion will begin as soon as your installation is finished.

Special compounds are sold to protect terminals, but you can have perfectly good results using common petroleum jelly (Vaseline). It will not inhibit electrical contact. Apply a thin coating with your fingers, and it won't look sloppy. If wire is exposed at a terminal lug, it should be sealed airtight, using either adhesive-lined heat-shrink tubing or submersible rubber splice tubing or submersible rubber splice tape. You can also seal an end of stranded wire by warming it gently, and dipping it in the petroleum jelly to liquify, and wick it into the wire.

It also helps to put the batteries over a floor drain, or in a space without a floor, so that they can be rinsed with water easily. Washing the battery tops (about twice per year) will remove accumulated moisture (acid spatter) and dust. This will further reduce corrosion, and will prevent stray currents from stealing energy. Batteries that we have protected by these measures show very little corrosion, even after 10 years without terminal cleaning. **Moderate the temperature**

Batteries lose approximately 25% of their capacity at a temperature of 30 F (compared to a baseline of 77 F). At higher temperatures, they deteriorate faster. Thus, it is desirable to protect them from temperature extremes. If no thermally-stable structure is available, consider an earth-sheltered enclosure. Where low temperature cannot be avoided, get a larger battery bank to make up for the loss of capacity in the winter. Avoid direct radiant heat sources that will cause some batteries to get warmer than others. **Use temperature compensation**

When batteries are cold, they require an increase in the charge voltage limit, in order to reach full charge. When they are warm, they require a reduction in the voltage limit in order to prevent overcharge. Temperature compensation is a feature in many charge controllers and power centers, as well as in the back-up chargers in some inverters. To use this feature, order the accessory temperature probe for each charging device, and attach it to any one of the batteries. **Use low-voltage disconnects**

Discharging a battery to exhaustion will cause immediate, irreversable loss of capacity and life expectancy. Your system should employ low voltage disconnect (LVD) in the load circuits. Most inverters have this feature, and so do many charge controllers and power centers. Don't depend on human behavior to prevent over-discharge. It can be caused easily by accident or by an irresponsible user. Again, most inverters have LVD built-in but if there are DC loads on the system, please incorporate an LVD device.

Bring batteries to a full state-of-charge at least every 3 weeks

Bring the batteries to a full state-of-charge (SOC) at least every 3 weeks. This reduces internal corrosion and degradation, and helps to insure equalization, so that any weaker cells do not fall continually farther behind. A full SOC may occur naturally during most of the year, but do not hesitate to run a generator when necessary, to bring the batteries up. Information like this should be posted at the power center. For more details, refer to the instructions for the inverter/charger and for the batteries.

How do you know when a battery is 100% charged?

The "charged" indicator on most PV charge controllers means only that battery voltage is relatively high. The SOC may be approaching full, but is not necessarily near 100% A voltmeter reading gets you closer, but it is not a certain indicator. It varies to much with current flow, temperature and time, to give a clear indication.

For flooded batteries, a hydrometer is the definitive indicating device, although not a convenient one. With it, you can measure every cell individually. Obtain one from a battery or automotive supplier. Even the cheapest hydrometer is fine. Rinse it after use, and keep it clean. An amp-hour meter is the most informative and user-friendly way to monitor SOC. For sealed batteries, it is the ONLY definitive method. See next paragraph.

Install a System Monitor

Would you drive a car with no dashboard? Metering is not just "bells and whistles". It is necessary to help you to read the status of the sytem. Many charge controllers have indicator lights and readouts built-in. For a full-scale remote home, consider the addition of a digital monitor, like Trace TM-500, Tri-Metric, E-Meter or Omni-Meter. These devices monitor voltage and current, record amp-hours, and accurately display the state-of-charge of the battery bank. They also record more detailed information that can be useful for troubleshooting. The monitor may be mounted in another room or building, for handy viewing. **How to Read a Hydrometer**

A hydrometer will help you to determine whether the battery bank is getting fully charged, and whether any individual cells are falling behind. You should be aware that a hydrometer will give you false readings under the following conditions.

(1) After adding water: For pure water to mix throughout the cell, it takes time and some bubbling during finish charge. A hydrometer will show a greatly reduced reading until the fluid mixes.

(2) Low temperature: As battery temperature drops, the fluid becomes more dense. A temperature compensating hydrometer is best. Otherwise, for every 10?F below 70?F, subtract 3.5 points from the reading.

(3) Time lag during recharge: As the battery recharges, the fluid becomes more dense down between the plates. The hydrometer reads the fluid above the plates. You will get a delayed reading until the fluid is mixed by the movement of bubbles during finish charge. The voltage will rise steadily, providing an indication that something is happening.

During discharge, you will get a true hydrometer reading because the fluid becomes less dense and will circulate to the top. Any time a hydrometer indicates a fully charged cell, you KNOW it is fully charged. **WARNING**

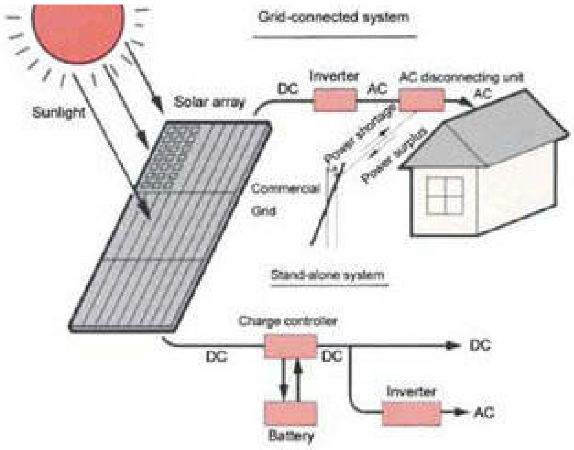
BATTERY ACID IS HAZARDOUS. When working around batteries, wear safety glasses. Get a rugged plastic bottle to keep with your service tools, and fill it with a sodium bicarbonate (baking soda) and water. Use it to neutralize accidental splash or spills and to clean normal acid spatter from battery tops. Finally, don't wear your favorite blue jeans! **Just add water**

Note: This applies only to "flooded batteries", not to "sealed batteries". The plates of every cell in your battery bank must be submerged at all times. Never add any fluid to a battery except distilled water, deionized water, or very clean rainwater collected in plastic containers. Most batteries require addition of water every 6 to 12 months. There is no need to fill them more frequently than needed to submerge the plates. Fill them only to the level recommended by the manufacturer, generally about an inch below the top, otherwise they may overflow during finish-charging.

Conclusion

Batteries are the heart of your power system. They may demand your attention occasionally, but your relationship with them need not be a struggle. With a proper installation, a little understanding and some simple maintenance, your batteries will live a long and healthy life.

Photovoltaic modules are so reliable that we forget that things can go wrong! The real world imposes temperature extremes, lightning and static electricity, moisture and wind stresses, as well as imperfect manufacturing. Here are some suggestions for testing and troubleshooting.



Selective shading test - If the array is in a parallel or series-parallel configuration, this trick will help you locate a fault without disconnecting any wiring. Find an object that is large enough to shade at least 4 cells. (A cowboy hat will do.) Shading just a few cells will drop the module's output to less than half. With the array connected andworking, monitor the current (or in the case of a nearby solar pump, just listen to it). Now, shade a portion of one module. You should see the current should drop noticeably (or the pump should slow down). If the current does NOT drop, then the module that you are shading is out of the circuit. Look for a fault in the wiring of that module, or of another module that is wired in series with it.

Fading in the heat

Occasionally somebody complains of reduced array output when the sun is hottest. Heat fade shows up most severely in battery systems. If the difference between the array voltage and the battery voltage approaches zero, then current flow can drop nearly to zero. This can also cause a solar pump to produce less than it should.

The voltage of a PV module normally decreases with temperature rise. PV manufacturers document this by showing several lines on the IV curve (the graph of amps vs. volts), or by stating it in volts per degree of deviation from 25?C (77?F). Nominal "12 volt" PV modules are designed to sustain good current flow all the way to 17 or 18V at 25?C. This allows for voltage drop at higher temperatures. If heat fade is severe, it MAY be caused by weak PV modules or by any other weak links in the power chain, including undersized wiring, poor connections and controller losses. Here are some tests to isolate these factors.

First, you can confirm heat fading by cooling the array with water while the system is operating. Monitor the current. Does it rise to normal? If so, you need to determine where the voltage drop is severe. Connect a voltmeter directly to the PV array (or it's combiner box). Disconnect the array from the controller, in order to read the open circuit voltage. If it is less than 18V (relative to a 12V configuration), then part or all of the PV array may be defective. The selective shading test (above) can help you locate weaker modules in an array.

Next, reconnect the array to the system. Under good sunlight, test for voltage drop in the wiring by measuring the voltage at the array, and then again at the controller input. Note that voltage drop in wiring will increase in proportion to the current flow. Next, test for drop in the controller by measuring the voltage at its PV input, and then at its battery terminals. Remember, if the battery is fully charged, the controller SHOULD drop the voltage. If that is the case, you can bring down the battery voltage by turning loads on. When the battery is at less than 13.5V (relative to a 12V system), the controller should allow full current to flow.

If voltage drop occurs at a single point (at a connector or within the controller) then concentrated heat will result. You may feel it, or see signs of heat damage. If voltage drop is evident at the loads (dimming lights, low voltage disconnection when batteries are not low) then check for corroded battery