A SunCam online continuing education course

Solar Power Part IV

Inspecting and Evaluating Systems

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COURSE DESCRIPTION

The current focus on energy consumption worldwide has rapidly spurred growth in the construction and installation of solar power for small structures, both residential and commercial. And today, because of that growth, the number of problems with those installations is also expanding exponentially… especially since sunlight is free, abundant, clean, maintenance free, reliable (no reported failures of the sun yet), and ***green***.

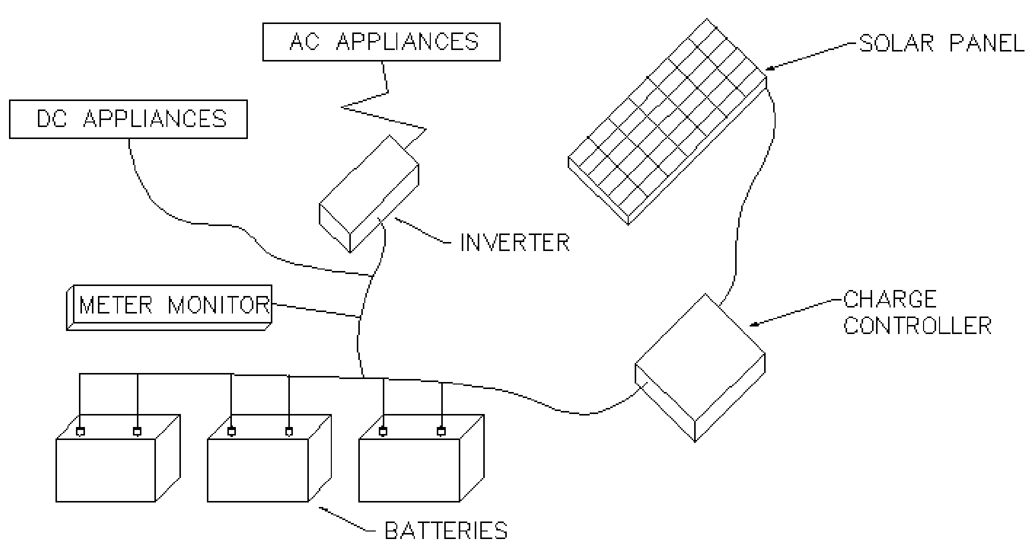
However, solar power *is only* free, abundant, clean, maintenance free, reliable, and ***green***... ***when*** it is working properly. Unfortunately, there isn't enough solar work for contractors to keep experienced staff employed. As a result, many installations are performed with inexperienced staff and problems are occurring within a year or two of the installation. Additionally, many owners/users are causing problems simply because they do not know how to properly operate and maintain the system. In this course, we will look at the process for inspecting and/or evaluating a system, problems commonly associated with solar photovoltaic (PV) systems, brief reviews of the system components, wiring issues, and some of the math… but just the calculations required for parallel and series wired circuits.

For this course, we will start "at the beginning" ... from the solar panels to the electrical outlets and the components installed along the way. This course is not intended to be all-inclusive in the evaluation and trouble-shooting of a solar PV electrical system but is intended to provide you with knowledge of how to evaluate a system and the typical problems associated with a solar PV system. Obviously, these same principles apply to a system for a larger structure but there is much more involved with larger power systems... higher voltages, amperages, and larger components. Note, that this is not the design course. The design course is entitled *"Solar Design for Small Structures"* and is also available from SunCam.

So, let's get started…

THE BASICS

The typical is comprised of solar panels (a.k.a. photovoltaic or PV panels), a charge controller, batteries, a power inverter, a meter or monitor, and the electrical distribution system (or the electrical wiring).



SYSTEM COMPONENTS

Like every manufactured item, all are subject to developing problems and, obviously, how a solar system is used after it is designed is subject to change. Therefore, a system may be functioning as it was designed but simply cannot meet the demands currently being placed on it.

WHAT YOU WILL NEED

Depending on the system you are inspecting or evaluating, you will definitely need a voltmeter, a DC ammeter. And you may need a flashlight, a screwdriver, a wrench, pen and paper, and possibly a digital camera. You may also need a ladder and a safety line if the solar panels are located on a pole, a steeply sloped roof, or a roof over a multi-story building. While you might be able to do the inspection alone, it is much easier... and generally, safer... to have an assistant. This is especially true when you are recording the monitor meter readings while you are turning loads on and off or when you are performing the Partial Panel Shading test... which we'll describe later.

STEP 1: IS THE SYSTEM PROPERLY MAINTAINED?

Perform a brief tour of the installed solar PV system looking at what components are installed, where they're installed, how they're installed, and their physical appearance. Do they appear to be well maintained or do they appear neglected? Are they easily accessible? Is there a record of any maintenance that has been performed or regular system checks? Even a quick look around will give you an indication of how the system is being used and maintained.

After completing your brief inspection of the system components, return to either the monitor meter or the charge controller to begin your evaluation.

Note in the picture below the wiring from the solar panels to the charger controller is wired without combiner boxes. Therefore, there are 6 wires coming from the solar panels that are spliced together with electrical tape and then two wires continue to the charge controller. This method of connecting the wires, while cheap and quick, is a problem waiting to happen. Again, a good contractor is invaluable for a good system installation.

STEP 2: IS THE SOLAR PV SYSTEM SIZED CORRECTLY

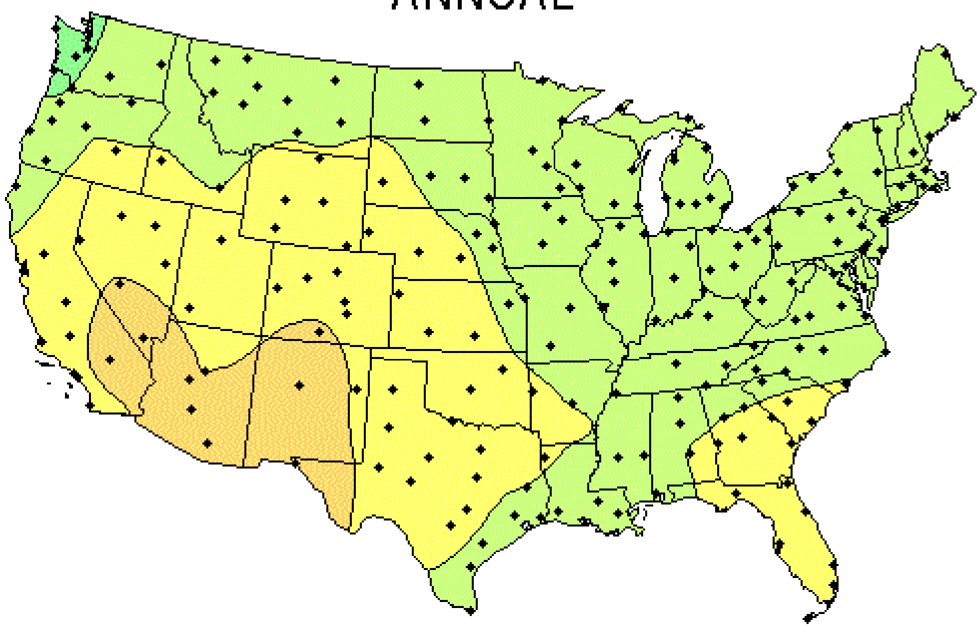
When a solar PV system is designed, ***every*** demand the end user has for power must be accounted for. Every light bulb, radio, fan, air conditioner, computer, toaster, whatever…. Otherwise, the system may experience brown-outs or black-outs because it's undersized.

Start with the designed specifications: As in any evaluation, you must know what you're evaluating. So your first task is to request a copy of the original design documents including the product specifications for each of the components installed. The owner should have a copy of all of the product manuals. If not, most can be obtained via the internet at the manufacturers' websites but will require you to properly identify the make and model of each component first. Compare these documents with the design plans and specs. Do the installed components meet the minimum design specifications? If not, are the differences significant enough to cause issues in the system performance?

Also, check the design calculations for the value of the hours of available daily sunlight used in the system and compare that to the hours available for your location (See the map below from the National Renewable Energy Laboratory Resource Assessment Program for the number of hours in your location or visit their website for more information at http://www.nrel.gov/gis/solar.html). How do they compare? Is the value used in the system design reasonable for your location? Then compare the value to the actual placement of the solar panels. Can the solar panels actually receive the sunlight hours required of them? For example, if the system calculations require 6 hours of sunlight daily but the chart shows that only 4 hours are available, then expect a problem. And if the chart shows 4 hours are available but the actual solar panel placement is such that only 3 hours are available because of shadows from vegetation or other structures, then the system design, while mathematically correct, is invalid for the site.

Average Daily Solar Radiation Per Month

ANNUAL



Flat Plate Tilted South at Latitude

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

National Renewable Energy Laboratory
Resource Assessment Program

$kWh/m^2/day$

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

FLATA1

Even if the original design plans are available, you may need to take an inventory of every electrical load that is being used in the building *today*. Then compare this current list with the original design load.

What if the original design is not available? If they're not available, you will have to re-design the solar PV system starting with a determination of the loads being placed on the system. Once again, this will require taking inventory of every item placing a demand on the system and determining the length of time each item will be used daily.

To do this you must know your end users (note that the end users may not be the owners). Know *what* they are using now and *how* they will be using the electricity in the future. Not knowing this information is setting your system up for failure again but this time with even unhappier clients... and a bad reputation for you. The best way to determine this is by interviewing the users about their daily electrical uses. Does this match up with the originally designed loads?

My experience has been that the end users are consuming much more electricity than was originally intended. In this case, the end users must conform to the original solar design usages or the system must be expanded to accommodate the increased demand. And then, if it is decided to expand the system, add even more capacity than is needed since the users will likely increase their usage again once more power is being provided. It's a never ending cycle.

Once the electrical demand inventory has been completed and verified with the original design plans, we are ready to check the system performance.

STEP 3: EVALUATE THE CURRENT SYSTEM PERFORMANCE

Using the monitor meter – The meter is used to monitor the condition of the batteries, the power being generated by the solar panels, and the user's current consumption rate. It can provide you with the information you need to help you locate the source of any system problems. Most of the monitors available in the market today can provide detailed information on the system status so take

Bogart Engineering TM-2020

advantage of the system meter that is provided. If a monitor meter is not included in the system, you will need to provide your own meter.

> **CAUTION:** You should never use cheap meters that are not intended for use with solar PV systems because they are not designed for low-voltage high-amperages and you really don't want to risk the batteries or the solar panels on cheap meters.

Also, if a monitor meter is not included, recommend to the owner that one be installed and ensure that the system's performance is monitored regularly. Also, recommend that a logbook be used to record the date, time, and meter readings for evaluation later. Any significant changes in the readings are worth investigating.

> **NOTE:** You should always check the system performance at mid-day when the solar panels are receiving full direct sunlight.

Checking the Voltage and Current readings in the system will tell you the batteries' current state and how fast they are charging or discharging. Many charge controllers display Amps, Watts, Volts, Amp-Hrs, and Total Amp-Hrs to provide easy monitoring of the system performance.

Bogart Engineering PentaMetric Meter

Typical Monitor Meter Readings

Charge State: Shows the battery's charge state based upon the amp-hour reading divided by the amp-hour capacity of the batteries. The values displayed are typically in percentages with values over 90% being considered fully charged. For example, a battery bank with a 2,000 amp-hr rating would have the following charge states:

Amp-hr reading	/	Amp-hr capacity	=	Charge State
1,900	/	2,000	=	Full (or >0.90)
1,500	/	2,000	=	75%
1,000	/	2,000	=	Low (or <50%)

Volts: Shows the real time system voltage. Typical values are:

System Voltage	Fully charged
12-Volt	14.3 - 14.9 V
24-Volt	28.6 - 29.6 V
48-Volt	57.2 - 59.2 V

Amps: Displays the charge or load current in amps that the system is currently experiencing.

Amp-Hours Used: Displays the total amp-hours used since the last time the amp-hour meter was reset. Note that for some meters, this value will automatically reset to zero once the system reaches a full charge state. So check the unit's manual to determine what is being displayed and how it is calculated.

Cumulative Amp-Hours: Displays the cumulative amp-hours used from the batteries. If available, this reading can be used to record the power consumption over a specific time period or as an indicator of the battery life. For example, if the meter is read or reset at 10 AM on a Tuesday and read again at 10 AM the next morning, you will have an indication of the power consumption over that 24-hour period... which you can use ***if*** it is a "typical" day. Checking it over 2 or more days will give you a better indication of the average power consumption per day.

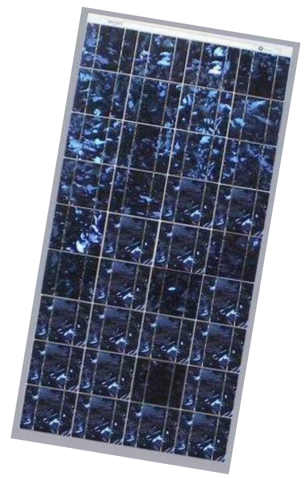
Morningstar ProStar charge controller display panel

Max Voltage: Displays the highest battery voltage recorded since the meter was reset. Using this reading, you can determine the maximum voltage the system experienced since the meter was reset. It will also let you know if an overvoltage condition occurred or if the system is charging at the proper rate.

Min Voltage: Displays the lowest battery voltage recorded since the meter was reset. Use this reading to determine if the batteries are being over-discharged. If an over-discharge is indicated, the batteries were probably damaged and will need testing.

Low Voltage Indicator: Indicates whether a voltage lower than the value set in the monitor meter has occurred. Typically, the value for the low voltage alarm/indicator can be set by the installer.

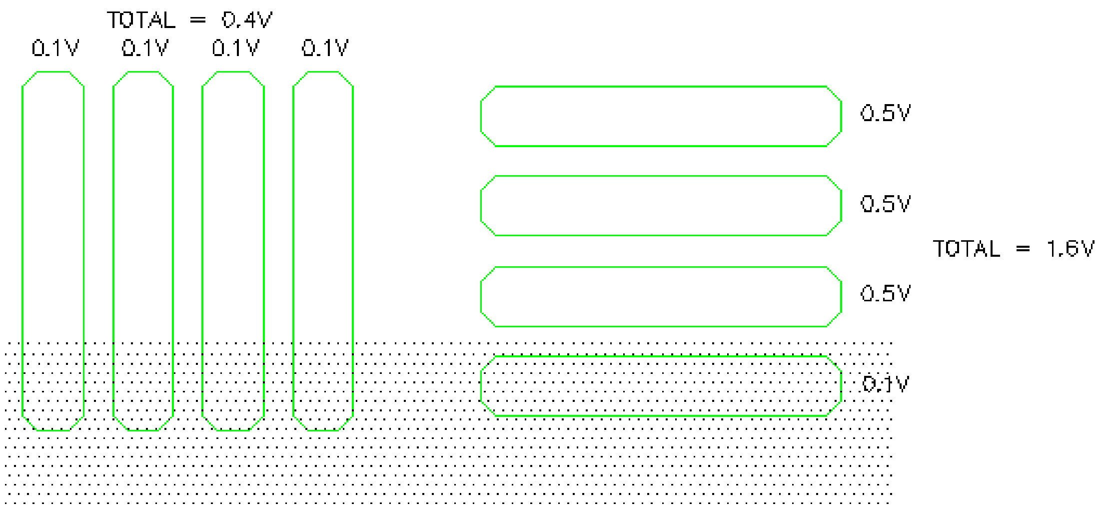
STEP 4: INSPECT THE SOLAR PANELS



If you're lucky, the solar panels will be ground mounted for easy access. However, you're more likely to find the panels located on the roof which means you may need a ladder and safety equipment to inspect the panels. While solar panels are very reliable and have no moving parts, they are susceptible to damage caused by the sun (UV damage to wiring), lightning, high winds, hail, animals, and, yes, even people... intentionally or accidentally.

Inspect the general condition of the panels. Are they clean and free of dirt and debris, leaves, bird nests, bird droppings, limbs, or fungus which may obstruct the sun's rays? Are the terminals free of corrosion? Are the mounts bent, rusted, or corroded? Is the electrical wiring in good condition? Are the electrical connections secure? Also, check for color changes in the solar panels, any indications of the panels delaminating, warping, or bent frames. Any deficiencies need to be noted and corrected.

Check for shadows. There should be full sunlight available during the peak hours of 9am to 3pm. If the sunlight can't reach the solar panels, the system will either not produce electricity or will seriously reduce its output. This may require checking for shadows throughout the day if there are nearby obstructions that may cast shadows. So ensure there are no rooftop vent stacks, antennas, satellite dishes, and chimneys that can cast shadows onto the solar panels — even small shadows can dramatically drop your solar panel's output. You will find that some solar panel manufacturers will advertise panels that can cope with shading but they do so by using internal diodes which comes at a cost... that being a slight reduction in the power output. The orientation of the shadow will also determine the amount of the impact as shown in the following figure.



Impact of partial shading on solar cells

Also, remember that the sun's inclination will change with the seasons. So a tree's shadow that is barely missing the solar panels in summer will be causing problems during the winter months when the sun is lower in the sky. Remind the owner that trimming is only a temporary solution and will require regular maintenance because the trees will grow back.

Solar Panel Wiring. Solar panel arrays are wired in parallel to increase the current capacity (or how much power is available for use). They will also be wired in series to increase the voltage… to 24, 48, or even higher voltage levels. Let's quickly review the different wiring situations using two 200-watt solar panels that have the following specifications:

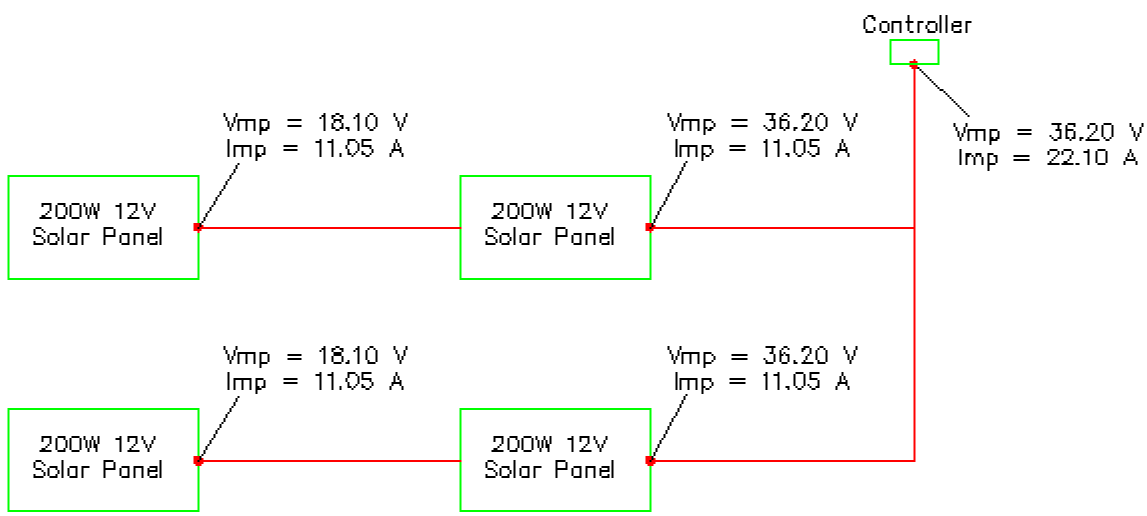
Typical 200 watt panel:

Voc = 22.60 V	Vmp = 18.10 V
Isc = 11.80 A	Imp = 11.05 A

Parallel wiring. Two 200-watt *solar panels* in parallel would yield 18.10 V and 22.10 A.

Series wiring. Two 200-watt *solar panels* in series would yield 36.20 V and 11.05 A.

If testing each panel individually off-line, you could expect to see a max of 22.6 V and 11.8 A. Always refer to the manufacturer's installation manual. Look at the figure below showing the expected amperage and voltage readings at different locations in the *solar panel array*:



Check the panel output. If the solar output is less than it should be, a panel may have a problem. The quickest and easiest way to locate the problem panel is with a towel. Shadows have dramatic impact on a panel's power output. Just covering a corner of the panel can decrease that panel's output by as much as 50%. If the panels are wired in a parallel or series-parallel configuration, the Partial Panel Shading Test will help you locate a problem without having to disconnect any of the wiring.

Partial Panel Shading Test. Ideally, have someone watch the monitor meter while you cover a portion of each panel. Each time the towel is placed on a panel, there should be a significant drop in the system performance. You have located the problem panel when you have placed the towel on a panel and there is minimal or no change in the output. If the panel is connected in series, you will then need to determine which panel in the series is the problem. Likely, the problem will be a wiring issue so check the wiring closely.

Check the panel wiring. Most of the time, a faulty panel is the result of a loose connection or of corrosion. Check the wiring for a good clean connection. If necessary, clean the connections of any corrosion and then recheck the system output. Also check for broken wires or wires that may be shorting out due to animals chewing on the wiring insulation. Squirrels are notorious for this.

Check for burned terminals. Burned terminals can increase the electrical resistance in a circuit. This can be caused by repeated contraction and expansion cycles from temperature fluctuations which cause bolts to work loose or metal connections to warp or it could be from corrosion of the metal parts. Bad connections can cause increased electrical resistance which will generate heat. But typically burned terminals are caused by too many wires being combined at a single point. If you find this condition, recommend to the owner that an electrician correct the problem by rewiring some of the panels and create a second circuit or use a larger wire size.

Check for heat fade. Solar panels do not perform as well when they become hot. This is typically a problem that occurs in the summer during midday when the panels' temperatures are at their hottest. It is also more of a problem for solar panels that have a glass facing since they can become a heat trap. When the panels' voltage and the battery voltage become nearly equal, the charging current will drop to almost nothing and the entire system will not perform as designed or expected.

With heat fade, the voltage of a solar panel will decrease as the temperature increases. Panel manufacturers state this value in their specifications by providing the volts per degree of deviation from 25°C (77°F). Most 12-volt rated panels will produce 17 – 18 volts at 25°C which will provide a nominal 12-volts even with the heat fade voltage drops.

Voltage drops may also be caused by poor connections or undersized wiring. Try spraying the panels with water to cool them down while someone is monitoring the current readings. This is the best way to determine if heat fade is a problem.

> **Caution** - Do not perform any electrical work that you are not experienced with. It is always safer, and easier, to hire an electrician and ensure no system warranties are voided. Many states require a minimum 2-year warranty on parts and labor and today most solar panels come with a 20 or 30-year manufacturer's warranty. So, if there is a problem, don't hesitate to call the original contractor or installer and let them troubleshoot any problems you may find.

Check for diode problems. Many solar panels will have bypass diodes located in the junction boxes. These diodes help protect the solar cells from damage when they experience periods of partial shading. Rarely will diodes fail, but if they do an ohm meter will be needed to locate the failed diode. Typically when they do fail, they will short out which will result in a drastic drop in the panel's voltage. To locate the shorted diode, test it with an ohm meter and look for a reading of almost zero ohms in both directions.

If the solar panels are located such that there is no possibility that they will experience any periods of partial shading, the diodes may not be necessary and you can remove them. In all other situations, simply replace it with a diode having an amp rating at or above the panel's maximum current and a voltage rating of 400V or more.

Check the Combiner Boxes. Check inside the combiner boxes, if used, for any loose, broken, or blackened connections. Using a voltmeter and a DC ammeter, check the solar array's voltage and amps at the output side of the final combiner box. Then securely close the combiner box ensuring the electrical conduits are secure.

If a string of solar panels are wired in series and use a combiner box to connect to the array wiring, this is a good place to check the open-circuit electrical values of that string. If the combiner box happens to be fused, even better. Simply remove the fuse and test the string there. If the combiner box is not fused, disconnect the string's connections in the combiner box and then test the voltage and amps. I recommend recording each string's voltages and amps for comparison to the readings of the other strings. If there are significant differences in the readings for one string as compared to the others, determine why. Also, the recordings will be a valuable resource over the years to determine the degradation of each string and the system array as a whole and it can also be used as indication for any preventative maintenance that may be needed.

> Note that a voltmeter's amp circuit <u>might</u> be capable of being used to measure the amps **<u>if</u>** the amp rating of the string is less than 10 amps. Verify the voltmeter's limitations. For strings with amps approaching or greater than 10 amps, always use a dc ammeter to measure the amps.

Remember: Series wiring → Amps stay the same and Voltage is additive.

Troubleshooting the Solar Panels

Always write down the readings of the voltage and amps from the solar panel array before you start doing anything to the system so you'll have a basis to refer to as you begin making changes. If the panels are not producing any power at all, check all the fuses or circuit breakers first. An electrical spike may have tripped the circuits. Then check for broken wires between the charge controller and the solar panels. There should be some voltage present if the wires are not broken and the fuses are good.

Check for bad connections. The most common cause of solar PV system problems is a bad connection. Especially, if the system was working, but now has problems and nothing has changed on the system, there has been no recent maintenance, and no new additions to the system. Also, check the voltage at the terminals in the last combiner box for the solar panels and then at the SOLAR terminals on the charge controller. Again, these voltages should be the nearly the same. If you find a voltage difference, inspect for bad or corroded connections, shorts in the electrical wiring, or bad fuses. If a visual inspection doesn't reveal the problem, you will need to check it with a voltmeter. At any rate, you have a bad connection somewhere.

When all else fails, wash the solar panels. Solar panels are generally black so it may be difficult to determine the amount of dirt that has accumulated on the solar panel's surface. A dirty surface can be just as detrimental as shading in reducing a panel's output. Simply washing the surface of the panel may make a substantial difference in the panel's output.

STEP 5: INSPECT THE SOLAR PANEL MOUNTS

Check the Solar Panel Mounts. Check all of the fasteners, nuts, and bolts used to secure the solar panels to the mounts. Then check the security of the mounts to the base, roof, or pole that the mounts are attached to. Check to ensure all grounding wires are securely attached to the frame and to the panel wiring and ensure that they are properly grounded. Check the building penetrations for both the mounting anchors and the wiring to ensure they are properly sealed and are in good condition. Then check all of the junction boxes for security and make sure you check the wiring inside the boxes for any loose or broken connections. Check the conduits for good tight connections and that the conduits are in good condition from end to end.

> **Caution** – If the solar panels are mounted on a roof or pole, use proper safety equipment and ladders to inspect the panels and their mounts.

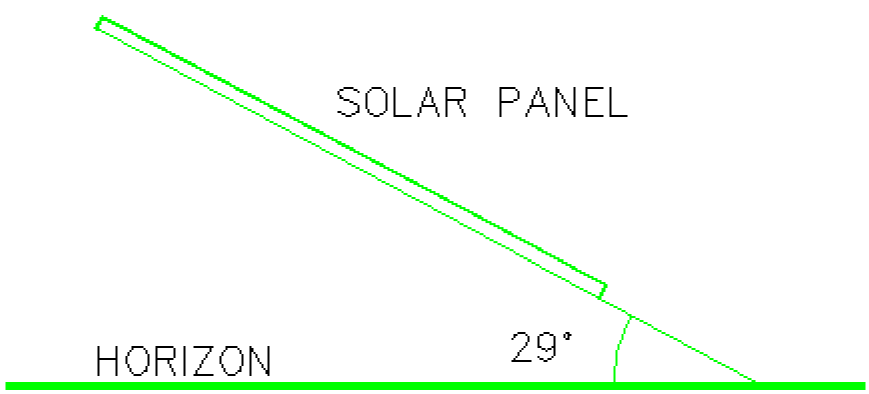
Notice that no conduits are used for the panel wiring. This should be noted and then corrected by the installer.

Check the Solar Panel Tracker (if installed). If the solar panel mounts are a tracking type, determine the type of tracker installed and refer to the tracker's manual. Is it an active or passive tracker... or is it a chronological tracker (a clock)? If it is an active or passive tracker that includes a lens over an optical sensor, ensure that it is clean and transparent. If it is a chronological tracker, check the timer clock. You may need to refer to the manufacturer's manual for instructions on resetting the clock to obtain the proper tracking alignment.

If the solar panel mounts are a tracking type, check the operation of the tracking mechanisms. Again, refer to the manufacturer's manual on how to test the tracker. Are they properly lubricated? Also, check the condition of the wiring. Are there any signs of chaffing on the wiring? Are the conduits properly secured to it? Then ensure the tracking mechanism is free of any corrosion or dirt that may prevent a continuous smooth operation of the tracking system for the full tracking range. If the tracking mechanism struggles at any point in the tracking arc, have the installer correct it.

Check the solar panel alignment. Solar panels must face true south in the U.S. And there is a difference between true south and magnetic south. In some areas this can make a significant difference in alignment and in the power produced. For fixed mounts, check the magnetic variation for the installation's location for proper alignment of the panels. Obviously, for roof mounted solar panels, there is generally not much control over the alignment.

Check the angle of inclination. The proper angle of inclination is another consideration to obtain maximum panel output. As a rule of thumb, the solar panel's angle of inclination (tilt) should be set equal to your latitude. If your installation is at latitude 29 degrees North, then check that the inclination of the solar panels are set at 29 degrees of inclination. The actual inclination for your location, if needed, can be obtained through various online website sources.



ANGLE OF INCLINATION

If the tracking mechanisms are a constant source of problems, an alternative worth considering is disabling the mechanisms and forcing them to always face south. If additional power is needed to supplement the lower efficiency of the fixed mounts, then consider purchasing additional panels instead. By purchasing additional panels, you will increase the power but have no mechanical failures to worry about.


Zomeworks UTR-F 120 Track Rack™ by Renewable Energy Concepts

Various mounts by Zomeworks
www.zomeworks.com

STEP 6: INSPECT THE CHARGE CONTROLLER

Check the Charge Controller. The charge controller is the brains of the system. Its purpose is to monitor the electricity produced by the solar panels which increases as the sun's rays become more direct and then regulate the electricity produced to properly charge the batteries and prevent them from becoming overcharged. Simply stated, as the input voltage from the solar panels increases, the charge controller adjusts the charge to the batteries to prevent any over-charging. If the charge controller is not properly charging the batteries, the batteries may be permanently damaged.

Blue Sky Energy
SOLAR BOOST

Determine the type of charge controller being used. Different technologies are available for selection including Pulse Width Modulation (PWM) and the increasingly popular MPPT (Maximum Power Point Tracking) charge controllers. Know which type of charge controller is installed in the system. If a system that is using a PWM charge controller is consistently having problems recharging the batteries to their full state, simply switching to a MPPT charge controller may resolve the problem.

Check that the proper battery type has been selected. Many charge controllers have a switch or a jumper that is used to select the type of batteries being used... i.e. sealed or flooded. Check the battery type being used in the system and compare that with the switch selection on the charge controller. The setting will determine the charge rates that are applied to the batteries so the type setting <u>does</u> matter.

Check the set points of the controller. The ideal voltages for controlling the charge to a battery change with the battery's temperature. Some controllers can compensate for the battery's temperature with set points that are established by the installer. Check the manufacturer's operating manual to verify if the set points were properly set up.

Typical set points for 12 V ***lead-acid*** batteries at 77°F (25°C) are:

High limit (flooded battery): 14.4 V

High limit (sealed battery): 14.0 V

Resume full charge: 13.0 V

Low voltage disconnect: 10.8 to 11.0 V

Reconnect: 12.5 V

The temperature compensation factor for a 12V battery is about 0.03 volts per degree Celsius from the standard of 25°C.

Check the temperature sensor, if installed. Some charge controllers also include an internal temperature sensor. If it does, the charge controller must be mounted in a place where the temperature is close to that of the batteries or it must use an optional remote temperature probe. The probe should be attached directly to a battery which reports the temperature to the charge controller so that it can adjust the charge rates to compensate for changes in the battery temperature.

Check for overload protection. Any overloaded circuit can cause damage or a fire. The overload could be caused by a short circuit in the wiring or by a faulty appliance. Some charge controllers include overload protection and can be reset by a push-button or switch.

Even if the controller includes overload protection, most systems will also have additional circuit breakers in a breaker box. The controller's overload protection is typically for the system and not for separate circuits within the system or the structure. Verify that the circuit breakers are working properly and are not tripped.

Outback Power
Systems - FLEXmax

Check the charge controller's display panel. Many charge controllers include a digital display of the operating status and the system input and output values. This information can be compared to the monitor meter readings. Any discrepancies between the two should be investigated.

Check the charge controller for a high-pitched buzzing noise. This sound could indicate that the charge controller is connected to the panels but it may not be properly connected to the battery. So check ALL of the connections and the circuit breakers (or fuses) between the charge controller and the batteries.

Check the charging indicator on the controller. If the charge controller is indicating that it is constantly charging all day, there may be problem with the solar PV system design. Either the building is using more power than the solar PV system can provide or the solar panels are not providing the power as they were designed to do. This could be due to an improperly designed system. For example, if the solar design was based on 6-hours of sunlight being available each day but the location only allows for 4 hours of direct sunlight each day, then the solar panel design is too small. However, if the batteries are deeply discharged due to multiple days of cloudy or rainy skies, it may require 2 or 3 days of sunny skies for the system to fully recover. The recovery time will be dependent on the solar array size, the daily power demand, and the number of hours of available sunlight... or the use of a backup generator may be required to recharge the batteries.

If the charging light is cycling on and off, the batteries are probably fully charged and the solar panels are providing most of the building's power. In this case, the system is probably functioning properly but make a mental note of the occurrence and monitor the situation. In a typical daily cycle, the batteries have provided the power needed during the night and then once the sun rises to the point that the sunlight reaches the solar panels, the charge controller will begin to continuously charge the batteries. As the battery charge increases, the charging light will turn off and eventually begin to cycle on and off during the day. High power demands in the building may cause the charging light to stay on as the system compensates for the increased power demand and then once the demand drops and the batteries are recharged, the light will turn off.

If the batteries are not charging when the sun is shining, try disconnecting the wires from the charge controller's SOLAR terminals. With a voltmeter, check the voltage at the SOLAR terminals on the charge controller. If the charge controller's charging light is on or if voltage is measured at the SOLAR terminals with the wires disconnected, the charge controller may be damaged.

Both the voltage and amperage being provided to the charge controller can be checked by testing the wires from the solar panels at the charge controller SOLAR terminals. Check the system design specifications for the input voltage and amperage. Always verify these specifications with the number of solar panels in the array. Solar panels may have been added or removed after the original installation.

Remember: Parallel wiring → Voltage stays the same and the Amps are additive.

Series wiring → Amps stay the same and Voltage is additive.

Again, with the system functioning, use a voltmeter to check the voltage at the terminals on the battery and at the charge controller's BATTERY terminals. These voltages should be nearly the same. If not, there is a bad connection somewhere in the wiring between the batteries and the charge controller.

STEP 7: INSPECT THE BATTERIES

Check the batteries. The batteries are required to store the excess electrical power from the solar panels for later use. Without the correct number of batteries with the proper amp-hours, the power will quickly diminish every time sunlight becomes unavailable to the solar panels. One of the more common problems with solar power systems is the battery maintenance... especially if the batteries are of the flooded cell type because it is easy for the user to neglect regular maintenance of these batteries. I have found battery cells that are almost totally dry... yet the person responsible for maintaining them assured me they "check the batteries regularly."

Determine the type of batteries being used. There are many types of batteries being used in solar PV systems today... some good and some that should not be used at all because they really do not have the capacity for continuous service with many charge and discharge cycles or cannot be discharged much more than 10% without internal damage. These include Auto, RV, or Marine type batteries. One exception to this is golf cart batteries which may be used satisfactorily in small solar PV systems since they are designed for longer discharge cycles.

Flooded type batteries are lead acid batteries that have caps to add water. They are used more frequently than other types because of cost but they require regular maintenance in the form of maintaining proper water levels, equalizing charges, and keeping their caps and terminals clean. Because flooded batteries release hydrogen gas when in use, ensure they are well ventilated and avoid any sources of ignition when you are inspecting them. Pull each battery cap and check the water level in each cell. Do not assume that because one cell is full that the others are as well. I have found in a single battery some cells that are full of water and other cells that have dry exposed plates. So check all of them.

If the batteries do not have vent caps, they are either sealed gel or AGM (Absorbed Glass Mat) batteries. **Sealed Gel** and **AGM** batteries are often used because they have no vents that can release gas during the charging process which allows them to be stored indoors. They are also maintenance free since they don't require someone adding water to them on a regular basis.

Sun Xtender battery

Checking the battery maintenance. Are the battery terminals clean or are they corroded? Are the battery cables clean and securely fastened to the battery terminals? Is there any indication of charred or blackened connections? Are there any indications of battery leakage around the terminals or the case? Does the case show any indications of being cracked or distorted?

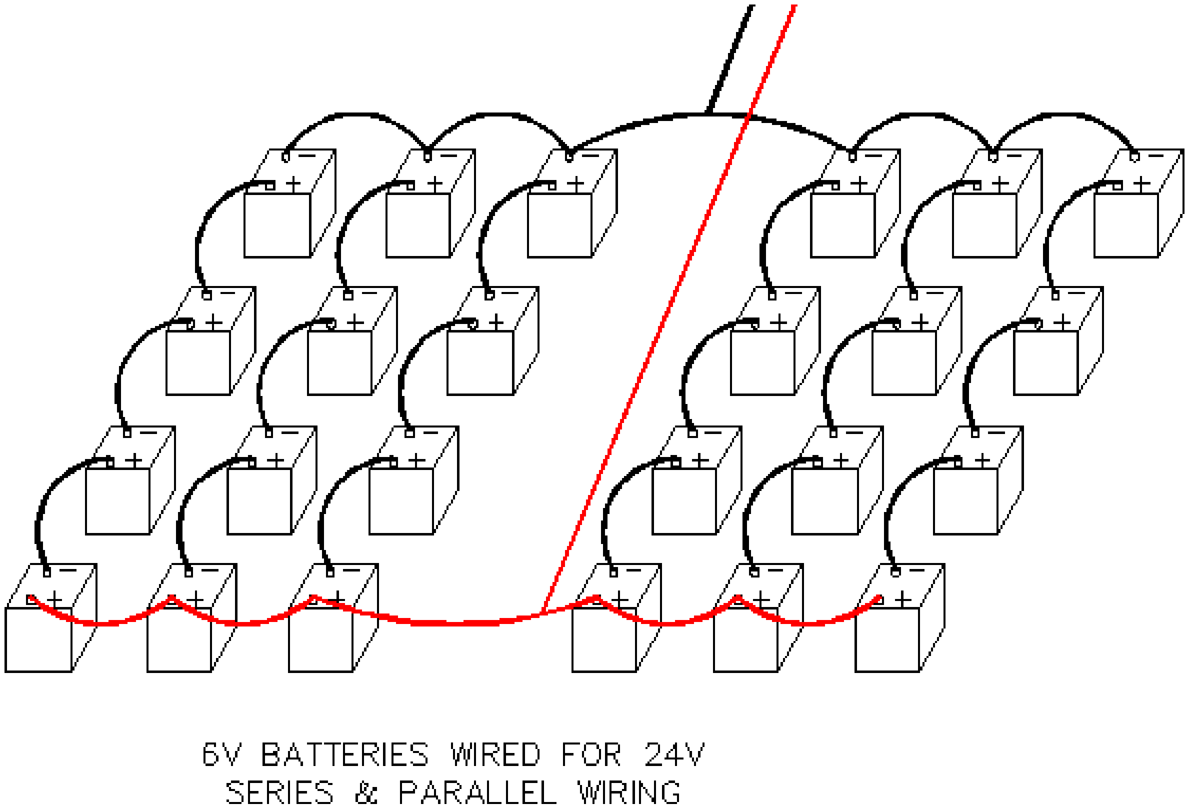
Checking old batteries. Are the batteries discharging much quicker now than when they were first installed? If so, the problem could be the sulfation of the battery cells or it could be the batteries are damaged due to over-discharge occurrences. Even a single over-discharge occurrence will damage a battery. Multiple occurrences can kill a battery. If the battery cells are sulfated, a de-sulfating battery charger may be able to salvage them. However, de-sulfating batteries requires days or even weeks for their reconditioning. So, it may be necessary to replace them if you don't have the luxury of waiting for weeks for the de-sulfating process.

Another check is determining if the batteries maintain a charge overnight with no loads on them. If the voltage decreases overnight with no load, the batteries will need to be replaced.

Typical Battery Voltages

% Charge	12-volt	24-volt	48-volt
100	12.7	25.4	50.8
80	12.5	25.0	50.0
50*	12.2	24.4	48.8
30*	12.0	24.0	48.0

* Battery damage may occur



Checking the battery array. Check that all of the wire connections in the system are clean and secure. Also, verify that the polarity of each of the connections is correct for both the parallel and series wiring found in the array.

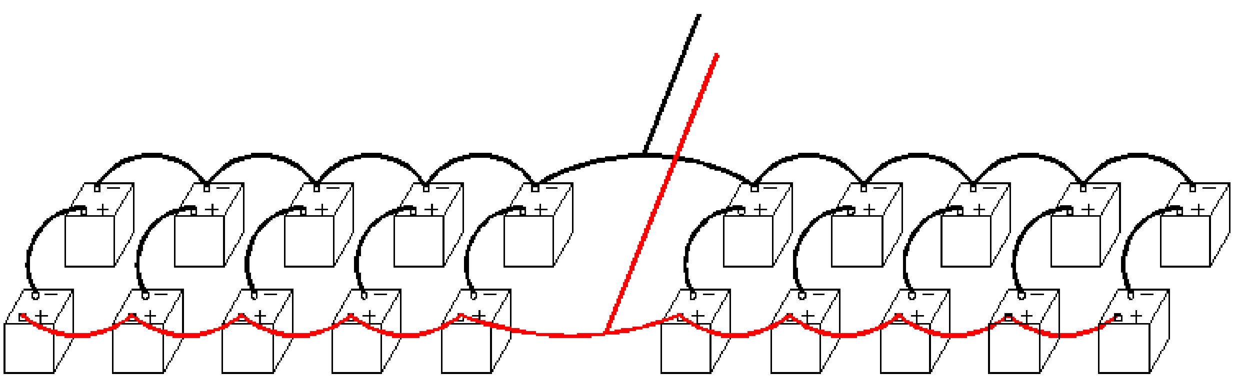
Check the battery array sizing. Check the watt-hour rating of the installed battery array. Does it match the design specifications? To avoid damaging these expensive batteries, the system should never reduce the battery charge below 50%. Some believe that you shouldn't reduce the charge below 80% to extend their useful lifespan. If you have a battery array that is designed for a 24,000 watt-hour system, then check that the batteries have that capacity. Using the following formula, you can determine the number of batteries you need. First determine the voltage of the batteries being used. In this example, we will assume they are 12-volt batteries.

P = E * I or P / E = I
24,000 watt-hrs / 12 v = 2,000 amp-hrs

Now check the batteries that are being used. If the batteries are rated at 105 amp-hrs, then there should be...

2,000 amp-hrs / 105 amp-hrs = 19 batteries

However, if the solar power system is set up for a 24-volt system, then there should be 20 batteries... with 2 batteries wired in series and having 10 banks of batteries wired in parallel similar to the diagram below. Having more batteries than is required is a good thing since additional batteries will provide more power and a provide a buffer for excessive loads.



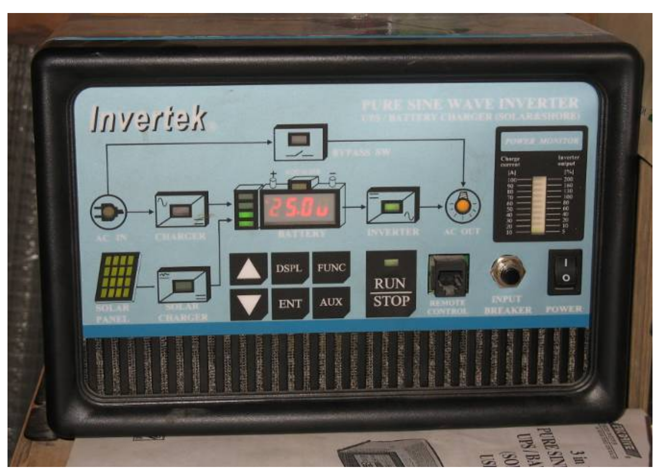
12V BATTERIES WIRED FOR 24V
SERIES & PARALLEL WIRING

STEP 8: INSPECT THE INVERTER

Check the inverter. The inverter converts the DC volts produced by the solar panels and the batteries into AC volts. The inverters can also be used to charge the batteries by connecting a backup generator to it or to another AC electrical source. Therefore it is critical that the inverter is working according to specs for the AC electrical appliances to function properly and for the batteries to be charged without overcharging them.

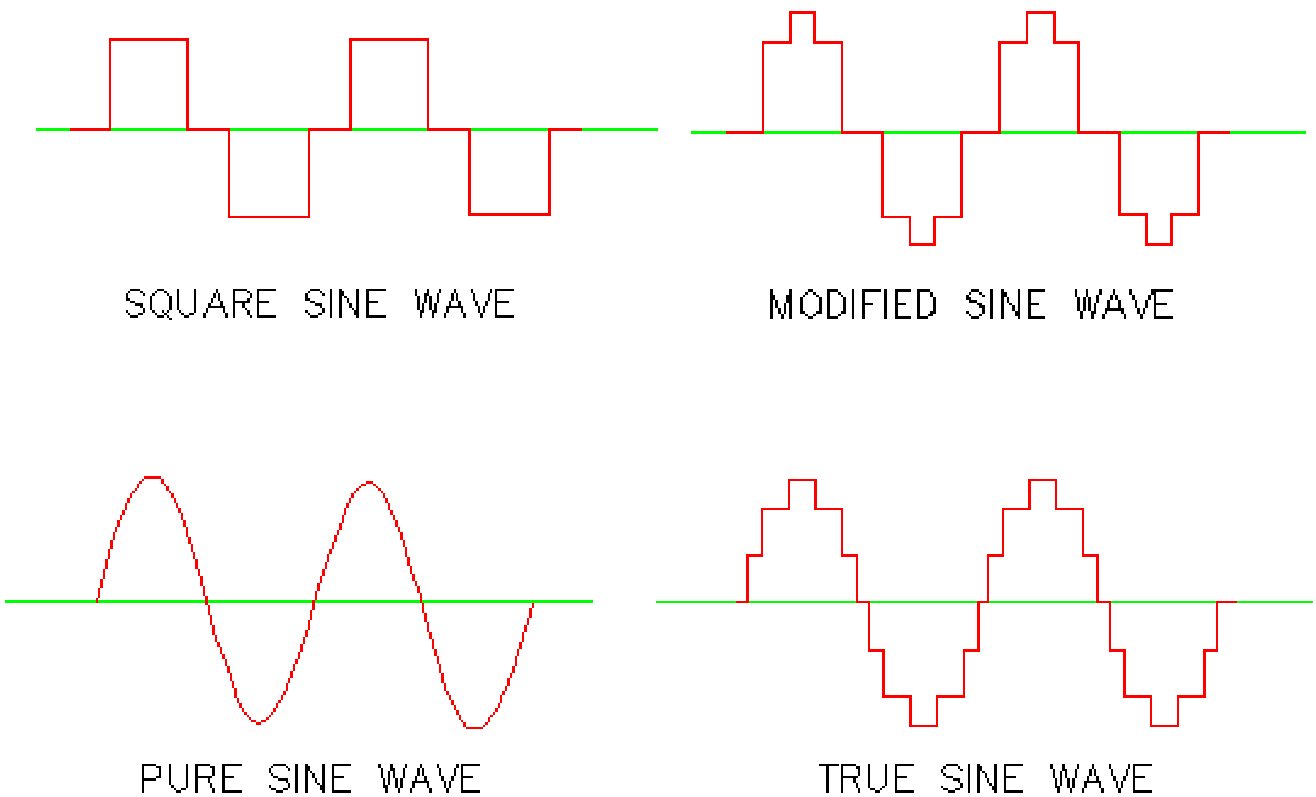
Check the inverter's specifications to determine the system voltage. The 24-volt and 48-volt systems have become the new standards now because the higher voltages reduce wire sizes (which reduce costs) and the smaller wire sizes are easier to work with. But the inverter may be operating on a 12-volt system... just verify what you're working with. Also, check the manufacturer's operating manual for proper settings and input / output parameters. It's not uncommon to find that the operating manual is for a different unit. The original inverter may have been replaced due to problems but the owner's manual was never switched.

Check the type of sine wave produced by the inverter. If problems are reported with timers, motors, or electronics, check the inverter for its produced sine wave. Most likely, the inverter is producing a square or modified sine wave. Some appliances that use motor speed controls or timers will not work properly with a Modified Sine Wave inverter. Keep this in mind since many consumer products are using speed controls & timers.



Invertek Pure Sine Inverter

Note that many appliances won't work on a square or modified sine wave power at all. Audio devices can give off an annoying buzz from the speakers and can also be heard from some fluorescent lights, ceiling fans, and transformers. Even microwave ovens will buzz and produce less heat. Televisions and computer monitors will likely show rolling lines on the screen. And surge protectors should not be used as they can overheat when using square or modified sine wave inverters. When using electronics and timers, the produced sine wave should be a pure or true sine wave.



Check the inverter's display panel for lights or digital displays for proper operation. Then turn the inverter off and check for loose, broken, or blackened wires or connections. Also, check and test the ground wires for proper grounding.

Then turn the system back on and use a voltmeter and a DC ammeter to check the DC input voltage and amps. Then check the AC output voltage and amps.

> **Caution** - Do not perform any electrical work that you are not experienced with or do not have the proper equipment for testing. It is always safer... and easier... to hire an electrician and ensure that no system warranties are voided.

Check the kilowatt hour readings. If the inverter's display shows the total kilowatt hours produced, check that against the previous recorded readings and the date. This will give you another indication of the systems performance and the average daily kilowatts since the previous date's reading. Note whether the average daily kilowatts are higher or lower than the previous readings. A sudden change in the average daily kilowatts is worth investigating.

Troubleshooting an Inverter Problem

An inoperative inverter is usually caused by a blown fuse/circuit breaker. However, it could be caused by a broken wire or ground wire. Or it could be caused by the inverter's internal high-voltage or low-voltage disconnect sensors. Turn off all loads and replace the fuse or reset the circuit breaker. Then turn on the various loads and monitor the readings with each additional load. Note the circuit that causes a problem and load at which the inverter shut off. Then check the circuit that caused the problem and verify the total load that the inverter is capable of handling.

The source of the problem could also be on the input side of the inverter that is tripping one of the internal disconnects. If the solar panels, charge controller, and batteries check out, then the inverter may need servicing.

STEP 9: INSPECT THE GENERATOR

Check the generator. – A gas powered generator is normally used to keep the batteries charged during extended rainy/cloudy periods or to provide the additional power needed for those temporary high power demands. In most small structures, generators are frequently used since its solar power system typically has minimal surplus power available for recharging the battery array... especially during rainy or cloudy seasons.

Inspecting the generator is generally limited to checking the engine oil levels and checking the wiring and conduit from the generator to the inverter. Also, ensure that the generator is well ventilated or stored outdoors.

I have found that asking the users how often they must run the generator will give you an idea how well the solar power system is working or if the solar system is undersized for the loads the users are requiring. If the users only started using the generator recently but have not added any new electrical loads then that may indicate a problem somewhere in the PV system.

STEP 10: INSPECT THE GRID-TIE SWITCH

Check the Grid-Tie Switch. A grid-tie system means that you can use the solar energy when it's available and when that source is not available or insufficient, have the system automatically switch to the on-grid electricity from a power company. If the user has excessive electrical usage from the power company, either the grid-tie switch has malfunctioned or the solar system is not producing as it should. Check all of the connections and ensure the settings on the grid-tie switch are set for proper operation. Someone may have mistakenly changed one of the settings.

Sunny Boy Grid Tie Inverter

A NOTE ON WIRING

Always check the wiring. Correct wire sizes are essential for wiring the various components of a Solar Energy System. The correct wire size ensures low energy loss and prevents overheating and damage. All of the components in a solar power system use wiring and having the proper wire size is essential to a system for it to perform properly. If you see wiring that is suspect due to discoloration, over-heating, being charred, or just seems too small in its size, check to see if the wire is properly sized.

Below is a sample chart showing the required wire size for various wire lengths. If you're using a 24-volt system, make sure you use a 24-volt wire size chart. Also note the allowable voltage drop when using the chart and be sure you account for the voltage drop in the wire run. Never use more than a 2% voltage drop when sizing wire from the solar panels to the charge controller. A 3% - 5% DC voltage drop may be allowable between the batteries and the appliances.

Interior wiring must never be used outdoors. All exterior components, wires, and cables must be rated for UV exposure or they will break down over time… and interior wiring is not provided with UV protection.

It is also important to note that when selecting circuit breakers, AC and DC breakers are NOT interchangeable. So be careful when you see breakers and make sure the proper breakers are being used and only allow DC rated products on DC wiring.

See the wire sizing chart below for the impacts of amps on various wire gauges for 12-volt and 24-volt wiring. The Voltage Loss chart values were calculated using Ohm's Law as shown:

Ohm's Law states **E = IR**

where: E = Voltage Loss (volts)

I = Current (amps)

R = Resistance (ohms)

Therefore, using the manufacturer's specifications for the Resistance values of the different size wires, we can calculate the allowable wire lengths for various amperages.

Voltage Loss = I * R (per 1,000 ft) * Dist (per 1,000 ft) * 2

Dist = (1000E) / (I / R)

The results of the calculations are in the chart below. However, use a chart supplied by the wire's manufacturer since the values will change with the manufactured actual cross-sections of the wire they produce.

Check the wiring from the batteries to the Inverter. Both the Inverter and the Batteries require the largest wires in the system. During operation, the inverter can draw a large number of amps from the batteries to produce the AC being required. These wires should be like the large battery cables found in your car or boat. An AC appliance that draws 10 amps (like a microwave) will require 100 amps at 12 volts DC.

12 Volts - 2% voltage drop

		AWG Wire Gauge										
		18	16	14	12	10	8	6	4	2	1/0	2/0
	1	17	28	45	71	114	181	288	457	730		
	2	8	14	22	35	57	90	144	228	365	581	730
	4	4	7	11	17	28	45	72	114	182	290	365
	6	2	4	7	11	19	30	48	76	121	193	243
	8	2	3	5	8	14	22	36	57	91	145	182
A	10		2	4	7	11	18	28	45	73	116	146
M	15		1	3	4	7	12	19	30	48	77	97
P	20			2	3	5	9	14	22	36	58	73
S	25			1	2	4	7	11	18	29	46	58
	30				2	3	6	9	15	24	38	48
	40				1	2	4	7	11	18	29	36
	50					2	3	5	9	14	23	29
	100						1	2	4	7	11	14
	150							1	3	4	7	9
	200								2	3	5	7

24 Volts - 2% voltage drop

		AWG Wire Gauge										
		18	16	14	12	10	8	6	4	2	1/0	2/0
	1	35	56	90	143	228	363	577	915			
	2	17	28	45	71	114	181	288	457	730		
	4	8	14	22	35	57	90	144	228	365	581	730
	6	5	9	15	23	38	60	96	152	243	387	487
	8	4	7	11	17	28	45	72	114	182	290	365
A	10	3	5	9	14	22	36	57	91	146	232	292
M	15	2	3	6	9	15	24	38	61	97	155	194
P	20	1	2	4	7	11	18	28	45	73	116	146
S	25		2	3	5	9	14	23	36	58	93	116
	30		1	3	4	7	12	19	30	48	77	97
	40			2	3	5	9	14	22	36	58	73
	50			1	2	4	7	11	18	29	46	58
	100				1	2	3	5	9	14	23	29
	150					1	2	3	6	9	15	19
	200						1	2	4	7	11	14

Disclaimer:
The values listed above are approximate values only and intended to demonstrate the voltage drop for various wire gauges. Use of the values for actual wire sizing is at the sole risk of the user.

The top row represents the Wire gauge size, the left column is the maximum number of amps, and the chart cells show the distances in feet allowed for a 2% voltage drop. For all numbers, use the next higher value in choosing amps or distances.

For example: If you have a wire carrying 12 volts with 18 amps that is 30 feet in length, then you would move down the chart to 20 amps (18 rounded up), and across to 36 (closest to 30), and then up the chart to 2 ga. You would need at least #2 AWG gauge wire to move 18 amps 30 feet with a minimum voltage drop of 2% or less, which is an acceptable loss.

Similarily, if you a wire carrying 24 volts with 18 amps that is 30 feet in length, then you would move down the chart to 20 amps (18 amps rounded up), and across to 45 (closest to 30), and then up the chart to 4 ga. You would need at least #4 AWG gauge wire to move 18 amps 30 feet with a minimum voltage drop of 2% or less.

Remember, if you can't find the exact values, choose either a larger gauge wire (smaller number) or select a distance longer than your actual distance. Using a larger gauge wire will also reduce the voltage drop for the same length of run.

TROUBLESHOOTING THE BUILDING

If the solar power system checks out with your inspection but there are still problems showing up in the building, you may need to troubleshoot the problem in the building. First, check all of the electrical loads in the building. Is there a new load that is using a significant proportion of the system's power? Check and turn off all of the switches in the building. Then check the monitor meter for any loads remaining on the system. With everything turned off, there should be no loads indicated by the system. If there are loads indicated, recheck the switches for proper setting and proper wiring. Continue checking all switches and outlets until the problem is located and no load is indicated with everything turned off.

Checking the electrical switches. Now start turning on one switch at a time and noting the load being generated. Is it an appropriate load for the switch turned on? If the switch controls a 20-watt light bulb but when turned on the system indicates a 1200-watt load, there are additional items on the circuit or there is a problem.

After each switch is tested, turn the switch back off and verify that the load drops to zero again. Then proceed to turn on the next switch and check its results. Continue this process throughout the entire building. You may be surprised at how the building was wired and which switches control what.

Checking the electrical outlets. Check the building plans for the type of voltage at each outlet. The building may have two electrical systems... one AC system and one DC system. A DC outlet, if provided, ***should*** be different from the AC outlets if... it is wired correctly. An AC receptacle should **NEVER** be used for a DC circuit. Most DC appliances are hard-wired into a junction box or will use a 12-volt outlet socket as is often found in automobiles. All DC outlet cover plates should be labeled with the circuit's voltage.

Turn on the circuit and check to see that the load is properly plugged in. Using a voltmeter, check the voltage at the load's connection point and that it is the proper voltage. If there are fuses or circuit breakers provided, check that they are not blown or tripped. If everything checks out but there are still problems with the circuit, try plugging in a different appliance and see if it functions properly.

If there are still problems with a circuit and the fuse keeps blowing or the circuit breaker keeps tripping, there may be a problem with the wire size or a short in the wiring. Check the wattage of the appliance and the wire size. Are they properly matched? If not, a different circuit may be required.

SO NOW WHAT?

You've checked the components... the solar panels, the charge controller, the batteries, the inverter, the wiring, and the appliances and the owner calls you to report that the system still isn't working properly. At this point, you need to recheck the system design including the power demand. Personally check every possible electrical load in the building, the amount of time each load is being used, and then check every switch setting.

Also, check the amount of daily available sunlight used in the system calculations against the amount of daily sunlight the array is actually receiving. Perhaps there is a new obstruction... a new tree, a new building addition, etc.... that was not present when the system was originally designed and installed. If the system was sized using 5 hours of daily sunlight when in reality the array is only receiving 3.5 hours of full useable sunlight because of shadows, then it's no surprise the system isn't functioning as designed.

Then double-check the installed wiring sizes versus the loads they are supposed to be carrying. The wire run may be too long or undersized for the amps being carried now... especially if a new solar panel has been added to boost the power available.

Another possibility is the battery array. One or more batteries may be damaged and cannot maintain a charge. This is especially true if the monitor meter indicates over-discharge conditions have occurred.

SOLAR INSPECTION SUMMARY

As we know, there are six basic components found in every solar powered system. They are the solar panels, charge controllers, batteries, monitor meters, inverters, and the electrical wiring. Fortunately, solar power system components are very reliable. If a problem ever does develop, generally it is relatively easy to determine the faulty component. And the monitor meter is a great place to start. Then proceed logically and methodically through the system... from the panels to the charge controller to the batteries and finally to the inverter.

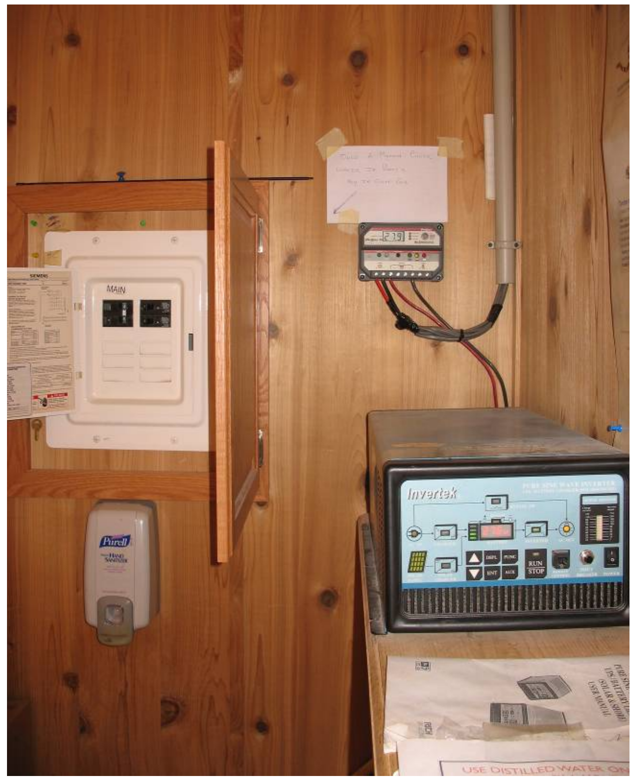
And don't forget the appliances that are using the generated electricity. They, too, are a critical part of the system and each one must be accounted for in the solar power system design.

And, last but not least, are the users. You must understand how they are using power... how, when, and how much. A system may be functioning up to the design limits but if the users need more power, the problem might not be a faulty component but the wrong design.

Before performing any inspection, make sure you have the proper tools and understand how to use them. A solar power system involves high voltage low amperage AC and low voltage high amperage DC components. If you don't know what you're doing, you can cause serious damage to the components and risk injury or even death. Do not get them confused. If in doubt, contact the installer or a licensed electrician.

Remember, that while standard AC appliances ***can*** be used in a solar PV system, DC powered appliances are much more efficient to use. Some commonly used powered appliances such as lights, fans, and air conditioners are also readily available in DC-wired models. Using these DC appliances can significantly reduce the size of the solar panel array and the number of batteries with no negative impact to the end user. And, for a system that is struggling for power, switching from AC fixtures to DC appliances and fluorescent lighting may make all the difference needed to make it an efficient functioning system again.

A small structure with a simple solar power system... a charge controller, inverter, and breaker panel shown... with the solar panels and batteries being outdoors.



Postscript... July 2010

Check the circuit breaker panel wiring. I was recently called to troubleshoot a solar system that had been working but now wasn't. Following the above procedures for inspecting the system, I was able to verify that the solar system components were working properly. Some of the installation work was done poorly... to put it mildly... but the system was properly configured and wired. But there still was no power to the building. We then checked that the building switches were correct, the circuit breakers were not tripped, the electrical outlets were in good condition, and the inverter passed the self-test... but still no power. As it turned out, when we removed the circuit breaker box panel cover, we discovered that the hot feed wire from the inverter had become disconnected from the main breaker and was hanging loose inside the panel box. Again, poor quality of work throughout by the installer. After ensuring the inverter was turned off and then testing the wire to ensure it was not hot, we reconnected the wire properly this time, turned the inverter on *and presto!* We had power restored. So, don't take anything for granted. Check *everything* when inspecting a solar electrical system.

Poor workmanship seems to be a recurring issue with solar installations. Apparently, there isn't enough solar installation work to train and keep experienced installers employed. As a result, new installations should be closely monitored and tested. If you're called to inspect or evaluate a solar installation, remember to *check everything.*

