Chapter Four
PV System Equipment and Maintenance

PV System Equipment

Solar modules are only one of the components needed to create a safe and reliable solar electric system. The additional components, referred to as "balance of system" (BOS) equipment, include "battery charge controllers, batteries, inverters (for loads requiring alternating current), wires, conduit, a grounding circuit, fuses, safety disconnects, outlets, metal structures for supporting the modules, and any additional components that are part of the PV system… Note that, in many systems, the cost of the BOS equipment can equal or exceed the cost of the PV modules."[1]

PV systems should be installed according to local electrical codes (insofar as this is possible in places where the code does not address PV), following all standard safety guidelines, using approved equipment appropriate to the applications for which it will be used. Proper grounding, adequate fuses or circuit breakers, appropriate wire sizing, and all other standard wiring practices are required to ensure the safety of a PV system. Ensure that you or your installer adheres to these safety practices. Also be aware of the risks associated with working on roofs, and follow best practices for ensuring that any roof penetrations are fully sealed to prevent leaks.

Figure 4.1: Charge controller *Morningstar Corporation*

Primary Balance of System Equipment

CHARGE CONTROLLER– "The charge controller regulates the flow of electricity from the PV modules to the battery and the load. The controller keeps the battery fully charged without overcharging it. When the load is drawing power, the controller allows the charge to flow from the modules into the battery, the load, or both. When the controller senses that the battery is fully charged, it stops the flow of charge from the modules. Many controllers will also sense when loads have taken too much electricity from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature [commonly referred to as the Low Voltage Disconnect (LVD), ed.] can greatly extend the battery's lifetime."[2]

Charge controllers can cost as little as $20 to more than $600, depending on their size (ampere capacity), the sophistication of the controller, and the monitoring features you select. "When selecting a controller, make sure it has the features you need; cost should be a secondary consideration."[3] Maximum power point tracking (MPPT) charge controllers are more expensive but deliver more power to the batteries than other types, improving the efficiency of the entire system.

Figure 4.2: Deep cycle lead acid batteries, *Trojan Battery Company*

BATTERIES- In a stand-alone system, batteries provide electricity when the PV panels are not producing sufficient power, such as at night or during cloudy weather. Batteries also allow the system to incorporate appliances that use more power than the PV panels are rated to deliver. PV systems require deep cycle batteries to provide electricity for extended time periods. Deep cycle batteries are designed to slowly discharge and recharge over 50 percent of their capacity hundreds of times. Automotive batteries are all shallow cycle and should NOT be used with PV systems. They are designed to discharge only 20 percent of their capacity and to recharge immediately. If discharged beyond 20 percent more than a few dozen times, automotive batteries will be damaged and will lose their capacity to hold a charge.

Golf cart batteries and the L-16 and L-16H industrial batteries (often used in industrial forklifts) are the most common deep cycle lead acid batteries used in solar electric systems. Regular maintenance for these batteries requires checking the water level on a monthly or semi-annual basis, and fully charging the batteries every three weeks. Lead acid and wet cell batteries give off explosive hydrogen gas when they are being charged near their fully charged point. For this reason they must be stored in a well-ventilated area, isolated from any flames or sparks. Depending upon the specific battery and how well they are maintained, lead-acid deep cycle batteries can last from three to ten years.

Maintenance-free deep cycle batteries are also available for PV systems. These types of batteries are sealed, do not off-gas hydrogen or other fumes, and cannot be spilled. Gel and AGM (absorbed glass mat) are two types of maintenance-free batteries. These batteries are more easily damaged from overcharging or improper charging and therefore require specialized charge controllers. They are typically more expensive than lead-acid or wet cell batteries and have a shorter life expectancy (ranging from three to five years).

Figure 4.3:
L-16 deep cycle battery
Real Goods/Gaiam, Inc.

Battery maintenance is the homeowner's primary responsibility with solar electric systems. Preventing batteries from being excessively discharged and carrying out regular maintenance will help to ensure the maximum life and performance from your batteries. Neglecting these responsibilities will significantly shorten battery life. That being said, these tasks are not difficult. Proper system design that includes enough battery storage capacity for your climate and energy use, and conscientious energy usage will help to ensure that your batteries are not overly-discharged on a regular basis. Equipment for monitoring battery conditions can be very helpful. These can include meters to measure voltage, amperage, or battery state-of-charge (expressed as a percent or in amp-hours). The low-voltage disconnect feature on the charge controller can also protect battery-life, if a potential loss of power is not a concern. Refer to the section on *PV System Maintenance* later in this chapter for more information on battery maintenance.

Figure 4.4:
175 watt inverter
Creative Energy Technologies, Inc.

INVERTERS– Inverters convert DC electricity into AC electricity, enabling conventional AC appliances to be used with a PV system. They are also essential components of a grid-intertied PV system, harmonizing the power from the PV module with the power from the grid and distributing it to the loads or the grid as appropriate. Inverters are rated by their maximum continuous output in watts, as well as the maximum power surge they can provide.

Inverters vary in the quality and waveform of AC power they provide, which affects which appliances can be used with the inverter. Modified sine-wave inverters are less expensive and slightly more efficient, but cannot operate appliances that are very sensitive to the waveform of the electricity. Some fans and stereo equipment may give off an audible "hum" with modified-sine wave inverters. Photocopy machines, laser printers, some computers, some battery chargers for portable power tools, and other sophisticated electronic equipment often require high quality, pure sine-wave electricity to operate properly. Pure sine-wave inverters are also required for grid-intertied systems. Your choice of inverter therefore depends upon the quality of AC electricity required by the appliances you'll be using, the average number of watts they demand during continuous use, and the maximum number of watts they will draw when surging. Note that some equipment will operate fine on modified sine wave inverters for short periods or with occasional use, but will overheat or be damaged under continuous operation. Unfortunately, most appliances do not indicate which form of AC electricity they require, and the requirements of your equipment may not be apparent until the equipment fails.

Figure 4.5: Sunny Boy inverter for grid-intertied systems
Real Goods/Gaiam, Inc.

PV System Maintenance

PV systems require very little maintenance. Grid-intertied PV systems without battery back-up require virtually no maintenance at all. If the PV racks require manual adjustments each season, this task must be carried out according to the appropriate schedule (see Chapter Five, Table 5.2). Due to Kentucky's latitude, winter PV positions tend to shed snow easily. The sun usually warms panels enough to allow snow build-up to slide off, but they may need to be swept clean after heavy snowfalls. To ensure maximum PV output after snowfalls, locate your PV array where the snow can be easily removed (on a ground-mounted pole, for instance). Typical Kentucky rain patterns keep PV surfaces clean without the need for hand washing.

If a tracking rack is used some minimal maintenance will be needed to keep moving parts in working order. Installation documentation for Wattsun active tracking racks, Zomeworks passive tracking racks, and other systems cover maintenance for their equipment.

Typically, various parts are greased and the tightness of nuts are checked once a year.

Most stand-alone battery-based systems are wired at a lower voltage than grid-intertied systems. For this reason ensure that all low voltage DC wire connections in a battery based system are clean and tight. This is particularly important for connections at the battery and the contacts on the inverter, especially if the inverter has a large output. A system monitor is a necessity for stand-alone battery based systems of all sizes, except perhaps very small systems, such as sign lights, fence chargers, etc.

Battery Maintenance

Of all the components in a solar electric system, the battery bank requires the most maintenance in order to ensure a long life. The greatest problems with batteries occur when more electricity is consistently withdrawn than is put back into them. This usually occurs during the winter months when batteries may go weeks without being fully recharged. Standard liquid electrolyte deep cycle lead acid batteries should be brought up to a complete charge at least every three weeks. Leaving them discharged over long periods of time will cause a coating of sulfate to crystallize on the surface of the internal plates. This impedes the normal charging process of the battery, and the battery will start to behave like a smaller battery. To remedy such a situation the batteries must be overcharged in a controlled fashion to drive off the sulfate coating.

When batteries are left discharged for extended lengths of time, unequal cell charge levels can also result. It is wise to test all cells every three months with a hydrometer, which measures the specific gravity of the electrolyte in the battery. Hydrometers can be bought from solar dealers and auto parts stores. Most batteries are full at a specific gravity of 1.265 and are overly-discharged if below 1.175. Batteries have multiple cells. If the cell measurements are unequal by a difference of more than 0.02, manually overcharge the batteries through an *equalization charge* which will cause the lesser cells to come up to the specific gravity of the rest of the battery pack. An *equalization charge* is a controlled overcharge, which is often accomplished by pressing a switch on the charge controller that allows the charger to slightly overcharge the batteries for a set length of time. Some charge controllers will even do this automatically on a regular schedule. In non-automatic systems, a manual charge control bypass switch can be used to equalize the batteries, but this requires careful monitoring and an understanding of the process. When using a hydrometer (or doing anything else around batteries), always follow battery and hydrometer manufacturers' cautions regarding safety. Battery acid is dangerous, especially to eyes.

The electrolyte level for each cell in a battery will have to be checked at least every three months. This is especially important during summer months. Only distilled water should be used to bring the electrolyte up to its proper level. This should be done when the batteries are near full, but not while being charged heavily. Often when distilled water is added to a discharged battery, the electrolyte will be overfilled and spill out of the battery when it becomes fully charged.

Keep battery tops clean and dry by wiping them occasionally with a rag. Wet, acidy tops provide a conductive path between terminals resulting in energy loss and more corrosion. If evidence of cruddy green buildup appears on the tops of batteries they should be wiped off with distilled water, then wiped dry. If there is heavy corrosion you might consider diluting a small amount of baking soda in the cleaning water. Be aware that this runs the risk of getting some of the baking soda solution into the battery cells, which is not good for them. Do without the baking soda for cleaning purposes if you can. However, it is a very good idea to keep a box or two of baking soda near the battery bank in case a spill ever occurs. The baking soda can be dumped on the spill to neutralize it.

In an enclosed space batteries should be vented to the outside. An enclosed box with a 1" pipe venting above the battery tops to the outdoors will suffice. Batteries are the nasty part of a PV system and usually warrant being located outside of living spaces (but still indoors). Be careful around batteries. They contain strong acids. Rubber gloves and safety glasses are minimum safety measures when working with them.

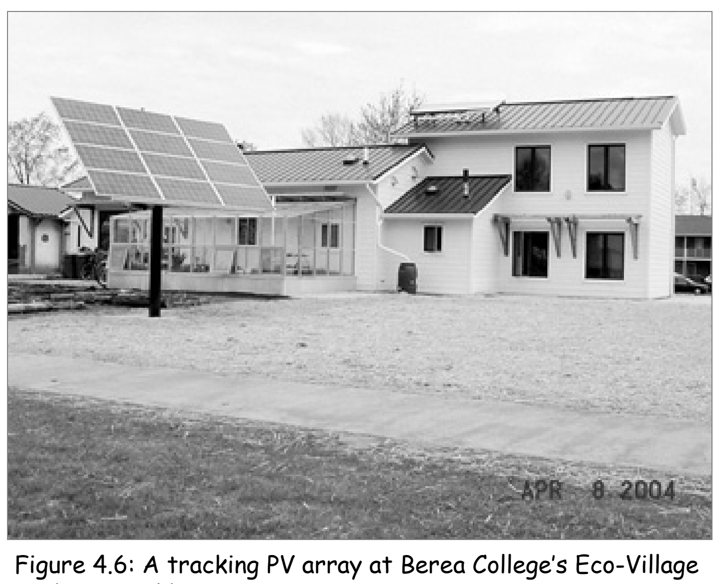

Figure 4.6: A tracking PV array at Berea College's Eco-Village
Andy McDonald

Component Failures

Solar equipment is generally high quality and equipment failures are rare. When problems do occur, PV owners often suspect equipment failure when the problem has another source. To identify the source of problems, check fuses and circuit breakers and look for loose or disconnected wires. If you have experience with voltmeters, trace the supply of electricity to the problem to see if it can be resolved. If your system was installed by a professional installer, do not hesitate to contact them, and be prepared with notes on all conditions and checks that you have made. In off-the-grid systems, consider using DC-power for refrigeration and maybe a few lights so they will continue to operate in case of inverter failure.

End Notes

1. "Photovoltaics: Basic Design Principles and Components," Energy Efficiency and Renewable Energy Clearinghouse, US Department of Energy, Document no. DOE/GO-10097-377, FS 231,March 1997, p.5.
2. Ibid, p.6.
3. Ibid, p.6.
4. Real Goods Summer 2004 Resource Guide, Hopland, California, p.85.

Battery Maintenance Checklist

Figure 4.7: Maintenance-free, deep cycle gel battery *Real Goods/Gaiam, Inc.*

Though most consider lead-acid batteries the "weak link" in renewable energy systems, today's batteries are better than ever, and so are the devices that regulate and protect them. In fact, battery failures are rarely the fault of the batteries themselves. Follow these guidelines to ensure that your batteries have a long, productive life.

1. Size the battery bank and PV array properly. Your battery bank should hold at least a five day load, and your PV array should produce (on average) 30 percent more energy than the load requires.

2. Buy high-quality batteries. Deep-cycle batteries can be expected to last from three to ten years, and sometimes longer.

3. Maintain even temperature distribution. Avoid uneven exposure to heat sources, and leave at least one inch of air space around each battery.

4. Prevent corrosion. Apply a non-hardening sealant to every terminal's metal parts BEFORE ASSEMBLY.

5. Keep batteries as close to room temperature as possible. Batteries work at a wide range of temperatures, but they lose capacity at very low temperatures and deteriorate faster at higher temperatures.

6. Rinse battery tops with water twice per year.

7. Avoid multiple parallel strings. If you must use them, distribute current evenly by connecting the two main cables to opposite corners of the battery bank and maintaining symmetry in wire size and lengths. If you exceed three parallel strings, it's time to move to a bigger battery.

8. Use a charge controller, power center or battery charger with temperature compensation.

9. Install a system monitor. Would you drive a car with no dashboard?

10. Bring batteries to a full state-of-charge at least every ten days.

11. Don't completely discharge batteries- it can cause immediate, irreversible loss of capacity. Monitor batteries, or use an inverter or charge controller with a low-voltage disconnect.

12. Add distilled water as needed. Most batteries require additional water every three to six months.

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