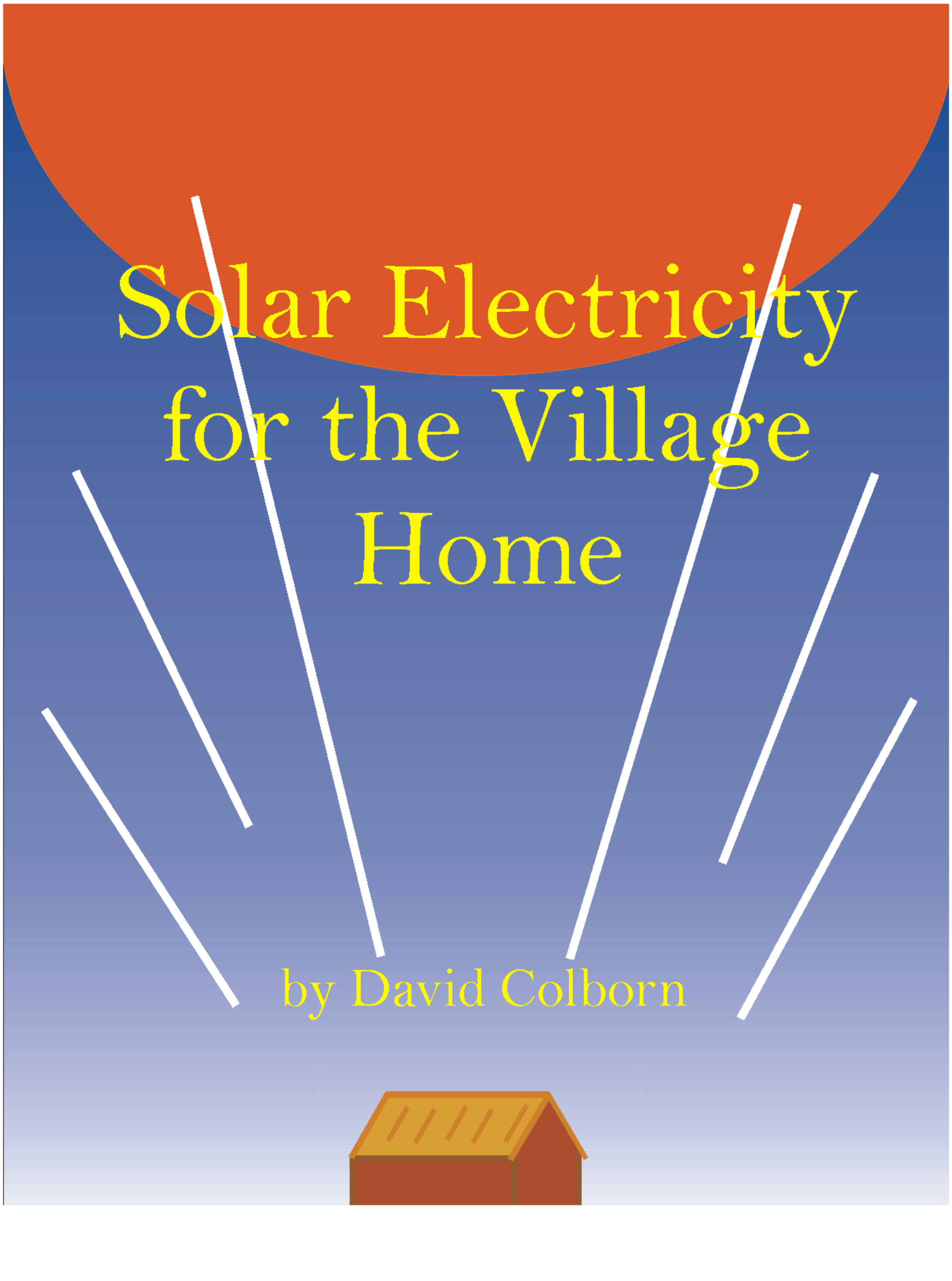
Solar Electricity
for the Village
Home
by David Colborn

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illustrated by Larry Noack

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Acknowledgments

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Chris Hochstrasser works in Cameroon and has extensive experience supporting PV for language and development workers.

Paul Kroening of the East Congo Group has extensive experience designing, installing, and maintaining PV systems.

Laurie Maskell is an electrical engineer who works with TECS department in Papua New Guinea, providing support for PV use.

Jay Peltz is a solar engineer and system designer with Alternative Energy Engineers in Redway, California.

George Peroni is a registered professional electrical engineer and has almost 60 years of experience with batteries and related applications. He is a principal in Hydrocaps, Miami, Florida.

Ernie Warnick and Reggie McClendon work at JAARS and provide PV systems for language and development workers.

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Thanks to Sierra Solar Systems for permission to use some of their publications. Sierra Solar Systems can be contacted by mail, email, fax, telephone, or you can see their webpage. 109-N Argall Way, Nevada City, CA 95959; tech info and foreign orders: (503) 265-8441; order line: (800) 51-SOLAR (USA only); fax: (530) 265-6151; email: solarjon@sierrasolar.com; Website: www.sierrasolar.com

About the author

David Colborn built his first solar-electric panel (9 watt/0.5 amp) from surplus satellite cells in 1976 and used it to recharge a car battery that ran a fluorescent light, a TV, and a bilge on his houseboat.

Later, on a farm four miles past the power lines, he used two 35 watt (2 amp) solar-electric panels to recharge a deep-cycle battery. The system powered 12-volt lights, stereo, TV, and a converted washing machine. Via a 500 watt inverter, he powered a vacuum, blender, typewriter, and computer.

While cruising for 14 months on a 38 foot sailboat, he used four 53 watt (3 amp) panels to charge a bank of batteries that provided much of the lighting, refrigeration, instrumentation and communications.

The author has been a technical writer for nearly 20 years. He wrote about solar electricity and documented industry hardware, software, and networks before becoming a member of Wycliffe Bible Translators and Summer Institute of Linguistics.

Get started with solar electricity

Introduction

This guide explains how to purchase, install, and live with a solar-electric system. All prices are in 1999 United States dollars.

The guide is geared for language and development workers living in villages, far from electrical utilities, and is focused on 12-volt systems using solar-electric panels and batteries.

The guide is written in collaboration with users and installers who have actual experience using solar electricity in various countries. Their comments are usually in italics (see *Paragraphs in italics*, below).

This guide provides information for three types of users:

- Those who have little time or interest in the details of solar electric systems can read the BASICS displayed in boxes.

> BASICS—The main points for those who don't have time right now for details

- Those who would like to get more efficiency from a solar-electric system will want to read both the boxes and the standard text.
- Technicians and the technically minded will find reference material on designing and troubleshooting solar systems in the "For technicians" section.

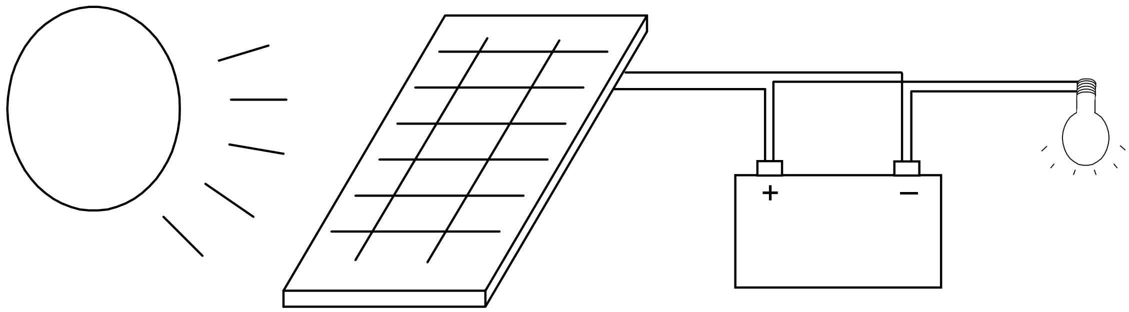
Paragraphs in italics are comments from users and installers in the field which we will call "field notes." Sometimes the writers of field notes will contradict each other or what I have written. There are many possible approaches, and I think airing differing views is healthy. Please think through conflicting opinions and use your own judgement. Interjections in these comments placed in brackets [ ] are mine.

Single words in italics are defined in the glossary. Some are also defined in footnotes, for the reader's convenience.

How solar electricity works

Simplified

The simplest system has a solar-electric panel, a battery, and 12-volt appliances that uses electricity (lights, radio, etc.). The panel transforms light from the sun into low-voltage electricity that is stored in a *deep-cycle*[1] battery.

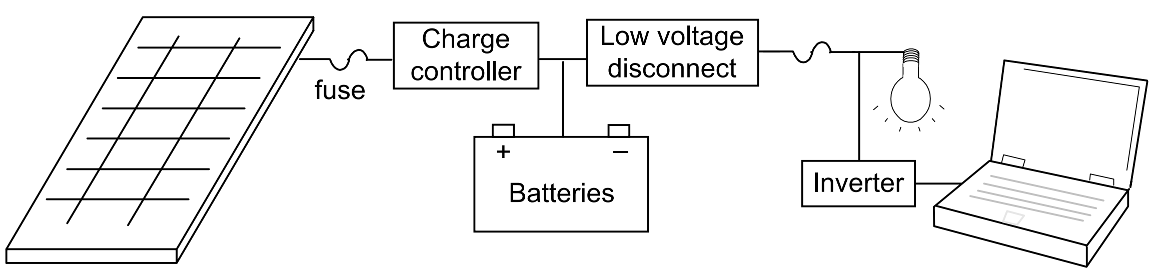


During the evening, or at other times, appliances use energy from the deep-cycle storage battery. During sunlight hours, the solar-electric panel replaces the energy used, and the battery returns to full charge.

BASICS—When sun strikes a solar-electric panel, an electrical charge is produced which can be stored in a battery for use now or later.

By using a battery, you can use appliances on a partially cloudy day, a very cloudy day, or during the night. When clouds block the sun, the panel stops producing power, but the battery provides stored electricity, acting as a buffer to maintain steady power to appliances.

A typical system also includes a *charge controller*[2] (plus a *low-voltage disconnect*[3], possibly internal to the charge controller), an *inverter*[4] (necessary to power 110-volt appliances such as a computer[5] and printer), and fuses to protect the system and your home from short circuits.



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[1] Deep-cycle battery: a battery capable of many deep discharge and recharge cycles. (In contrast, car batteries are designed for shallow cycles.)

[2] Charge-controller: a device that regulates the amount of charge your batteries get from solar-electric panels.

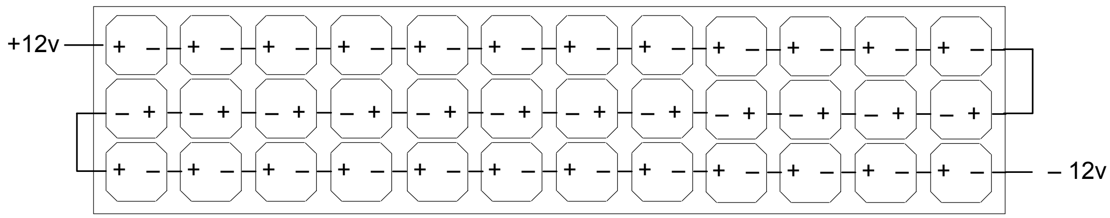
[3] Low-voltage disconnect (LVC): a device that disconnects loads (appliances) from a battery when that battery falls below a preset voltage.

[4] Inverter: a device that converts direct current (battery) electricity into alternating current electricity.

[5] In reality, the output from a solar-electric system is being converted to alternating current (AC) and back to a different direct current (DC) voltage for a laptop computer. The inverter can also be used to power a printer.

More detail

Position solar-electric panels so they receive lots of sunlight. Sunlight strikes the *photovoltaic*[6] cells and each cell (0.5 volts each) sends electrons along connections to a junction on the back of the panel. The accumulated voltage from the cells reaches over 12 volts (14–19 volts) at the junction box, and this low-voltage, direct current (DC) electricity is sent via wires to a deep-cycle battery.



On a sunny day, a 60 *watt* (3.5 *amp)* panel provides 60 watts (3.5 amps) per hour for around 5 hours (varies with location), for a total of 300 watts (17.5 amps) per day. Appliances might use up to 300 watts (17.5 amps) of electricity during a 24 hour period and, if the next day is sunny for 5 hours, this wattage (amperage) could be restored to the battery[7]. (For a explanation of watts, amps, and *volts*, see "Electricity for the novice" below.)

Someone is likely to say, "Wait a minute, we have a lot more than five hours of sunlight in our area!" Yes, you probably do. But what we mean by a number like "5 hours of sun" is something different: we mean "peak sun hours" or "equivalent full sun hours," the amount of charge received in an average day, expressed as if were always noon. When the sun is not overhead, its light passes through more atmosphere which reduces its intensity; also, some of the sun's angled light is reflected off the panel, rather than being absorbed by the cells. Peak sun hours are the sum of some less-than-100% morning sunlight, some 100% noontime sunlight, and some-less-than 100% afternoon sunlight. Even this total is reduced by the average number of cloudy days in your area. (See the appendix for peak sun hour maps called "*Insolation* maps.")

> BASICS—You must adjust your usage to fit within a system's electrical budget.

A solar-electric system may not produce electricity every day. The sun may shine for two days and then produce little or no electricity on a very cloudy day. A user might also consume a great deal of electricity on some days. To accommodate these variations, users rely on batteries and budget their use of appliances. (More about electrical budgets in the section, "Sizing your system" in the appendix.)

In practice, we start with the system the [sizing] calculations suggest, and try it. If the battery regularly comes up to full charge, all is well. We might even be able to leave lights on longer, or whatever our felt need is. If the battery does not regularly come to full charge, then we need to cut back our usage somewhere, or [install] more charging capacity. If we experience an unusually cloudy few days, we may need to temporarily cut back our usage until the battery recovers. (Laurie Maskell—Papua New Guinea)

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[6] photovoltaic – The conversion of solar energy directly to electrical energy. Photo means *light*; voltaic means *electric*.

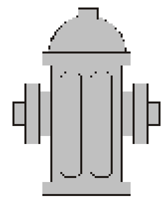
[7] As you will see later, there is some inefficiency and therefore you will get back less watts/amps than you put in.

Electricity simplified[8]—volts, amps, and watts

Voltage

If electricity were water, voltage would measure the amount of pressure at the faucet. Voltage is the "pressure" of electron flow. It is measured in volts.

Amperage or amps



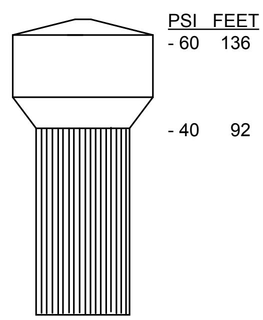
If electricity were water, amperage would measure the flow or how much water got through the faucet (determined by the amount of water and the size of the pipe and faucet). The amount of electrical "flow" at a given voltage is called *amperage* or *current* and is measured in *amperes*, or *amps* for short.

Amp hours are the number of amps produced or used in one hour. Batteries are rated by how many amp hours they will store. Solar-electric panels are rated by how many amps-per-hour they will produce.

Watts

Electrical power is the power to do work; it is a function of pressure (voltage) and amount (amperage). If you double either voltage or amperage, you double the power that is being carried through the circuit. The formula *volts x amps = watts* defines this relationship (Ohm's law). A watt is the measure of the power of electricity; many appliances are rated as using a certain number of watts. Some appliance specifications use the abbreviation *VA* or *Wp,* which mean the same as *W* or watts.

Storing and retrieving electrical power



A battery stores electricity much as a water tower stores water. The taller the tower, the higher the water pressure at its base. The higher the voltage of a battery bank, the greater the "pressure" of the electron flow. Just as with a tower of water, as electricity is drained from the battery, the voltage (pressure) slowly drops.

Much of the water in a tower is available from 45 to 60 psi (pounds per square inch). Once drained below 40 psi, usage will rapidly deplete the supply at an ever decreasing pressure. Similarly, a nominal 12-volt battery has most of its stored electricity available from just below 12 to 12.6 volts. When drained below 12 volts, little amperage remains.

Just as a pump designed to refill a water tower till it provides 45 to 60 psi would need to be able to produce water pressure of at least 60 psi, so a solar electric panel needs to be able to produce at least 15 to 16 volts in order to charge a 12-volt battery.

[8] Based on Solar Electric Design Guide by Golden Genesis Company. Available for US$5 from Sierra Solar Systems; included with Sunbeam Solutions US$10 packet. See "Sources" at back of guide.

How to purchase a system

System sizes

The JAARS starter system

You can elect to order the JAARS[9] starter system. With five hours of peak sunlight per day, this system provides about 300 watts/17.5 amps of electricity per day (you can read the previous page if you do not know what *watts*[10] and *amps*[11] mean).

Quantity	Description	US$
1	Solar-electric panel, MSX-60 watts	$372.75
1	Deep-cycle battery, 12-volt	$60.12
1	Charge controller, M8	$50.56
1	Low voltage disconnect	$38.45
1 roll	100 feet of wire, #12	$6.00
1	Inverter, Prowatt 150 watt	$64.35
Total (1999 prices)		$592.35

This is a possible electricity budget for this system:

Appliance	Watts/amps per hour	Estimated hours per day	Watts/amps per day
Fluorescent light	12/1	3	36/3
Notebook computer	18/1.5	5	90/7.5
Computer printer	36/3	1	36/3
2-way radio—listening	12/1	1	12/1
2-way radio—transmitting	48/4	.125 (7.5 min.)	6/.5
Total watts/amps per day			180/14

As you can see, the budget above is well within the 300 watt/17.5 amps-per-day system. This allows for some system watt/amp losses.[12]

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[9] JAARS Inc. is an international organization with headquarters in Waxhaw, North Carolina. Its purpose is to provide high quality technical support services to Wycliffe Bible Translators (WBT) and to the Summer Institute of Linguistics (SIL).

[10] watts – A watt is a measurement of total electrical power. Volts x amps = watts.

[11] amps – Electric current is measured in amps or amperes.

[12] There are up to 20% losses in wiring, batteries and inverters, so it is likely you will realize only 80% of the rated electricity you expect from a particular solar-electric panel (for example, 5 hours x 3.5 amps = 17.5 amps, factored by 80% to 14 amps). As you can see, we are emphasizing amps over watts since measuring amps is easier and more accurate for small 12V systems. (More about losses in “Size your system” in the Appendix.)

If you buy the starter system, you still need to make decisions regarding 12-volt switches, fuses, and two-way radios; you can skip to those sections below.

An average system

A limited survey of solar-electric systems for village homes revealed that many users employ four panels and an equal number of batteries. Here is what the typical system looks like and what it could power.

Quantity	Description	US$
4	Solar-electric panel, MSX-60 watts (3.5 amps each)	$1,360.00*
4	Deep-cycle battery 12-volt (105 AH each)	$240.48
1	Charge controller, Prostar 20 (up to 20 amps) w/meter and low voltage disconnect	$200.00*
1 roll	100 feet of wire, #12	$6.00
1	Inverter, Prowatt 150 watt	$64.35
Total (1999 prices)		$1,870.83

*You must shop to get these prices.

Here is a possible electricity budget for this system:

Appliance	Watts/amps per hour	Estimated hours per day	Watts/amps per day
Fluorescent lights (3)	12/1	3 x 3 lights = 9	108/9
Notebook computer	18/1.5	8	144/12
Computer printer	36/3	1	36/3
2-way radio—listening	12/1	1	12/1
2-way radio—transmitting	48/4	.125 (7.5 min.)	6/.5
Fans	30/2.5[13]	3 x 2 fans = 6	180/15
Stereo	12/1	10	120/10
Other occasional use: blender, electric drill, keyboard, water pump, TV/VCR, sewing machine, etc.	—	—	36/3
Total watts/amps per day			642/53.5

With five hours of peak sunlight per day, this system provides about 1,200 watts/70 amps of electricity per day. As you can see, the budget above is well within the 1,200 watt/70 amps-per-day system. This allows for some system watt/amp losses

[13] This is the typical usage of an inefficient fan. See “Fans” in the “For technicians” section for more efficient fans.

Build your own system

What kind of solar-electric panels to buy

Panels vary by three main characteristics:

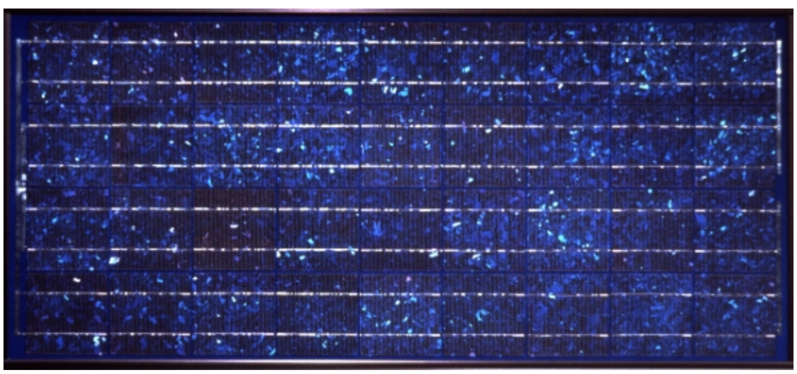
- type of cells used
- *watts*[14] or *amps* they put out
- *voltage* they put out

Cell types

There are currently four types of cells used in solar-electric panels:

- single crystal (mono crystalline)
- semicrystalline
- polycrystalline
- amorphous film.

These cell types vary in their output for a given area (square feet/meters), but end up being fairly close in price per watt/amp.



Panel of semicrystalline cells—the Solarex MSX-60 is part of the JAARS starter system

Amorphous cells take significantly more space and may not last as long as the other three types. However, you can purchase them as flexible or rigid panels. In addition, if the panels feature triple junction cells, they are significantly more robust when it comes to thrown rocks or sharp objects.[15] You can roll up flexible panels and carry them in a backpack.

If shade falls on part of a crystalline panel, the voltage falls so much that it will not charge a battery. An amorphous cell will work with partial shade on it. In a rain forest, a 32-watt amorphous panel will outperform crystalline panels. (Chris Hochstrasser—Cameroon)

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[14] Solar-electric panels are usually rated in watts. To determine how many amps they will provide, divide by their rated voltage (e.g., 60 watts / 17 volts = 3.5 amps).

[15] Amorphous triple-junction cell panels will usually continue to produce approximately the same amount of power even if damaged in one area.

Watt/amp output

Buy panels that have a good watts/amps to price ratio. If a panel costs US$375 and puts out 3.5 amps, you pay US$107 per amp (375/3.5=107). If another panel, of the same voltage (see below) costs US$425 but puts out 4.5 amps, you pay less than US$95 per amp.

You can mix panels with different amp ratings in a 12-volt system because you can wire them together in *parallel*. In a parallel system, the amps of each panel are added together. For example, the 3.5 amp and 4.5 amp panels in the paragraph above could be wired together to produce 8 amps an hour.

Compare panels using the amperage specification "Amps," "Rated Amps," "Peak Power Amps," or "Current @ max power," but do not use "Short circuit current."

If you buy panels that are rated at 16.5 volts and 1.9 amps [as I have], on a sunny day the amperage output may drop to only 1.5 amps. Keep this in mind when you size your system. (Mike Sweeney—Pioneer Bible Translators, Papua New Guinea) [This is because, as the panels heat up, their output decreases—more about solutions to this in the next section, "Voltage output" and in the section, "How to mount your panels."]

Voltage output

BASICS—Buy 17-volt panels for hotter climates; for temperate climates, buy 16-volt panels.

Buy panels that are rated at 16–19 volts. The reason for buying panels that are higher than 12 volts is that batteries have something called "internal resistance." They resist any voltage that is nearly equal to their own voltage. It actually takes panels that are 40 to 50% higher than 12 volts to efficiently charge a battery, especially during mornings and late afternoons.

For temperate climates, 16-volt panels are ideal. For hotter climates, use higher voltages of 17–19 volts. This is because as the solar-electric cell temperature rises, the voltage output drops, for example, from 17 to 16 volts. As a matter of fact, the amperage also drops when panels get hot, as the field note by Mike Sweeney illustrates in the section above, "Watt/Amp output."

Compare panels using the voltage specification "Rated volts" or "Peak power volts" or "Voltage @ max power," but do not use "Open circuit voltage."

What kind of batteries to buy

The battery is the heart of a solar-electric system. It stores power for the times when the sun is not shining. It allows you to use more power for a short time than your panels provide at any given moment. Your battery is also the part of your system that commonly wears out and needs replacing. Buy good batteries, maintain them properly, and avoid battery abuse to maintain a successful system.

Deep-cycle versus car batteries

BASICS—Ideally, buy deep-cycle batteries. It may make sense to buy automotive batteries in some situations.

Deep-cycle batteries are designed to provide a steady, relatively small amount of power over a long period and can tolerate not getting fully recharged immediately.[16] Car batteries are normally not recommended for a solar-electric system since they are designed to provide many amps for a short period and to be recharged quickly. But this is a controversial subject as the tech notes below point out.

[16] Whenever possible, recharge your batteries soon after a discharge, as delayed recharging will somewhat shorten the life of your batteries.

Deep-cycle technology allows the battery to be discharged far deeper than a car battery without degrading the plates, a big problem in the field. Car, truck, and motorcycle batteries are all heavy current, shallow discharge batteries. (Paul Kroening—E. Congo Group)

There seem to be locations where people have had better experiences with car batteries. Cost, time waiting for shipment of a deep-cycle battery, and comparable performance under particular conditions are the main reasons.

> BASICS—If you do buy a car battery, buy one with enough capacity that it usually won't be discharged by more than 20%.

I use car batteries. Deep-cycle batteries are not available in all countries and often the price is too high. It is also a matter of using the right device for the place and purpose it is used for. Here in Africa, I use most of my power during the day (when the sun shines) for my computer and printer. I also buy car batteries with enough capacity so I will never use more than 50% before recharging. For emergencies, a small generator that I use to run my electric hand tools is available to also charge my batteries. (Chris Hochstrasser—Cameroon)

One type of deep-cycle battery used for solar-electric systems is called an electric vehicle, forklift, or golf-cart battery. These are either 6 or 12 volt and weigh from 55 to 75 pounds (25–34 kg). Expect a life of 2–3 years.

A long lasting (8–12 years), heavier (about 120 lbs./54kg), taller (almost 17"/33cm) battery that has a very good reputation is the L-16. People often recommend the Trojan brand L-16. These are 6-volt batteries so you must buy in multiples of two to get 12 volts.

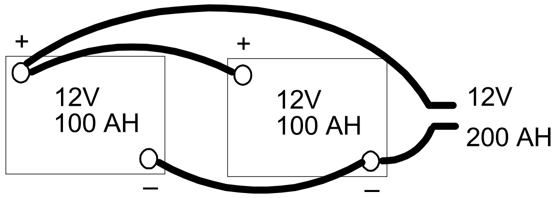
There are larger, very heavy industrial batteries available that weigh around 300 pounds each. Some larger batteries are 2 volts each and six of them must be wired together in series to create one 12-volt "battery."

JAARS sells great quantities of very fine 12-volt golf-cart/forklift batteries for US$60. They have a 105 amp-hour capacity and weigh 18 kilograms (44 pounds) dry. They can be shipped by air or sea. Each battery takes about 6 litres of acid and has decent carrying handles. I figure that sea-freighted in quantity, a $60 JAARS battery will cost my member, by the time we pay sea freight and customs, $83 in Kenya. Then add $1.50 per pound to freight to Congo ($60) for a total of US$143. Compare that to any good-quality local batteries you may have available. (Paul Kroening—E. Congo Group)

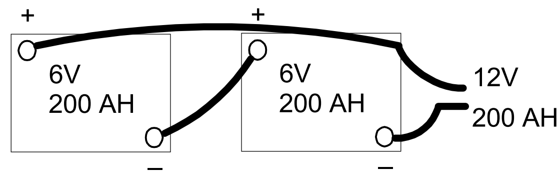
12-volt versus 6-volt batteries

If, when you size your system, you decide to get about 100 amp hours of battery storage capacity,[17] then a single 12-volt battery will be fine. If you want 200 amp hours of battery storage capacity, you could buy two 100 amp hour 12-volt batteries and connect them together in *parallel*. However, two 200 amp hour 6-volt batteries (connected together in *series* to provide 12 volt) are preferable because 6-volt batteries have thicker plates and therefore should last longer than two 12-volt batteries.

[17] Capacity – the amount of amp hours stored in a battery. For example, one 100 amp hour battery is a small capacity system. Four 100 amp hour batteries wired together to produce 400 amp hours is a moderate capacity system for a village home.



12V batteries in parallel



6V batteries in series are better

Ideally, buy enough battery capacity so that your appliance amp usage is only a small portion of your battery amp-hour rating. (See “Sizing your system” in the appendix.) If your battery has a total amp-hour rating of, say, 100 amp-hours (AH), you can get the most amp hours from it if you generally discharge it at a rate that is 5% of its capacity, or 5 amps per hour. If you put a heavier load of 20 amps per hour on your 100AH battery, you can only withdraw about 60 of the 100 amps stored in your battery.

The idea is to use a small amount of a battery’s capacity at one time. If you normally need to withdraw more amps, get more battery capacity.

Mixed batteries

BASICS—Buy matching deep-cycle batteries of the same age and type. It is OK to mix amp-hour ratings.

Ideally, do not mix batteries of different voltages and ages. Once you connect them together, your best battery will be reduced to the level of the worst battery. It is OK to mix batteries with different amp-hour ratings; tests have shown that smaller capacity batteries mixed with larger do not work harder and fail sooner than larger batteries.

Mixing two deep-cycle batteries of comparable age (or condition) and same type, or from different but reliable manufacturers, will not be a noticeable problem. But mixing old and new, even of the same make, model and size will. What is “aged?” Probably a year or more apart. (Paul Kroening—E. Congo Group)

BASICS—Plan to replace your batteries every 3–4 years, even if you’ve maintained them properly.

If you return to your home country for a year’s break every few years, it makes economic sense to size your batteries so that they are used up by the time you leave. After batteries are left uncharged for a year, they usually are not functional. See “Calculating battery storage needs” in the appendix.

Used batteries

Used batteries are a high-risk proposition. Get good technical advise before investing money. Can you verify how they were used and how well they were maintained?

Batteries to avoid

- Nicads require specialized charge controllers, so you should not use them in a village solar-electric system.
- Gel-cell batteries are more expensive than lead-acid batteries.
- Do not be fooled by the term “marine deep-cycle batteries.” They are a compromise between a starting battery (many, thin plates) and a deep-cycle battery (fewer, thick plates). They will not provide the number and depth of deep-cycles that their name implies. If their price and availability in-country is much better than deep-cycles, then they may be worth considering.

When to fill and charge a new battery

- If you live in a city or can drive from a city to your location without spilling battery acid, purchase batteries filled with acid and fully charged. It is nice to start with a fully charged battery, rather than waiting for up to several days of charging via a solar-electric panel.
- If you need to fly to your village, purchase batteries dry (without acid). Fill them in your village[18] and then connect them to a solar electric panel(s) and charge them for up to one week.[19] Dry-charged batteries, once filled with acid, have a partial charge (about 50% of full capacity) so they need to be charged before using. Do not use the panel(s) for anything else or try running anything with the batteries until they are fully charged.

Charge controllers

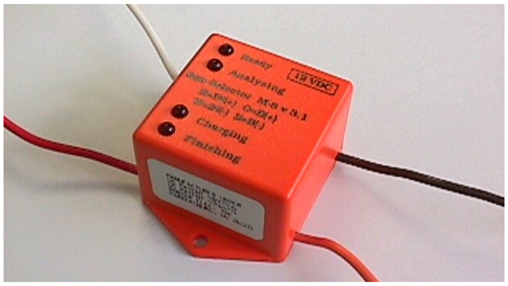
BASICS—A charge controller is very important for the protection of your batteries. If your system may expand in the future, buy a charge controller rated for more amps than you'll need now.

The charge controller is a very important part of a solar-electric system. It is a voltage regulation device that prevents excessive charging of your batteries. If the panels were constantly connected directly to your batteries, the batteries would overcharge and boil off too much battery water (*gassing*), requiring extra maintenance. In extreme cases, the batteries would be damaged.

Charge controllers allow maximum charging rates up to the point of *gassing* and then restrict the current so that full charge can be reached gradually.

The charge controller also serves to connect the panels to the batteries in the morning and disconnect them as the light of day fades. If left connected, during the night the batteries leak some of their power backward through the panels (unless the panels are equipped with anti-discharge *diodes*).

When selecting a charge controller, get a 12-volt version that can handle the number of amps your system provides. If your system may expand in the future, buy a controller that will handle a larger amp output.



Charge controller– M-8 is part of JAARS starter system

At temperatures higher than 77°F (25°C), battery life normally decreases. To compensate for higher temperature environments, select a charge controller that adjusts for higher temperature operation.

Some charge controllers are simpler than others. The more complex ones usually contain more features. Some features are merely nice, such as having the controller and LVD (Low Voltage Disconnect) in the same box, more indicator lights, disconnect switches, better wire connector panels, and sometimes even meters. Other features include more sophisticated charge cycles which utilize the panel more efficiently and keep the battery topped off better. In a larger system, one with more than a couple panels and batteries, I find the more sophisticated controller to be economical. (Paul Kroening—E. Congo Group)

The SunSaver charge controller employs an advanced charging method, but at a low cost for smaller, 1–3 panel systems. It handles 10 amps, is easy to wire, and includes a low voltage disconnect for US$66–74,

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[18] If you buy your battery acid locally, make sure the vendor does not mix acid and *tap water* to create the electrolyte. Unless you use distilled or filtered rainwater, your battery life will be shortened. In a tropical environment, also obtain battery acid designed for tropical temperatures (specific gravity of fully charged electrolyte used in tropics ranges from 1.210 to 1.230).

[19] Charge them fully according to the output of your panel(s). This may take several days or even a week.

depending on the supplier. Available from Alternative Energy Engineering, Sierra Solar Systems, and Sunbeam Solutions. See "Sources" at the end of the appendix.

Meters

In order to be successful with a solar-electric system, you should monitor your system's performance. You can accomplish this by purchasing two types of meters (some charge controllers include metering):

Battery voltage meter

BASICS—A battery voltage meter is essential to a successful system. A digital multimeter is the most useful type.

The absolute minimum in monitoring is to be able to check the condition of your batteries. It makes good sense to buy a digital multimeter (DMM) for US$19–50. You can use it on your solar-electric system, car, motorcycle, and radio. When not using it elsewhere, leave it connected to your battery system with alligator clips and turn it on periodically to read your battery voltage (leaving it on may wear out the meter's internal battery). The digital multimeter is very accurate, accuracy you need to analyze your battery's condition.[20] Try to find a meter that will not be damaged if you connect it backwards; look for protection for reverse polarity.

Other meters

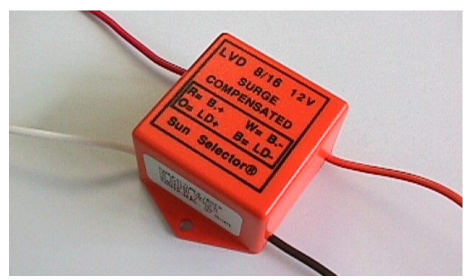
You can monitor the output of your solar-electric panels (panel amps) and the load your appliances draw (house amps). This is very helpful in overseeing the electrical supply and demand your system experiences during various times of the year.

Complete meter sets are available, and they will include wiring instructions. Or you can buy individual meters and a metal bracket to hold them.

Low voltage disconnect

If the battery gets too low, a Low Voltage Disconnect (LVD) automatically disconnects all appliances connected to it. This protects your battery from being too deeply discharged which would harm the battery. Once the battery is charged again to a set level (about 75%), the appliances are reconnected. See "Low voltage disconnect" in the "For technicians" section for pros and cons of their use.

Charge controllers that include the LVD in the module sometimes have a set screw which permits adjusting the cut-out and/or cut-in voltages.



Low voltage disconnect—LVD-8/16 is part of JAARS starter system

[20] To get accurate voltage readings, there must be no input from your panels and no appliances drawing power. More about this in a footnote of "Maintenance procedures" in the "Safety, maintenance, and shipping" section.

Inverters

An inverter takes direct current (DC) electricity and converts it to 120-volt/240-volt household alternating current (AC) current. This allows the use of items such as computers and printers, that are not typically available in 12-volt DC models. JAARS sells small inverters (150 and 250 watt) that are ideal for providing 120-volt AC power to a notebook computer and some printers.[21]

Inverter—Statpower ProWatt 250 is part of JAARS starter system

Modern inverters are over 90% efficient. So the small or even negligent increase in power consumption make inverters a better investment than higher cost and harder to find 12-volt DC appliances. (Paul Kroening—E. Congo Group)

Medium size inverter—Statpower 600 watt

For larger systems, you may save money on heavy, expensive 12-volt wire and expensive 12-volt lights and appliances by buying a larger inverter. You need to do some comparison shopping to verify savings. It is a good idea to buy a larger inverter than you think you need since efficiency is highest at about 50% of full power.

Large inverter pros and cons

Pros	**Cons**
Less expensive wiring	Higher cost of inverter
Use common 120V electrical connections	Dependence of whole house on fragile electronic circuits
Less expensive appliances	Potential cost of knowledgeable or licensed installer

12-volt plugs and receptacles

The standard for 12-volt plugs and receptacles are based on automobile cigarette lighters. Some auto lighter plugs and receptacles can handle 15 to 20 amps.

12-volt switches

In the low-voltage DC electrical path, the current loads tend to be higher, and therefore require more robust metal contacts at the point where the switch is opened and closed.

[21] Unplug small inverters when they are not being used—they use power even when no AC appliance is running.

To turn appliances on and off, some people simply plug and unplug them. If you tire of that, DC wall switches rated to 10 amps are available via catalogs for US$4–5. DC toggle switches rated to 25 amps are typically available at automotive stores; these are not in-line switches, but are mounted through a hole in some sort of thin panel (typically a 7/16 or ½ inch hole).

In Papua New Guinea, we started out with homemade switches for our lights. These were made by driving two nails in some wood and separating the nails by about 2 inches. One of the wires to the appliance was cut, the wire's covering stripped back an inch or so on each side of the break, and the exposed wire wrapped tightly around each nail. The "switch" was made from another short piece of wire, stripped at each end and one end wrapped around either nail. When we wanted the light, or whatever, on, we would move the free end of the short piece of wire over to the other nail and wrap it some. When we wanted it off, we would lift the short piece off and push it away from the other nail. (Verna Stutzman—Papua New Guinea) [Editor: this could be dangerous; it might be OK if used with care and for only a short time until standard switches can be located.]

You can switch larger DC loads using relays. For more about relays, see "Special switches" in the "For technicians" section.

Digital timers are available for switching up to six appliances (even pumps) on and off. For more about timers, see "Special switches" in the "For technicians" section.

Fuses

BASICS—Use fuses. Without them between batteries, controller, inverter, and appliances, houses can burn down.

The wire path between the batteries and the charge controller should have a fuse or circuit breaker. Each circuit from the batteries (and your inverter) to your appliances should also have a fuse or a circuit breaker. Some appliances have a built-in fuse.

I am not so sure of the need for a fuse (or breaker) between the battery and the charge controller. We have had quite a number of failures of charge controllers directly attributable to failure (or partial failure) of such a fuse. Excellent [connections] are needed in this area in order that the charge controller can sense the true voltage of the battery; [otherwise the charge controller] will cycle quickly, turning the charge off/on/off/on . . . repeatedly. (Laurie Maskell—Papua New Guinea)

Good fuses and circuit breakers are expensive. Automotive fuses and fuse holder are not particularly reliable. (Laurie Maskell—Papua New Guinea)

There are various classes of fuses for different purposes. Class R fuses are designed for higher amp loads than automotive fuses. Class T fuses are for very high amp loads such as large xinverters. They are available from Alternative Energy Engineering; see “Sources” at the end of the appendix.

Class	Amp rating	US$
R	10–30A	$6.50
R	40–60A	$8.50
R	100A	$18.00

Fuse blocks for 10–30A, $5; 40–60A, $7; 100A, $26

Class	Amp rating	US$
T	110A	$53
T	200A	$50
T	300A	$79
T	400A	$79

Includes fuse block. Replacement fuses: 110A and 200A, $18; 300A and 400A, $38.

Lights

The key to effective lighting is to use small lights wherever they are needed, rather than big lights that cover a general area. (Mike Sweeney—Pioneer Bible Translators, Papua New Guinea)

Fluorescent area light

Halogen reading light

Twelve-volt fluorescent and halogen lamps provide the most light for the least amps. Fluorescent lights provide general light, while halogens offer more focused light and their light output is said to be good for situations where color perception is important. Both 12-volt types are relatively expensive, but are readily available through solar-electric catalogs (see “Sources” at the end of the appendix) or marine and recreational vehicle suppliers.

You can also buy 12-volt incandescent lights that use medium bases (standard 120-volt screw-in bases). They put out less light than fluorescent or halogen lamps for the power used, but are still 30% more efficient than 120-volt lights.

Adapters are available for converting halogen bulbs to medium base. This allows you to convert a medium-base light fixture by also replacing the AC plug with a 12-volt auto lighter plug. You can also convert bayonet base bulbs (auto tail lights) to medium base. These adapters are available through solar-electric catalogs (see “Sources” at the end of the appendix).

Twelve-volt lights are rated in watts. To determine how many amps they draw, divide by 12.

Incandescent medium base light

Comparing typical 12-volt lights

Type	Watts/amps	Lumens	US$ (approx.)	Comments
Fluorescent	15W/1.25A	870	$35	Includes fixture. Replacement bulb, about US$4.
Halogen	25W/2.1A	640	$7.50	Plus $8 for reusable adapter that fits standard medium base socket. Plus cost of fixture.
Incandescent medium base bulbs	50W/4.2A	865	$1.75	Plus cost of fixture. Not recommended due to power use.

There are many switches and specialty lights available. For example, 12-volt dimmer switches, light controlled switches, outdoor floodlights and path lights, reading lights, and area spot lights. See solar-electric catalogs in “Sources” at the end of the appendix.

Twelve-volt fluorescent lamps give more light per watt than incandescent lamps (and create less heat). But fluorescent lamps have a tiny inverter inside the unit. There are now fluorescent lamps of 15 to 20 watts consumption which use 120 VAC from an inverter: more light, but still at power levels acceptable in a solar-panel system. These are usually the folded-fluorescent [compact fluorescent] design. Some 12-volt fluorescents will burn out bulbs if fed low voltages; using a Low Voltage Disconnect should prevent this problem.

In our next house, I plan to use regular 240-volt fluorescent fixtures. They are much cheaper and more reliable than their 12-volt cousins. To do this I will need a 240-volt, 50 cycle inverter. (Mike Sweeney—Papua New Guinea) [Count the cost of all the 12-volt lights, fans, and other appliances, and compare to the cost of a larger inverter. It may be less expensive in the long run to buy a larger inverter.]

Two-way radios

Transceivers are the communication lifeline of the village home. However, during transmission they consume a significant amount of power.

Radio watt rating	Amps* used during transmission
25	4–4.5
50	8–9
100	16–18

***typical**

The SGC Model 2020 for US$625 is a rugged 20 watt transceiver that offers low current performance: about 0.4 amps in receive mode; about 4 amps in transmit mode.

Elecraft offers a kit radio optimized for low-current operation for about US$630. Their model K2, 50W version, draws about 0.2 amps in receive mode and about 10 amps in transmit mode. However, the radio allows you to adjust the power usage lower to save electricity when conditions are good and up to full power for clear communication during difficult conditions (this power saving feature is also available with radios from other manufacturers).

Consult a radio expert about the best two-way radio for your location.

Fans

It is quite possible to include 12-volt fans in your solar-electric system, but you will need to monitor your battery's condition if you use them frequently. See "Fans" in the "For technicians" section for more details.

Making your own appliances

We cannibalized worn-out cars for 12-volt parts. We made a reading light for over our bed from a taillight bulb; a fan by using a windshield wiper motor. (James and Karen Ashley—Solomon Islands)

What not to power with a solar-electric system

There are some appliances that are not practical to power with a solar-electric system. Electric heaters and air conditioners are the most inefficient.

← Inefficient: Electric heater, air conditioner, electric clothes dryer.

→ Efficient: Fluorescent lights, notebook computer, radio (receiver).

Some other appliances are not that efficient, but we need them so much that we find a way to power them anyway. Refrigerators and well pumps fall in that category (see more about these items in the "For technicians" section).

Install your system

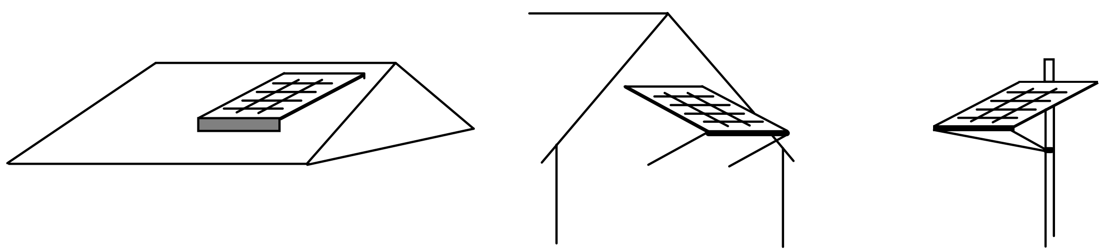
Where to mount your panels

Pick a place for panel installation that does not have much foot traffic and that provides some security. Most users place their panel on their roof, though they may also be mounted on a side wall of a building, on a pole(s) or on a ground support. It is also best if your panel is relatively close to your battery.

BASICS—Place panels where they will not be shaded (shading even half a cell is too much).

Orient the panel to capture the maximum sunlight available, avoiding any shade; even the shadow from a nearby branch will reduce your efficiency.[22]

BASICS—Face panels toward the equator.



In relation to compass direction, face (or angle) your panel toward the equator (northern hemisphere, true south; southern hemisphere, true north).

How to mount your panels

Roof mounts

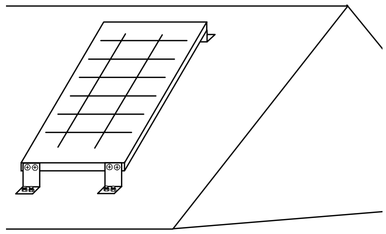
Solar-electric panels need some air circulation behind them to maintain full efficiency (heat reduces their output). Even though panels come with an offsetting frame, they should not be put flush on a metal roof, but rather be offset a few additional inches. Mounts should be sturdy enough to hold panels securely during high winds.

BASICS—Allow for air flow since heat reduces a panel's output.

Our 3 amp, 14-volt panel, which we placed on our metal roof, gave us 3 amps in bright sunlight until the panel heated up; then it would only supply 1 amp. (Mike Herchenroeder—Papua New Guinea) [Editor: This emphasizes the need to buy a higher-voltage panel and/or provide more air circulation for hot roof conditions.]

[22] Panel output will be substantially reduced by the shading of more than half of any cell(s).

You can mount panels on a roof using pieces of metal at each short end. The metal pieces should be tall enough to hold the panel off the roof a few inches to allow air circulation. They should be bolted to the panel and, ideally, lag bolted through the roof and into the roof supports. Seal your roof around the lag bolts with roof cement or clear silicone seal.



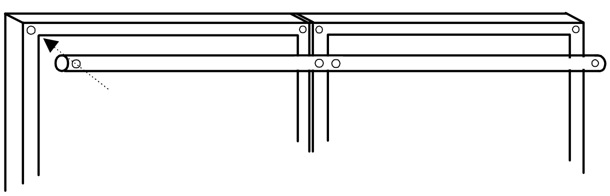
A common metal roof installation method is to tie strong wire [not electrical wire] from both upper corners of a panel, slide the wire up under the roof cap, and securely tie it around the roof rafter. Often the base of the panel is not attached, relying only on gravity to keep it in place. (Verna Stutzman—Papua New Guinea) [Editor: While some seem to get by with only attaching the upper end of a panel, there could be severe damage to the panel and to people if strong winds were to lift it and then pull it free. If attachment wire is used, I recommend that you also attach the lower edge of the panels to something secure.]

Some thatch roofs[23] may not be very amenable to a panel frame, either because they crush the thatch so it is no longer waterproof, or there is no decent rafter underneath. Often the local carpenter can dream up a solution. (Paul Kroening—E. Congo Group)

Frames for multiple panels

Many solar-electric manufacturers sell mounting frames[24] that fit their panels. These frames are aluminum and are predrilled for the particular panels.

You may be able to design and construct frames using local materials. Frames can be made of aluminum, steel (even bed frame rails), electrical conduit, or even sturdy, painted or treated wood (the wood must not twist as it ages). The idea is to provide a stiff rail across each set of ends of adjoining panels.



Most people will use what ever they can get for frames, which is often local, untreated lumber. The aluminum frames of the panels themselves are pretty rigid and I have never damaged a panel because of what I bolted it to! If you describe the job to a local carpenter in terms of load the frame has to carry, wind, etc., they can often come up with the appropriate local solution. I too like to have the proper mounts, but there are locations in which some people would steal the panel and mount just to get the aluminum channel, ignoring the panel! (Paul Kroening—E. Congo Group)

For security, I bolt my panels to a secured frame with three bolts and the fourth corner with a padlock. (Ken Sawka—E. Congo Group)

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[23] Thatch roofs offer at least two challenges: steepness and rough-on-the-skin surface. For safer roof-walking, attach a long rope to a tree or something solid on the other side of the house; throw it over and tie a comfortable loop you can put around you as you work. For prickly surface problems, wear protective clothing (and work in the morning).

[24] By frames, we mean some method of connecting panels together so they become one physical unit.

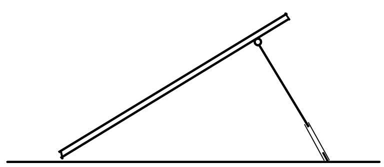
General

- Panels should not necessarily be pointed toward the equator.[25] If shading is a problem, more hours of sunlight may be available by pointing panels up to 25 degrees east or west of the equator. For instance, if you have a mountain that shades your area from morning sunlight and a valley in the other direction that allows more afternoon sunlight. In that case, turn the panels to the west to capture the most available sunlight.
- For permanent mounting, tilt your panels at a specific angle above the ground according to your latitude. Use this chart to calculate the best tilt angle. (Feedback from users in the field indicates that tilt angle is not critical, whereas wire sizes and electrical connections are.) If you do not know your approximate latitude, consult an atlas or almanac.

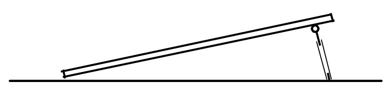
Your latitude in degrees	For year-round fixed mount, tilt panels at this angle off the ground
0–15°	15°
15–25°	angle same as latitude
25–30°	latitude + 5°
30–35°	latitude + 10°
35–40°	latitude + 15°
+45°	latitude + 20°

(Note: a small tilt angle means the panel will lie almost flat [see Fall, below]; a large tilt angle indicates it will stand up on one edge.)

Some users will want to maximize the efficiency of their systems. To bring in more electrical energy from your panel, you can modify your mount to allow for two seasonal adjustments per year to better point at right angles to the sun: one at the beginning of the cooler season (fall) and one at the beginning of the warmer season (spring).



Fall



Spring

On the equator, we sometimes moved the panels from the south side of the roof to the north to get the best seasonal sunlight. (Paul Thomas—E. Congo Group)

For bigger systems using four or more panels, mounts called trackers automatically follow the sun from east to west. In sunny climates (0–35 degrees latitude), trackers are supposedly less expensive than additional panels (investigate the finances of this yourself when you are ready to buy, as these technologies change rapidly). In climates with less sun (36 degrees latitude or higher), money is better spent on additional panels that increase your winter harvesting of sunlight.

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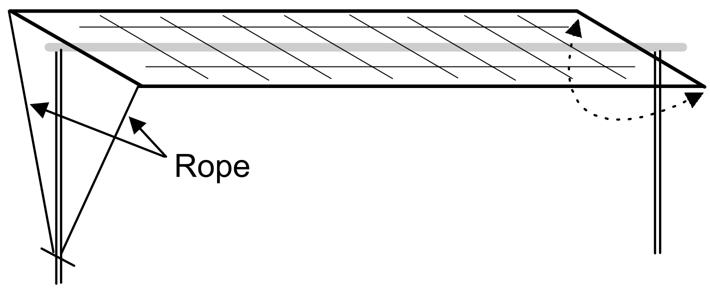
[25] While not super important, to calculate true North or true South, make allowances for compass deviation in your area. Contact a local pilot or a marine navigator for more information.

Another solution, seen in the field, offers (or requires) adjustment several times daily. Support your panel on an axle between two tall posts (which are placed so the panel can be pivoted to follow the sun). Connect two ropes to your panel that are led to a cleat on one of the posts. Use the ropes to adjust the panel to point at the sun all through the day. Alternately, run ropes to a drum with an adjustment handle.



- Dissimilar metals, such as aluminum and steel, will corrode when touching one another.
  To avoid corrosion, attach aluminum panels to aluminum frames with aluminum or stainless steel nuts and bolts. (In a salt-air environment, even stainless steel nuts and bolts bolted through aluminum should be coated with petroleum jelly or something similar.) If you use steel frames, use stainless steel nuts and bolts, but also separate the aluminum panels from the steel frames by using rubber or stainless steel washers.

  Temporary installations with the wrong materials will not affect the function of the panel, but be sure to get the right parts when possible to avoid jammed and corroded fasteners later. (Paul Kroening—Congo Group)

- In cold weather climates, where there is snow cover, adjust your panels in winter for a sun low in the sky and pick up an extra 20% of the light from snow reflection. To help keep snow off, orient your panels so the long edges are on a vertical plane.

- In areas where lightning is a problem, ground your panel frames.

  BASICS—Ground your panels. Lightning can easily destroy your controller, inverter, computer, and fluorescent lights.

  Lightning is a problem almost everywhere SIL[26] people work. Always ground panels. Aside from near or direct strikes, this helps to protect against the large static charges that build up in the vicinity of storms and can easily damage sensitive electronic systems like computers. (Paul Kroening—E. Congo Group)

  The general principle in lightning protection is to use the largest wire with the shortest, straightest path (avoid sharp turns) to ground; this creates the least resistance and the fastest dissipation of a lightning surge. If possible, contact an electrical supplier for the following:

  - 4 to 10 foot ground rod
  - 6 to 2 gauge wire from panels to ground rod (shortest and straightest possible path)
  - wire-to-ground rod fastener
  - wire-to-panel connector and bolt

  In dry or hard ground, dig a trench six feet long directed away from your house and lay a six foot metal rod or copper pipe or cable in the trench. Pour rock-salt into the trench and cover it with dirt to fill the trench. The salt will draw moisture and increase the conductivity of the grounding system. (Paul Thomas—E. Congo Group)

[26] SIL – Summer Institute of Linguistics

Another way to deal with dry ground is to place your ground rod where water drains from the house, near a rain barrel, etc.. (Paul Kroening—E. Congo Group)

- Many experienced users break their multipanel and multibattery systems into two or more smaller systems. While this could add some cost for charge controllers and meters, there are several advantages.
  - ✓ If one system has a problem, the other can provide electricity until repairs can be made.
  - ✓ Less interference is caused by fluorescent lights and inverters if you put the radio on a separate circuit.
  - ✓ You have better safety in emergencies if your radio is kept on a separate, reliable battery.
  - ✓ If one battery goes bad, it will not drain the others.
  - ✓ If one battery is overused, you can be swap it into a system that is underused.
  - ✓ You can explore the potential for shorter wire runs.

  Tip: Place a battery for each system near the lights of another system in order to see well during troubleshooting. (Ken Sawka—E. Congro Group)

How to wire your system

There are a wide variety of ways to connect wire to your panels, batteries and other major components. The conservative methods detailed below give you better, safer results, but you can also just twist wires and bend them into loops for connections.

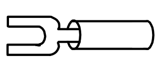
Tool list

- Wire crimper-stripper tool
- Flat-blade screw driver
- Soldering iron[27]

Parts list

- Wire: use stranded wire and see wiring chart for distances and amps (#10 is available as a cable of two insulated wires bound in a vinyl cover which is designed for weather protection).

- Spade connectors: #12-10; two for each panel; two to four for other connections.



Spade connector

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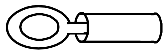
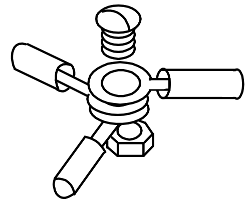
[27] While 12 volt DC soldering irons are useful for small jobs, heavy wire require more heat. A propane soldering iron (a soldering "pen") is a very handy tool. Available through JAARS or specialty catalogs.

- Ring connectors: you have to calculate the number and sizes for your particular equipment. You can also connect three or four ring connectors together using a small bolt and nut.



Ring connector



- Solder: 60/40 or 50/50 multicore resin. Do not use acid-core, as it will corrode copper wire.

Wire sizes

As size of wire goes up, the gauge number goes down.

> BASICS—Place the following items close together and use large wires to connect them: panels, batteries, charge controller, large inverter, and any appliance that draws high amps (like your two-way radio).

Almost any DC circuit must use 12 gauge (4mm) or larger wire to avoid what is called "line loss"[28] or low voltage (as size of wire goes up, the gauge number goes down). Low direct current (DC) voltages can not handle much line loss; for example, a voltage loss of 10% (1.2 volts) is more than many 12-volt appliances can tolerate (especially fluorescent lamps). Line loss increases as amperage being carried increases. To avoid lowered voltages, you must use either larger wire or shorter lengths of wire. The charge controller, batteries, two-way radio, and fuses for these high-current lines should be centrally located to allow for the shortest and most direct routes. Size the wire for each path (circuit) to your appliances by using the wire sizing chart below.

> BASICS—Use properly sized wire (see wiring chart) and quality connectors, or your system performance will be disappointing.

To calculate current in amps for various appliances, divide the watts by the voltage (watts/12V=amps). Using this formula, a 12-watt light will use 1 amp, and an 18-watt appliance will draw 1.5 amps. (Two-way radios are a special case.[29]) Add the amps used by appliances sharing any wire path (circuit) and size the wire in that circuit accordingly.

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[28] Line loss is the voltage drop over a length of wire. Line loss wastes power by producing heat in the wire. It is caused by running too many amps through too small a wire for too long a distance.

[29] Two-way radio watt ratings are indications of transmission power, but not power consumption. Look in your radio manual for the number of amps used during transmission. Use this amp draw rate to figure the wire size needed for your radio.

Wire sizing chart for 12-volt systems

Maximum wire length[30] for acceptable (5%) voltage loss

Note that the numbered columns are in both American Wire Gauge (AWG) and in European metric, millimeters squared (circular cross-section). See "For technicians" section for European metric wire sizing in meters. Maximum distances are expressed in feet (') and meters (m).

Wire size	**12 / 4mm^2**	**10 / 6mm^2**	**8 / 9mm^2**	**6 / 14mm^2**	**4 / 22mm^2**	**2 / 34mm^2**	**1 / 43mm^2**	**0 or 1/0 / 54mm^2**	**00 or 2/0 / 68mm^2**
Amps	Smaller wire ◄							►	Larger wire
1	169'/ 51m	269'/ 82m	427'/ 130m	-	-	-	-	-	-
2	85'/ 26m	134'/ 40m	214'/ 65m	340'/ 103m	540'/ 164m	-	-	-	-
3	56'/ 17m	90'/ 27m	142'/ 43m	226'/ 68m	360'/ 109m	572'/ 174m	-	-	-
4	42'/ 12m	67'/ 20m	107'/ 32m	170'/ 51m	270'/ 82	429'/ 130m	542'/ 165m	-	-
5	34'/ 10m	54'/ 16m	85'/ 25m	136'/ 41m	216'/ 65m	343'/ 104m	433'/ 132m	546'/ 166m	-
6	28'/ 8m	45'/ 13m	71'/ 21m	113'/ 34m	180'/ 54m	286'/ 87m	361'/ 110m	455'/ 138m	574'/ 175m
7	24'/ 7m	38'/ 11m	61'/ 18m	97'/ 29m	154'/ 46m	245'/ 74m	309'/ 94m	390'/ 118m	492'/ 150m
8	21'/ 6m	34'/ 10m	53'/ 16m	85'/ 25m	135'/ 41m	215'/ 65m	271'/ 82m	341'/ 104m	430'/ 131m
9	19'/ 5m	30'/ 9m	47'/ 14m	75'/ 22m	120'/ 36m	191'/ 58m	241'/ 73m	303'/ 92m	383'/ 116m
10	17'/ 5m	27'/ 8m	43'/ 13m	68'/ 20m	108'/ 32m	172'/ 52m	217'/ 66m	273'/ 83m	344'/ 104m
15	11'/ 3m	18'/ 5m	28'/ 8m	45'/ 13m	72'/ 21m	114'/ 34m	182'/ 55m	230'/ 70m	289'/ 88m
20	8'/ 2m	13'/ 4m	21'/ 6m	34'/ 10m	54'/ 16m	86'/ 26m	108'/ 32m	136'/ 41m	172'/ 52m

Chart adapted from information courtesy of Atlantic Solar Products, Inc.

[30] The length of two parallel wires (positive and negative) between components such as a battery and one or more appliances.

For example, if a particular circuit uses a total of 10 amps and the circuit is 17 feet (5 meters) or less in length, then 12 gauge (4mm) wire or larger will be appropriate. See table below for further examples.

Example of length and wire size for 10 amp peak usage

Length	Wire size
17' (5m)	12 gauge (4mm)
27' (8m)	10 gauge (6mm)
43' (13m)	8 gauge (9mm)

Note that long runs of wire and/or heavy current loads require cumbersome and expensive wire.

To calculate wire sizes for higher voltages, multiply the maximum distances times the conversion factor that follows:

24V	x2
32V	x2.5
36V	x3
48V	x4
120V	x10

To calculate for 2.5% voltage drop (recommended by JAARS), reduce the maximum distances by half.

Wire colors

Commonly, United States automotive and marine wiring uses red wire for positive and black wire for negative terminals. United States home electrical codes call for black for positive and white for negative terminals. UK and European standards use brown for positive and blue for negative terminals. Wire colors vary.

Whatever colors you use, you should be consistent throughout your system and draw a map of your wiring paths, including wire colors and *polarity*; keep your map in or near the fuse box for future reference.

How to wire to the panels

Most solar-electric panels have one or two junction boxes on the back for wiring.

The best connections are made by using spade connectors; bare wire connections can also be made if there is space for the wire under the screw head.

The Solarex MSX-60 panel currently sold by JAARS has a single junction box with terminal post screws that accept spade connectors or bared wire (positive wire to screw #2, negative wire to screw #5). Make connections using the following steps for either spade connectors or bare wires:

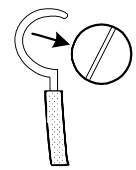
Spade connectors

1. Using a wire crimper/stripper tool, strip ¼ inch (12mm) of insulation off each end of the wire.
2. Crimp #12-10 spade connectors on each bare wire end.

3. For best results, solder the wire-to-connector interface. First get the connector hot enough so that solder flows freely when touched to connector.
4. Using a screwdriver, loosen the terminal post screws on the back of the panels (if appropriate) and slip the spade connectors on.
5. Carefully tighten the screws on each post.

Bare wire connections

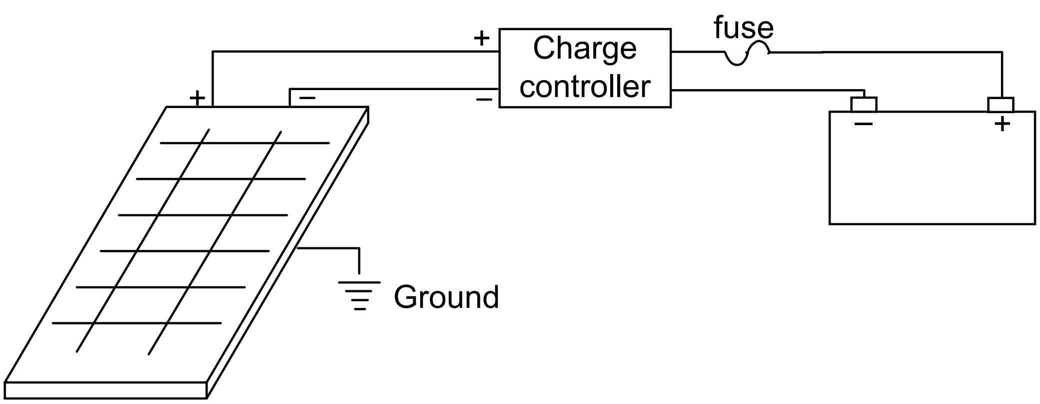
1. Using a wire crimper/stripper tool, strip 5/8 inch (17mm) of insulation off the panel end of the wire.
2. For a sturdy connection, bend loops into the ends of the bare wires.
3. Keeping polarity in mind, slide the bare wires clockwise around the screws.
4. Tighten each screw until the wire is held firmly.



For systems 24 volt or higher, see the "For technicians" section for instructions.

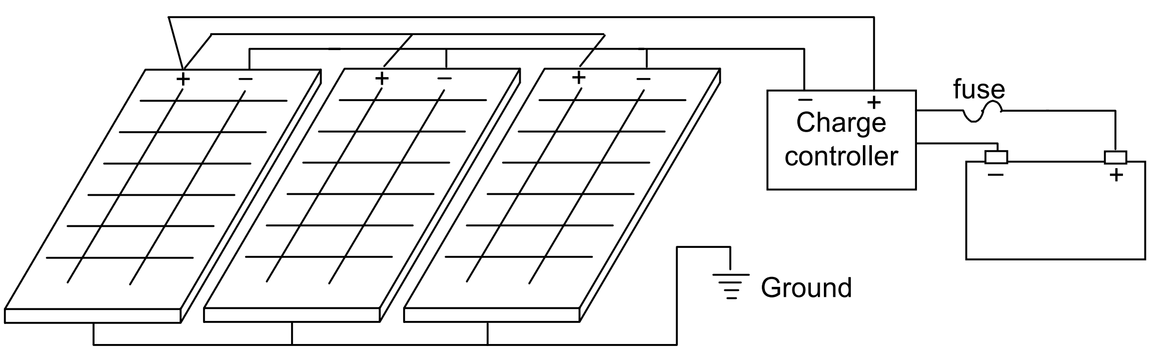
Single panels

If you use only one panel, wiring is very straightforward. Use the appropriate steps above, the illustration that follows, and the instructions under "Connect panels to batteries."



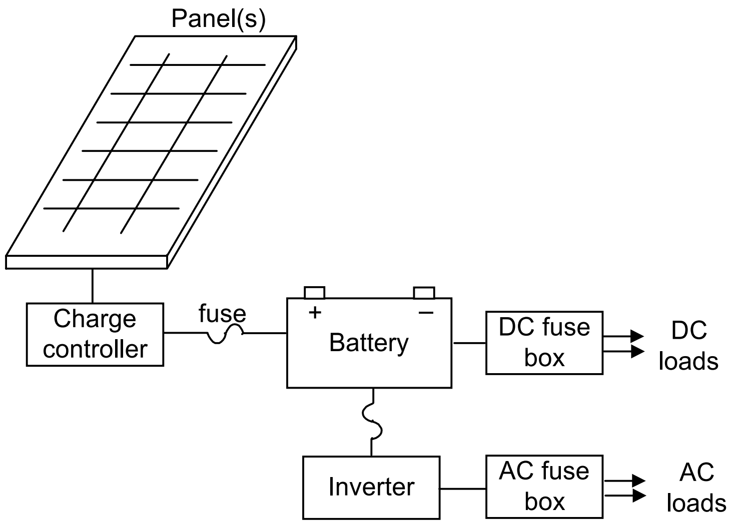
Connect multiple panels together

If you have more than one panel for a 12-volt system, wire the panels together in parallel (connect all the positive terminals); do the same for all the negative terminals. Use the appropriate steps above, the illustration that follows, and the instructions under "Connect panels to batteries." With more than four panels, break them into two groups and join the two groups in a separate junction box.

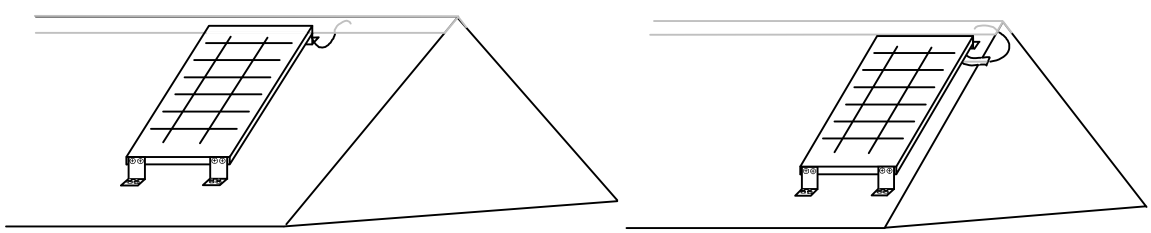


Connect panels to batteries

Connect the panels to the charge controller (regulator) first and then to your batteries. Use the appropriate size wire for the distance from panels to controller and the total amps produced by the panels. See "Wire sizing chart for 12-volt systems," above.



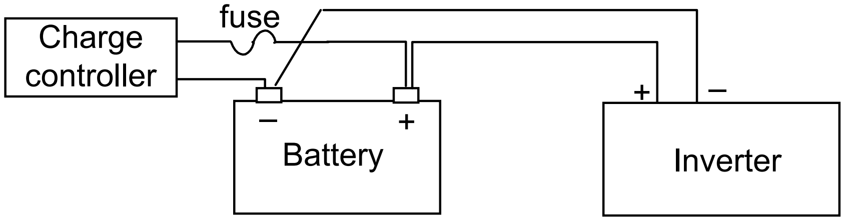
Typically, you will run wire from the panels on the roof to the batteries in the house below. Keep the run as short as possible and protect your wire from any abrasive surfaces (like the edge of metal roofing) by using "stand offs" or running the wire through pieces of old hose and using plastic wire-wraps or nailed clips to hold it in place.



Keep the length of wire exposed to the sun and weather as short as possible because the insulation on an exposed wire becomes very brittle in a few years. Exposed wire should slope downward where it leaves walls or other enclosed spaces so that water cannot follow the wiring through the hole. (Laurie Maskell—Papua New Guinea)

Connect charge controller, batteries and inverter

Use large wire (at least #4) to connect your controller to your batteries, to connect batteries together, and to connect to a large inverter (greater than 500 watts). You can purchase premade cables or build them. If you choose to build them, the proper connectors for this larger wire are heavy-duty lugs and require a large crimp tool; check with your local technician for this phase. He or she should be able to make up the wires and connections by using measurements you supply.



Wiring batteries together

First, two cautions:

> BASICS—Avoid contact with battery acid; wear protective eyewear. Cover one terminal of battery with heavy rag.

- Be very careful when dealing with batteries; they are filled with acid which will
  - ✓ burn skin or eyes,
  - ✓ damage clothing, and
  - ✓ eat into almost anything it comes in contact with.
- Wear eye protection; in case of eye contact with acid, flush with water for 15 minutes.
- Be very careful with tools around batteries. If a metal tool contacts more than one terminal, there will be sparks, hot metal, and possibly an exploding battery. When working on a battery, cover one of its terminals with a thick rag, old towel, rubber mat, or other insulation.

Deep-cycle batteries may come with a wing nut on the top of a post. Or they may come with terminal posts that have a hole drilled in them and a nut and bolt through the hole. Use the wing nut or bolt to make secure connections.

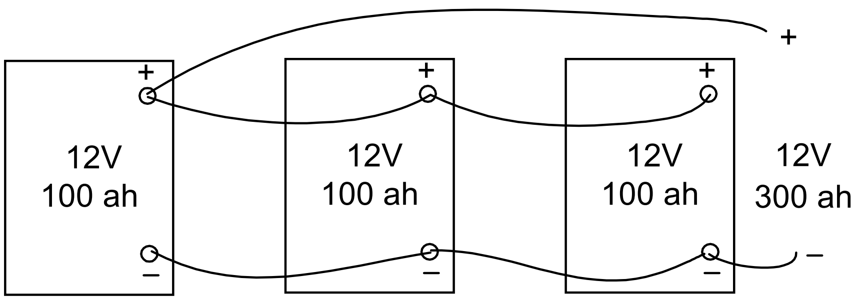
For batteries without holes in the terminal posts, there are inexpensive adapters that bolt to the tapered battery terminal post and provide wing nuts; these are available at marine stores and through solar-electric catalogs.

To connect batteries to one another, use heavy battery cables (at least #4 wire) and appropriate connector lugs. Smear a thick layer of Vaseline on the connections during and after installing them; this will help prevent corrosion.

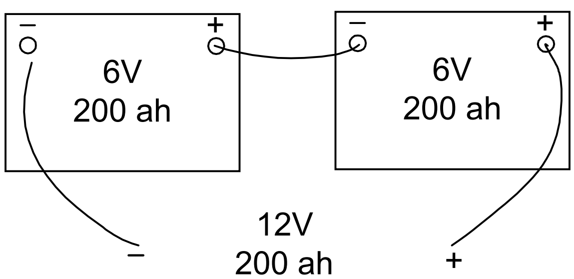
On battery terminals I would use a thick coat of Vaseline rather than a thin smear. Last time we replaced some eight-year-old "telephone" batteries, there was no trace of corrosion on the thickly Vaseline-coated terminals. (Laurie Maskell—Papua New Guinea)

You can wire multiple batteries together to supply more amp hours of capacity, to supply higher voltages, or a combination of both. Here are some diagrams for each:

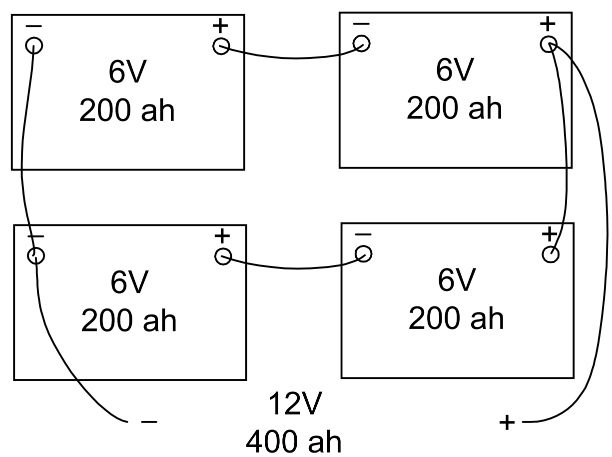
Batteries in parallel



Two 6V batteries in series

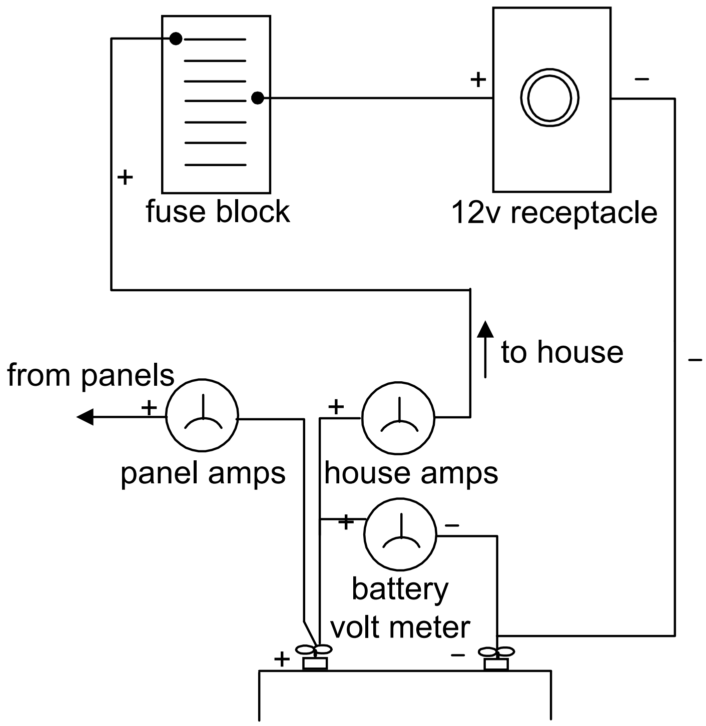


Four 6V batteries in both series and parallel



Meters

Here is how to wire individual meters into a system:



Ground your system

BASICS—Ground your inverter, radio, and negative post of your battery.

You can protect your equipment from lightning and induced voltage surges from distant lightning if you ground the inverter, radio, and the negative pole of the battery bank (which will also take care of your 12-volt fluorescent lights). Use separate ground wires for your inverter, radio, and the negative pole of your battery bank and lead these to a common ground rod. Separate ground rods create electrical differences during lightning strikes and the differences could destroy connected equipment.

If lightning is a problem, we suggest that radio antennas be unplugged from the radio whenever it is not being used, and be plugged into a matching socket which is connected to ground. This may not save the antenna, but it should prevent a fire. (Laurie Maskell —Papua New Guinea)

Wiring to avoid radio interference

Fluorescent lights and some computers tend to create radio frequency (RF) interference when they are wired in the same system with a two-way radio. Sometimes this interference can be reduced by moving the radio farther away from the fluorescent lights or computer. If the radio schedule is during the day, the computer is off during transmission, and lights are only used at night, the problem is solved.

If RF interference continues to be a problem, one solution is to wire two different systems: one for your lights and computer and one for your radio. If you have three or four solar-electric panels and multiple batteries, you can split them up into two systems. Do not forget to buy a charge controller for the radio system. The field note below brings up another good reason for split systems.

For reliable communications, put your two-way radio on a separate, reliable battery. Reliability is more important for emergency radio calls than it is for the rest of your appliances. (Ken Sawka—E. Congo Group)

Older inverters can create radio interference, even when on a different system, in a different house 75 yards away. If you have this problem, see a local technician and ask for a large capacitor and instructions for installing it on the noisy inverter.

Safety, maintenance, and shipping

Safety issues

Avoid fire

BASICS—Use fuses. Again, without them between batteries, controller, inverter and appliances, houses can burn down.

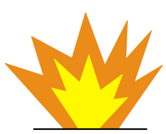
In a small system, 12–14 volts of *direct current* (DC) electricity will not give you a shock, but the heat generated by a short circuit can burn you or even burn your house down. Batteries are very powerful units and must be treated with respect. The wire path between the batteries and the *charge controller* should have a fuse or circuit breaker. Each circuit from the batteries (and your *inverter*) to your appliances should also have a fuse or a circuit breaker.

Some appliances come with an inline fuse.

Avoid shock

Inverters provide 120-volt AC and can shock if, for example, someone touches the partially inserted plug of a 120-volt appliance. An inverter must be fused to handle its input load, often 20, 30, or more amps. Follow the instructions carefully.

Avoid explosion



BASICS—Shield your battery terminals, but keep the battery ventilated.

Take care around batteries since tools dropped across their terminals will cause great trauma to the batteries, the tool, and, potentially, anyone nearby. If something metal gets stuck lying across battery terminals, the battery can overheat and explode, spraying acid everywhere. Place batteries in a closed area where children do not have access.

It is really wise to cover at least the positive terminal with a plastic or rubber terminal cover. You can buy these at RV or marine suppliers, or an old tennis ball can be split open and forced over the terminal.

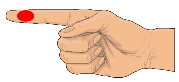
There is always a compromise between enclosing the batteries for safety and keeping them open for venting and maintenance. Most village houses do not have much enclosed storage space.

One method which keeps them "in the breeze" to dissipate gases, yet safe from little hands or dropped objects, is a box whose walls are alternately open-and-closed, made by alternating sticks of wood (like making a basket). "Basket" battery boxes should have a hinged lid so the batteries are easily accessible for maintenance.

In a pantry area (where we had ours, because it was central–we put the panels immediately above it), the batteries can go on a shelf or a tray just off the floor with a small lattice screen to keep things from falling on them, yet easy to get at for maintenance. (Paul Kroening—E. Congo Group)

If the number of batteries in your system grows, check with a knowledgeable technician to see if your batteries should be stored in a special, vented enclosure.

Avoid acid burns

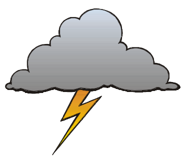


Batteries contain acids that can burn the skin and blind the eyes.

BASICS—Avoid contact with battery acid.

When filling your batteries with acid, resist the temptation to peer down into the battery. [Editor: Even better, wear protective goggles when dealing with battery acid. My understanding is that eyes are immediately damaged by any contact with battery acid. If contact occurs, flush them for 15 minutes with water.] Have water close by for immediate washing if even a small splash occurs. (Laurie Maskell—Papua New Guinea)

Avoid lightning damage



BASICS—During lightning, disconnect inverter, radio, and fluorescent lights.

When lightning occurs in your area, disconnect your inverter (and thereby your computer and printer as well), radio, and fluorescent lights. High voltage surges are often induced in your home's wiring when lightning strikes and, unless you unplug electronic devices, they are likely to be harmed (it is a good idea to unplug these at night before you go to bed).

Alternatively, you can protect your equipment without disconnecting it if you ground the inverter, radio, and the negative pole of the battery bank (which will also take care of your 12-volt fluorescent lights). See "Ground your system" at the end of the previous section for details. Even with grounding, it is still a good idea to unplug your computer when not in use.[31]

Solar electric panel maintenance

- Periodically check your electrical connections for corrosion. Disconnect one of the battery connections to avoid shorts, and clean wires or connectors with wire brush or sandpaper to reveal bright metal.
- To keep your electrical output up, clean the face of your panels when they get dirty. Use water and a little vinegar, if you have it. Dry with newspaper, if available. (Using dish soap and water may leave streaks.)

  I recommend that people get up and clean them with water and a rag midway through and at the end of each dry season to get the worst of the settling dust off them. Use water first before the rag to avoid scratching the glass. (Paul Kroening—E. Congo Group)

Battery care and maintenance

Monitoring your battery is your most important maintenance task.

Battery care

Discharge batteries slowly

BASICS—Normally, don't discharge your deep-cycle batteries at more than 5% of their capacity.

Different discharge rates effect the useable amps stored in your battery. If you are running all your lights, transmitting on the radio, and printing

[31] In lightning storms, some users have wrapped their notebook computer in aluminum foil for additional protection.

at the same time, you might be discharging your battery at a rate which will not give you the amp hours you would expect. The best discharge rate is 5% of your total battery amp hour capacity as the following table illustrates:

Size of battery system in amp hours	Maximum discharge rate in amps per hour
100	5
200	10
400	20

For example, if a 100 amp-hour battery has a 25 amp load put on it, it will probably only supply about 50 of its amps or half its capacity. On the other hand, if the same battery has a one amp load, it will probably deliver about 110 amps[32].

Do not discharge batteries too deeply

BASICS—Normally, do not discharge your deep-cycle batteries past 50% of their capacity.

- Avoid discharging your deep-cycle battery past one-half (50%) of its capacity. Deep-cycle batteries will tolerate a 75% discharge repeatedly without damaging the plates, but they will last longer and perform more efficiently if you make this an exception.

BASICS—If you use auto batteries, do not discharge them past 80% of their capacity (only use 20%) and recharge them fully very soon.

- The standard auto battery is used in some locations instead of the deep-cycle because of the economics of battery prices and shipping. (See "Automotive batteries" in the "For technicians" section for a fuller discussion of this topic.) Typically, an automotive battery will not last nearly as long as a deep-cycle battery in a solar-electric system unless it is managed very carefully. Avoid discharging it by more than 20%. This usually will require adding additional batteries to the system or reducing your electrical use. Compare the cost of additional batteries and/or the high turnover rate of automotive batteries when considering which type of battery to buy.

Charge batteries correctly

- Do not overcharge your batteries. Use a charge controller to avoid this.
- Bring your deep-cycle battery to a full charge at least every four weeks as this will prevent it from losing part of its capacity. You may have to use less electricity to allow your battery to fully charge.
- If you are unable to recharge your batteries fully every four weeks, a coating of sulfate will crystallize on the plates. This makes it more difficult to charge your batteries fully. You can drive some of the sulfate off your battery plates by bypassing the charge controller and equalizing (overcharging) your batteries.[33] For best results, contact a knowledgeable technician for equalizing instructions; to do it yourself, see "Equalizing" in the "For technicians" section.

[32] A battery is rated at 100 amp hours on the basis of delivering 5 amps over a 20 hour period. If it is discharged more slowly, it will deliver more amp hours.

[33] Discharged batteries left for over four weeks typically results in unequal cell charge levels. Use a hydrometer to test each cell before equalizing and then equalize until the lower cells equal the higher cells.

Battery maintenance

Maintenance tools and supplies

- Wire brush
- Battery terminal brush
- Baking soda
- Clean rags
- Distilled or filtered rainwater
- Digital multimeter or hydrometer
- Eye protection and rubber gloves
- Old tennis balls

Maintenance procedures

- Check the water (acid) level in your battery regularly (each cell) and add distilled water or filtered rainwater[34] to the bottom of the fill tubes. (Do not overfill—water should not cover the slots on the tube sides; the slots allow gases to escape.) Check water levels especially during hot, dry weather. If acid falls below the level of the plates, battery performance will be permanently reduced by the percentage of the plate that was exposed. After adding a substantial amount of water, your batteries may need a period of charging before they are back up to where they were before adding water.[35]

> BASICS—Keep your battery water at the proper level (at the bottom of the fill tubes).

- For best results, monitor the charge level of your battery. Purchase a digital voltage meter[36] or buy a quality *hydrometer*[37] to accurately measure the *specific gravity*. See "Table of voltage and specific gravity," in the "For technicians" section.
- Keep your batteries clean. Use soap and water and an old, clean rag. Dirty battery cases cause your batteries to slowly discharge.

> BASICS—Keep your batteries clean and up off floors by using wooden blocks or a small pallet.

- Split old tennis balls and force then over each battery terminal in order to protect against short circuits.
- If you have a split system[38] and more than one battery in each system, put any batteries together that do not hold a charge.

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[34] If you live near the ocean and the prevailing wind is onshore, tankwater (stored rainwater) will contain enough salt to harm batteries. In this case, use distilled water from a closed container. (Laurie Maskell–Papua New Guinea)

[35] Only add distilled water or filtered rainwater. Adding more electrolyte may revive a failing battery, but only temporarily.

[36] Make a habit of reading the voltmeter and recording the results twice daily. Read it each evening just before sunset for the "charged" state of the batteries. Read it each morning before the sun reaches your panels, and before you turn on any appliances, to establish the "discharged" state of the batteries. After a few months, you can accurately estimate the state of your batteries.

[37] Hydrometers require opening each cell and pulling acid up into the hydrometer to measure the specific gravity (can get messy). Paul Kroening, of the E. Congo Group, feels they take a lot of practice to learn to read accurately. Use the same time-of-day testing as the footnote above.

[38] Split system: one (or more) panel feeds a battery and another panel separately feeds a different battery.

- Keep your battery connectors clean. To clean, use wire brush with baking soda and water. (Avoid getting any baking soda into your battery's vent holes.)

BASICS—Keep your battery connectors clean.

Battery terminal brushes are sold in automotive parts stores (or through JAARS) for about US$3. They have a wire brush on one half and a wire-bristle terminal cleaner in the other half, and fit together for easy storage.

Compensate for high or low temperature

- Temperature plays a role in the performance of your battery. It will perform ideally at 77°F (25°C); it will still perform at 35° to 40°F (2° to 5°C) with only a 10–15% loss of storage capacity. At temperatures higher than 77°F (25°C), battery life normally decreases. To compensate for higher temperature environments, use battery acid designed for tropical temperatures and a charge controller that can be adjusted[39] for a higher temperature operation.

- At temperatures below 32°F (0°C), batteries lose significant storage capacity. If fully discharged, they can freeze, which would ruin the battery. To prevent freezing, either move your batteries to a warmer location or keep them charged.[40]

Battery repair

Sometimes batteries are cracked in shipping. Often the cost of shipping exceeds the cost of the battery. What to do? Here are some things that users have learned about emergency repairs:

- *One of my JAARS battery had a crack in it when it arrived. It arrived without acid in it. I wanted to find any other cracks before I began a repair effort, so I filled it with distilled water to see where it would run out. Big mistake. It was ruined by the water. A tech told me later that only battery acid should be put in batteries. (James Ashley—Solomon Islands)*

- *A truck battery arrived with a crack in it; acid was leaking out. After emptying the acid out, I applied several layers of Shoe Goo to the crack and put the acid back in. I was able to keep the battery going for two years. (Paul Thomas—E. Congo Group)*

Live within your electrical budget

Often, during periods of low sun or high usage, you are faced with a choice between shortening the battery life or easing off on your use of appliances. Depending on your work and financial priorities, the choice is yours. Consider shortening use of the following:

- Two-way radio conversions
- Printer
- Lights
- Computer (Leaving your computer on for long periods unused will use 1–3 amps per hour if it does not have a power-saver feature.)

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[39] By lowering the charging rate of a charge controller, a battery in a tropical environment will avoid overheating.

[40] At 14°F (-8°C), do not let batteries fall below 75% discharge (¼ charge); at -4°F (-20°C), do not go below 50% discharge; at -22°F (-30°C), do not go below 35% discharge; at -40°F (-40°C), don't go below 25% discharge.

How to store or ship your system

Storage

To take your system out of service, store your panels where they will not receive sunlight and keep your batteries where they will not freeze. For best results, your electronics should be stored in an environment that is not high in humidity.

Batteries once wet and charged do not store well. They need to be charged occasionally in storage in order to keep from running down and sulphating the plates from lack of activity. I would expect that a battery that is in storage in the village for anything over a few months is a lost battery (depending on its age of course. A new battery in good condition could last up to a year in storage, but it will still need some help coming back). I have been recommending that people taking a year break from their field work trade their batteries to friends, sell them at prorated prices, or donate them to community needs in the village. (Laurie Maskell—Papua New Guinea)

Here are various storage scenarios; for each scenario there are possible actions to preserve your battery: *(provided by Laurie Maskell—Papua New Guinea TECS)*

Time away from village	***Charge controller in service?***	***Battery charged?***	***Action***
3 months	*No*	*Yes*	*Disconnect from panels and leave it*
3 months	*No*	*No*	• *Connect one panel to battery; battery life will be reduced slightly* • *Alternative: place panel so it only gets one hour of sun per day (inside house, facing window)*
6 months	*Yes*	*n/a*	*Top battery water; system takes care of itself*
More than 6 months	*not necessary, though preferable*	*n/a*	• *Arrange for topping of battery water; if can not get battery water topped, arrange to sell or give away battery; bring in new battery* • *Alternative, if no controller: place panel so it only gets one hour of sun per day (inside house, facing window)*

Batteries characteristically have some internal charge leakage; new batteries about 1–2%/day, increasing with age. (Laurie Maskell—Papua New Guinea)

Shipping

To ship your system, stack your panels using cardboard to separate them and plywood to protect the vulnerable back of your panel. Place the prepared stack in a cardboard or wooden box with spacers to keep the panels from being directly against the outside. The panel glass is tough, but not unbreakable. Check shipping regulations for batteries and for the lengths of your panels.

If you need to ship your batteries, remember that batteries are in some ways delicate. They can not be dropped and banged around. The plates can come loose inside or break free from the terminals. (Paul Kroening—E. Congo Group)

For technicians

Panel technologies

Ambient temperature is important in deciding the voltage of the solar-electric panels to buy. In a hot area, you will need a higher voltage (and may pay more for the extra cells to provide that voltage): 17–19 volts. If you put the panels on a hot metal roof, 19 volts may be the best choice. In a temperate area, you may save money by ordering a 16-volt panel, but do not go lower than 16 volts, unless you have special circumstances.

Different types of cells produce varying amounts of electricity for a given area. Since the frames that hold the panels are a cost factor, sometimes it pays to buy panels that give the most power (amps) for the fewest square feet.

In general, rigid solar-electric panel manufacturers guarantee that their panels will produce at least 80 or 90% of their rated output for a period of 20 or even 25 years.

Flexible panels have special advantages, but some users have discovered that their amperage output degrades significantly within a year or two of service. Flexible panels definitely have some advantages as the reports that follow illustrate:

- *We use audiovisual equipment in Quechua villages. We have been using two, small 12V, 7 amp hr. sealed batteries per set of equipment and the UNI-SOLAR MBC-525 rated at 1.4 amps to charge the batteries. The video equipment runs for about 1.5 hours on a charged battery and then needs to be charged by the solar panel for about 3 hours.*

  The neat thing about these solar cells is that they are lightweight (4 lbs.) and can be rolled in a 6 inch diameter tube that is only 15 inches long. That way they fit into a backpack nicely with the batteries in pockets on each side. We have even hung the flexible panels on the rear of the backpacks and charged the batteries while walking.

  UNI-SOLAR now puts out a USF-32 model that produces 1.94 amps, which will make the difference on clouded days. These are so superior to the solid, fragile versions. These are waterproof, sunproof, flexible, and unbreakable. We have had them in the field now for over two years under the hardest use possible and have never had a failure. (Al Shannon—Peru)

- *The efficiency of monocrystalline cells is 13–16%, for polycrystalline cells 12–13%, and for amorphous cells 6–8% [also compare warranty differences]. On the other hand, in rainy regions, a 32-watt amorphous panel can provide as much power harvest as a 50-watt crystalline panel (Chris Hochstrasser—Cameroon)*

How batteries work

Batteries are not as easy to understand as other parts of an electrical system, mainly because they are a chemical reaction, subject to the laws of chemistry—an area most of us know little about. Many variables can alter the capacity of a battery to take a charge, store power, and discharge it. The information below will cover these variables and should enable you to use your batteries to their fullest while making them last as long as possible.

The following observations are for lead-acid batteries only.

The chemical process

A lead-acid battery is made of individual cells. Each cell puts out a nominal 2 volts. Connected in series, these cells provide a nominal 6-volt, 12-volt or even 24-volt DC.

A lead-acid cell is, in its simplest form, two plates of lead immersed in a weak sulfuric acid solution called an electrolyte. In the manufacturing process, DC voltage is applied to the two plates. The positive plate changes by picking up oxygen from the electrolyte and becomes *lead dioxide.* The negative plate continues to be lead, but becomes "spongy" in appearance. We call the negative plate *sponge lead*.

When the battery is fully charged, the two plates have the potential of putting out about two volts of stored energy. (Actually each cell is made of several positive and negative plates which are kept separate from each other by dividers.) This cell, usually connected in series with other 2-volt cells to achieve a particular voltage, can run a load until the plates revert to their original chemical condition.

During discharge, the plates pick up sulfate from the sulfuric acid electrolyte and their composition becomes lead sulfate.

When subsequently recharged, the sulfate again moves off the plates and into the electrolyte. This returns the positive and negative plates to lead dioxide and sponge lead respectively.

This process of discharging into a load and recharging from a source like PV panels can be repeated over and over, depending on how long the lead stays on the plates.

The lead on the plates is like mud on a screen; if you flex the screen by heat or cold, the "mud" will fall off, reducing the battery's capacity. (George Peroni—Hydrocaps, Miami, Florida)

Sulfation

Whether it is a long period with not much sun or a period with too many loads, deep-cycle batteries left uncharged for longer than four weeks will lose capacity. Remember that charged battery plates are lead and lead dioxide. As discharge takes place, the plates take on a coating of lead sulfate. So far, there is no problem. But if there is no recharge for a prolonged period, the lead sulfate coating begins to change to a crystal state called crystalline lead sulfate. Crystalline lead sulfate resists charging and stays adhered to the plate.

The major cause of aging of the lead-acid battery is sulphation of the lead plates. In the normal discharge of the battery, lead sulphate is formed on both the positive and the negative electrodes within the battery. In the charging process, this sulphate is converted into other materials. When first formed, the lead sulphate is in the form of tiny crystals, thus there is a large surface area available for the reactions. If recharging is delayed, the sulphate grows into larger crystals.

After several weeks, the crystals are large enough that the chemical reactions are severely hindered. This is because much of the sulphate is in the middle of the crystal, and this material is effectively "lost" to the system. The net result is a reduction in battery capacity. When the battery is recharged promptly, only a very little of the material is lost in this way, and the battery life is maximized.The more deeply the battery is discharged, the more the sulphate there is present and the more rapid the deterioration. This is why it is best to operate a lead-acid battery near full charge as much as possible. There is less sulphate present to grow, and the sulphate that is there is disbursed throughout the battery, so the aging process is slower. (Laurie Maskell—Papua New Guinea)

Cycling

When you discharge a battery and then charge it back up again, your battery has experienced one cycle. How deeply a battery is discharged is called depth of discharge (DOD).[41] There are shallow cycles and deep cycles.

Shallow cycles are about a 20% discharge and recharge. Automotive batteries are designed for this type of shallow cycling. In order to supply a lot of amps over a short period of time, their plates are thin and their

[41] Another term used to describe the status of a battery is state of charge (SOC) and is the opposite of depth of discharge (DOD). State of charge indicates the percentage that the battery is charged. A battery that has a 70% state of charge (SOC) is said to have a 30% depth of discharge (DOD).

surface area is large. The greater surface area offers a faster chemical reaction and thus more amps in a shorter period.

Deep cycles are defined as up to 80% discharge and recharge. Since typical usage involves providing a limited number of amps over a longer period of time, the deep-cycle battery can be constructed with thick plates and less surface area. The thicker plates provide a deeper discharge without warping and allow for a delayed recharge without doing excessive harm.

How deep you cycle a battery greatly effects the length of battery life. Even deep-cycle batteries are "used up" more quickly as the depth of the cycle increases. There are always sunless periods where your deep-cycle battery deeply discharges; that is what they are designed for. But shallow cycle your deep-cycle batteries if you wish to get the longest life.

Temperature effects

How fast the chemical reaction occurs in a lead-acid battery is determined by temperature. If colder, the chemical reaction takes place more slowly. If hotter, it happens faster and more amps are drawn from the battery.

The ideal temperature for a lead-acid battery is about 77 degrees F (25 degrees C). High temperatures can shorten the life of a battery and should be avoided or compensated for. Batteries destined for tropical climates often use electrolyte containing less sulfuric acid (1.210–1.230 specific gravity). This allows the chemical reaction to take place more normally, even at higher temperatures. Some charge controllers have lower settings for higher temperature environments.

Self-discharge

Batteries have a natural tendency to slowly discharge, even if you put no loads on them. New batteries may lose .5–2% of their charge each day. This is due to the unavoidable impurities in the chemicals used in their construction. These impurities cause an internal chemical reaction. This slow discharge is called *self-discharge*. The variables of self-discharge are:

- Battery type (lead-antimony versus lead-calcium)
- Temperature (higher temperature causes more self-discharge)
- Age of the battery (self-discharge increases with battery age until a significant amount of charging is required to stay even)

Poor maintenance of batteries can add to the self-discharge problem: adding water with minerals (salts) instead of distilled water; leaving the battery caps off so that dirt can get in.

Pure lead grid plates, as used in stationary batteries, have the lowest self-discharge. I think that the cases are made stronger in these than in conventional batteries and so the plates are better supported. Thus they do not need the addition of antimony or cadmium to strengthen the plates, both materials which increase self-discharge. [This type of battery is very expensive.] (Laurie Maskell—Papua New Guinea)

As batteries self-discharge more rapidly, some possible solutions are:

- Charge them more (adjust panels more frequently) or buy additional panels so there is more power available to compensate for self-discharge.
- Use them less (cut down on unnecessary loads) so there is more power available to compensate for self-discharge.
- Replace them.

Inefficiency

Lead-acid batteries use an electrochemical reaction to absorb and give up electricity. However, the efficiency of this process is not 100%. That is, you will not get back 100% of a charge. New batteries will return 80–90% of the charge put into them.

In general, use 80% as the factor to determine what number of amps to expect from a given number of charging amps. This means that if you get 18 amps of charge from your solar-electric panels on a given day, you can only expect to use 14.4 amps to run your loads.

Delayed capacity

Deep-cycle batteries will not return their full amp hour capacity for several cycles. So the first discharge cycle after a full charge of a 100 amp hour battery may give back only about 30 amp hours. The second will give back 35 or 40, and so on until it gives a full charge back. The number of cycles may be specified in the battery manufacturer's documentation. (Paul Kroening—E. Congo Group)

Gassing and corrosion

When the rate of charging is greater than a battery can accept, each battery cell heats up and creates bubbles of gas. Gassing is the process of water molecules being split into hydrogen and oxygen. The result is that the cells lose some of their water which subsequently must be replaced.

Some gassing is normal and useful. Gassing mixes the electrolyte, keeping a higher concentration of sulfuric acid from stratifying on the bottom of the cell.

On the other hand, excessive gassing causes lead to fall off the plates and loss of water in the cells.

During normal gassing, an acid mist is created which is very corrosive to the terminal posts on the battery and any attached connectors.

If left to accumulate, the corrosion on the battery terminals creates electrical resistance, causing disappointing system results and shortening battery life. These terminals need regular cleaning; use baking soda and water with an old toothbrush. Coat with petroleum jelly during and after reconnecting.

Battery terminals need to be cleaned from time to time to eliminate the accumulation of caustic salts which seep from the battery. The best way is the "whole" way. Rather than trying to clean batteries in place, every couple months disconnect them, take them outside and with the caps on the cells, wash the battery with clear water. Clean the salts off with an old toothbrush and baking soda. Rinse thoroughly and dry it with a cloth. Rinse the cloth and after it dries, set it aside for the same job next time, because it will probably have some salts left in it. [Clean the terminal and connectors to a bright finish.]

After reconnecting the terminals, a fine coating of light grease will help keep them from corroding. When removing a tight automotive type clamp, use a proper terminal puller to avoid bending or twisting the battery post in the case. Lay something like a work glove or thick rag over the terminal that you are not working on, to avoid shorting the battery with a dropped tool. Wear glasses. Wear old work clothes, because it is very hard not to get at least a little battery acid on your clothes, and if you notice that some has gotten on the clothes, you can save them by promptly rinsing them. (Paul Kroening—E. Congo Group)

Discharge rate

A 20 hour discharge rate means that at a certain discharge rate, your 100 amp hour battery should provide 100 amps over a 20 hour period. Theoretically, a 100 amp hour battery should return 100 amps in an hour. But no battery actually gives you that much charge back at that rate. A 100 amp hour battery, fully discharged in one hour, will get too hot to deliver it all, damage the plates, and probably drop below 11 volts after maybe 70 or 80 amps.

Amp hour capacity vs. discharge rate for 100AH, 20 hour rated 12-volt battery

Discharge amps	Discharge hours	Available amps from 100 amp-hour battery
5	20	100
10	10	84
13.5	5	70
23	2	54
44	1	44

Battery how-to

Manual fast-charging a deep-cycle battery

As a general rule, you can fast-charge a battery at an amperage rate equal to the number of amp hours discharged. A 100AH battery discharged to 20% can, at first, handle 80 amps. This rate diminishes in a curve as the amount left to be replaced grows smaller. Starting at the rate of the discharged percentage (80% of 100AH = 80A), every six minutes drop the rate to 90% of the previous rate (80A x 90% = 72A). Continue reducing the rate every six minutes until you reach a float charge rate of .5–2 amps.

It is interesting to note that by following this formula for a fully discharged battery, 90% of its capacity would be restored in about two hours, while the last 10% would take an additional two hours.

If, during charging, a battery overheats,[42] stop the charge and allow the battery to cool. High cell temperatures—above 110°F (43°C)—can cause plates to buckle.

Multi-stage charging

To fully charge a typical 12-volt, non-sealed,[43] lead-acid battery, it must reach 14.4 to 14.8 volts. If it does not reach this voltage, some sulfation will remain on the plates. If charging is repeatedly done this way, eventually the battery will lose its capacity and will die an early death.

After a 12-volt battery has reached its fully charged voltage, it should be held at a lower voltage to maintain the charge; typically 13.2 to 13.4 volts. If left charging at a higher voltage, internal heating and gassing occurs, shortening battery life.

Multistage charge controllers are designed to provide an initial *bulk charge* and subsequent *float* or maintenance charge. Some also insert an intermediate *absorption charge*. Standard charge controllers take

[42] A battery is too hot if it is hot to the touch or is boiling very rapidly.

[43] A non-sealed battery has removable battery caps, allowing access to each cell. Sealed batteries must reach 14.2–14.4 volts to be fully charged.

a compromise voltage of about 13.8 volts which results in some permanent sulfate deposits, excessive gassing, and reduced battery life.

Pulse charging

Pulse charging offers an advantage over multistage charging because it moves more sulfate off the plates during the charging process. It does this by providing microsecond pulses of higher amperage followed by short rest periods. This allows bursts of chemical activity followed by cooling down periods. These pulses avoid the problem of battery overheating, while providing the benefits of high amp charging which gets more sulfate off the plates. The final effect is that batteries last longer.

JAARS currently sells a 12 amp pulse charge controller (PS-12) that includes LVD for US$120. Higher amperage, metering, and other options are also available.

By placing old, dead batteries on a pulse charger, some technicians have found that they can bring 40% of them back to life (for awhile).

In addition, more sophisticated chargers have another feature which will allow them to stop charging altogether and then restart, as part of their design. This feature brings the battery to the cut-out voltage and then shuts off, letting the chemicals mix so that in a few minutes the terminal voltage is more accurate and thus a truer representation of the battery state. When the charger turns back on again it sees this lower, more realistic voltage, and starts charging again. Eventually it will bring the battery up to a fuller charge.(Paul Kroening—E. Congo Group)

Measuring state of charge using specific gravity and voltage

You can determine the state of charge of a battery by either measuring the specific gravity of its electrolyte or by reading the voltage at its terminals at least one hour after charging and with no discharge taking place.

Specific gravity

The amount of sulfuric acid in electrolyte varies with the state of charge of the battery. You can measure this density of sulfuric acid as *specific gravity* using an hydrometer. (The amount of sulfuric acid is lower when a battery is discharged; higher when charged.) This provides information about the battery's state of charge and is not influenced by whether the battery is being charged or discharged.

Here is how to do a specific gravity test

1. Do not add water at this time.
2. Fill and drain the hydrometer three times before pulling out a sample.
3. Be sure there is enough electrolyte in the hydrometer to support the float.
4. Take a reading, record it, and return the electrolyte to the cell.
   Tip: there will be a curve to the liquid in the hydrometer, so use the center of the curve for accuracy.
5. Check all cells by repeating steps 2 through 4.
6. Replace the vent caps and wipe off any spilled electrolyte.
7. Correct the readings for temperature.
8. Compare the readings. If the readings are not within .020 of each other, you may need an equalization. (See "Equalization" below.)

Voltage

Voltage meters are also used to indicate a battery's state of charge, but the reading they supply is effected by whether a battery is being charged or discharged. If a battery is being charged, the voltage appears artificially higher; if it is being discharged, the voltage appears lower. For this reason you should establish a regular schedule of voltage testing (and write it in a log) at a time when neither charging or discharging is taking place. Often this requires two times a day: once in the morning before the sun strikes the panels; once after sunset, but before you turn on lights and other loads.

The best type of voltmeter is the digital multimeter, which provides precision to the tenth of a volt.

By comparing both voltage and hydrometer readings in various circumstances, you can learn what is taking place in the solar-electric system.

Table of voltage and specific gravity

12V battery voltage	Specific gravity used in cold and temperate climates	Specific gravity used in tropical climates*	Percentage of charge
12.70	1.265	1.225	100
12.64	1.257	1.127	95
12.58	1.249	1.209	90
12.52	1.241	1.201	85
12.46	1.233	1.193	80
12.40	1.225	1.185	75
12.36	1.218	1.178	70
12.32	1.211	1.171	65
12.28	1.204	1.164	60
12.24	1.197	1.157	55
12.20	1.190	1.150	50
12.16	1.183	1.143	45
12.12	1.176	1.136	40
12.08	1.169	1.129	35
12.04	1.162	1.122	30
12.00	1.155	1.115	25
11.98	1.148	1.108	20
11.96	1.141	1.101	15
11.94	1.134	1.094	10
11.92	1.127	1.087	5
11.90	1.120	1.080	Discharged

*Specific gravity of fully charged electrolyte used in tropics ranges from 1.210 to 1.230

Note: Specific gravity values can vary + or – .015 from specifications in the chart above. Specifications assume batteries are at rest: not being charged or discharged. Specifications assume 77 degrees F (25 degrees C).

Since most people have cars, motorcycles, radios and battery systems, I have found that having them buy a US$19 to $50 digital volt-amp meter (digital multimeter, DMM) is good economy for them. They can carry it anywhere to check their car battery, the radio input, which line is positive and which negative at the end *of the new circuit they just put in, or at what place in a certain line there is voltage and where there is not. (Were the rats really chewing the line??) When not carrying it around, they can just stick the DMM on their battery system with alligator clips and leave it there, turning it on and logging the voltage twice a day [Editor: see "Voltage" above]. This method has been satisfactory to the average user. The analog multimeters are not very useful for voltage (current, yes) not because of inherent accuracy, but because analog scales are usually at 3, 10, and 50 volts or 100 volts DC. Since the difference between a fully charged "at-rest" battery and fully discharged only a volt and a half, an analog scale from 0–50 volts is too imprecise. (Paul Kroening—E. Congo Group)*

Monitoring

Use the voltage or specific gravity table above to keep your deep-cycle battery at or above a 50% state of charge to insure maximum battery life. Be sure to fully charge (100%) your deep-cycle batteries at least every four weeks.

Maintenance

Checking your battery is the single most important responsibility of a system owner. Avoid prolonged deep discharges, keep your battery electrolyte up to the bottom of the vents in the fill tubes by adding distilled water or filtered rain water, and do not fill your batteries when they are discharged. Charge first, then fill, then charge again to reach 100%.

Equalization

Equalization is the controlled overcharging of a fully-charged battery. The overcharge

- mixes the electrolyte,
- evens the charge among varying battery cells,
- and reduces permanent sulfation of the battery plates.

Though the solar-electric system battery bank receives a good deal of cycling and gassing through normal activity, equalization is a complement to this activity and should be done every 60 to 90 days to lengthen the life of batteries.

Prerequisites

- Disconnect any loads before you begin equalization.
- Make sure batteries are at a 100% charge before equalization.
- Remove battery caps before equalization (Hydrocaps[44] included).
- Record the specific gravity of each of your cells before you start. Note any low cells (if difference between highest and lowest cell is less than .020, equalization may not be needed).
- Make sure batteries are well ventilated during the charging.
- Monitor batteries closely during this process; overheating and excessive gassing will ruin your batteries.

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[44] Hydrocaps are special battery caps that reduce water loss, electrolyte mist, and explosive gas concentrations during normal charging. For more information, go to http://metalab.unc.edu/pub/academic/environment/alternative-energy/energy-resources/homepower-magazine/archives/11/11pg37.txt. The cost is about $5.50 each direct from Hydrocap Corporation, 975 NW 95th Street, Miami, FL 33150; telephone: 305-696-2504. Contact them before ordering.

Equalization process

- Bypass your charge controller and allow your battery to reach just over 14 volts in temperate or tropical climates; 15–16 volts in cold climates.
- Check each cell periodically during the process. You do not have to check every cell every time, but watch any that show a higher variation. If the batteries become hot to the touch, stop charging and wait for the gasses to dissipate. Take hydrometer readings again. If the cells are still not with .020, continue charging.
- Keep checking electrolyte densities until you receive three readings, 30 minutes apart, which indicate no further increase of specific gravity values.
- Record voltages and specific gravities of each cell after equalizing.

Also called a equalization charge, it involves bringing the battery up to the point (about 14.5 volts depending upon ambient temperature) that the battery is bubbling vigorously and holding it there for a specific period of time. Without automated controls, the user has to be watchful to avoid boiling off the water. This equalization charge will re-dissolve some of the sulphates and restore function. It is a normal battery maintenance feature and most people will need to do it, but how they do so is a bit controversial. The only accurate way is with a charger than has tight voltage monitoring. But the inaccurate way will work reasonably well! (Paul Kroening—E. Congo Group)

Equalization can be very harmful to functioning batteries. Equalization at high rates (high voltages), for longer than an hour, can overheat the plates. Overheating is especially likely during hot weather. This will subsequently cause buckling of the grids, making the paste fall off, and reducing capacity. Telephone companies equalize their standby batteries at 14.2 volts for an hour every six months. We tell people not to try equalization on functioning batteries since the process is tricky and can cause more harm than good. In any case, equlaize for no longer than one hour after gassing begins. (George Peroni—Hydrocaps, Miami, Florida)

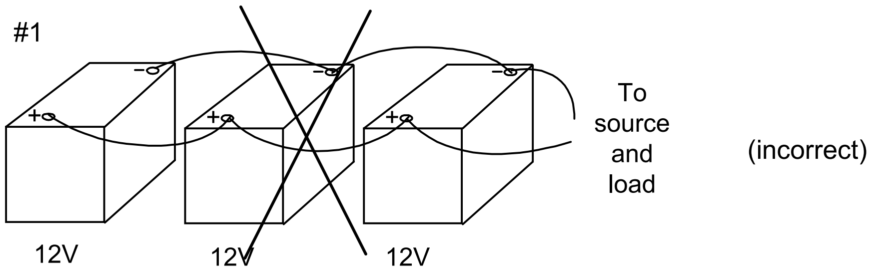
Maintain connections

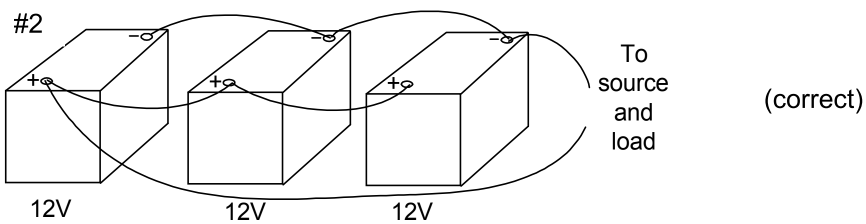
Wire brush terminals and connectors to a bright metal surface, grease them with a thick coating of petroleum jelly, and tighten the fastening hardware. Torque all bolts (approximately 10-foot-pounds) to minimize resistance variations.

Parallel connections

In a parallel battery bank, place the main positive and negative connections at opposite corners.

In multiple parallel connections, if batteries are connected incorrectly (as in #1) the batteries closest to the charging source will charged (and discharge) at a greater rate than those farther down the line. This could cause batteries at the far end of the line to sulfate and reduce their life-span. If connected as in #2, the batteries will charge and discharge as a single unit which will both maximize their efficiency and their life.





Enclosures

Now we will consider larger installations, since we have already given some advice regarding village house battery enclosures. As stated earlier, batteries produce an explosive mixture of hydrogen and oxygen and therefore need to be vented to prevent a dangerous buildup. Hydrogen is lighter than air and will naturally rise. By building an enclosure with both a low air intake and a top vent, the gases can safely dissipate in the air by convection currents.

Since you want the batteries stored close to where the power is used, one solution is to build an enclosure on an exterior wall (in the tropics, select a shaded wall to reduce battery temperature). You can run the power cables through the exterior wall and place your charge controller and other large components on the inside wall.

Short protection

Batteries can produce a great deal of heat, melt conductors, and even start a fire. It is essential that DC rated fuses or breakers are placed between the battery, inverter, charge controller, and PV panels. Kyocera Solar, Inc. offers a free publication called PV Power Systems and the N.E.C. Suggested Practices (see "References" at the end of the publication) that is a good guide for safe system design, both for DC and AC portions of a system.

Safety

We have had two accidents in my group due to battery explosions. One a solar panel system, the other a car battery. Both were caused by short circuits during maintenance, like a dropped wrench across the terminals or from the positive terminal to the body of the car. In neither case was anyone badly hurt. But boy, do they scare me. (Paul Kroening—E. Congo Group)

Low voltage disconnect

Contributed by Paul Kroening—E. Congo Group

An LVD protects the battery from excessive discharge, which, when it happens repeatedly, inevitably ruins the battery. I like to see some sort of low voltage protection for that reason.[45] *I tend to take a middle course between depending upon the LVD and not using one at all. What I recommend depends on the size of the system, what its normal operating pattern is, and how much money there is to spend.*

If a radio is part of the system

If you have a marginal situation in which the panel or battery capacity are small and/or marginal, but in which you have OCCASIONAL large loads, the LVD can be a problem. The usual case in which you see this is in an installation that has a need for a couple lights and a computer but also has a radio transmitter. Most of the time, the single panel and battery do fine. In the daytime the panel is running the computer with the battery acting as a buffer. Any extra charge that gets to the battery can be used at night for a couple hours of light. And if the charge falls too low, then the LVD will turn all loads off till morning.

But if radio communication takes place in the morning, the battery will still be low. The radio transmitter takes little current to listen (say 2 amps), but a lot of current to transmit (10 to 20 amps depending upon the model). So while the system works fine when the user is listening to the radio, when he or she keys the microphone to talk, the current demand drops the voltage and the LVD senses this and cuts out. When he/she unkeys the mic, the LVD turns the system back on again. VERY annoying.

[Editor's note: According to Laurie Maskell who works in Papua New Guinea, this low voltage condition can also be caused by a poor connection between the regulator and the battery, undersized wiring, or even a battery with a poor internal connection. It is worthwhile to identify the true cause.]

The typical solution is to get either more panels or more batteries or both; but rather than spend more money on batteries or panels, often a user will put the radio outside the LVD circuit. The radio will probably work down to 11 volts or less and if you only talk a little, it will not ruin the battery, and you are still protecting the battery at night. This is a good solution as long as you don't talk too much. Or it is a good solution if you can use the radio after the battery charges for a couple hours in the morning.

Adding a radio later

In another situation a person finds that his lights and computer have never run his battery too low, so he never bothered with an LVD. When he added a radio, he did not notice a problem: he may run the battery down with the radio, but with no LVD, he may not notice, especially if the battery has time to recharge before evening. Once again, if he does not in fact talk too much, he can get away without the LVD and not ruin the battery. Probably.

Low voltage problems can also happen with a largish and older inverter used only occasionally (modern inverters have their own cutout).

Problems even with no radio

Another problem we ran into a lot was that certain users, even without a radio, found that the LVD was annoying because it turned off their lights at night, just when they needed them the most! So they merely bypassed the LVD and let the battery run down. The problem was that they ran through batteries quickly!

Or, some of the older fluorescent lamps could not tolerate the higher current they drew at low voltages (under 11 or 11.5 volts) and burned out tubes or even the ballast. Happened a lot! Then the user would bring in burnt up lamps to be fixed (the ballast usually can not be fixed) and blamed the lamps rather than the low voltage they were attempting to run them at.

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[45] I have never seen an LVD interfere with the charging or the charge controller.

Solutions for low voltage problems

If you use a radio or need an inverter a lot, it becomes clear that you must get more batteries or more panels, or both. More panels give more charge capacity and more batteries give more storage capacity. The extremes to illustrate the two situations are 1) a cabin in the mountains that you use once a month. A very small panel will charge a ton of batteries all month and you will have plenty of power the one weekend a month you use it. And 2) a group of computers and printers, run off an inverter, but which are used only in the daytime. A bunch of panels are needed to provide enough power, but only a small battery will provide the buffering.

In our usual village installation we have something in between, but we design for the average weekly load. Often we have to compromise because of cost or availability of panels, batteries, or whatever. Maybe a person can not justify getting all those panels, but has a lot of batteries. So in the rainy season, they have enough capacity to go a few days in light loads, but save all their print jobs till sunny days.

This is also an OK design for a person who is gone, or not using power, for a few days at a time. The panel charges the batteries in the days he is off in town or on survey, and he can use more power on his "home" days than the panels deliver per day.

Buying batteries

Compare batteries

If possible, compare batteries by using the following:

- Amp-hour (A/H) ratings at a constant 20-hour discharge rate[46]
- Price
- Number of cycles of discharge-charge that they provide in their lifetime
- Delivery cost
- Reputation of the imported or locally made battery

Comparison of batteries–US$

Battery	Price	Amp-hours	Cost per amp hour	Discharge rate in hrs.	# or discharge cycles	Weight (lbs.)
X	$65	220	$ .30	20	600	65
Y	$90	230	$ .39	20	900	75
Z	$60	215	$ .28	24	600	63

Consider the comparisons in the table above. Battery X is less expensive than battery Y, even when considering its cost per amp hour (battery Y costs 30% more per amp hour). But when you also consider the number of discharge cycles Y will perform, Y becomes less expensive over its lifetime (battery Y will supply 50% more cycles). Battery Z is the cheapest, but it is measured at a 24-hour discharge rate. Since you should compare like things, you should reject it.

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[46] Amp-hour ratings are specified with discharge rates such as 10, 20, or 24 hours. This means that a battery has a particular amp-hour capacity if it is discharged at a particular rate. For example, 220 amp hours at 20 hours means the battery is being constantly discharged at 11 amps (220÷20=11). If less amps are drained per hour, the capacity is somewhat higher. The relationship between the amp-hour rating of a given battery and the amps being drained (load current), can be found in battery manufacture's literature.

"Cold cranking amps" is not a helpful specification for comparing solar-electric system batteries for amp hour capacity. Cold cranking amps refers to the amount of amps a battery can discharge in 30 seconds at 0 degrees F (about –18 degrees C).

Used batteries

Get as much information as you can before buying used batteries. Find out if they have received good maintenance, and find a way to perform a load test (use an automotive load-tester; about US$60).

Occasionally you can get a used battery locally from someone that is leaving. Large used batteries are sometimes available via a hospital run by a development agency or a local telephone company. [Sometimes these larger batteries are 2 volts each and six of them must be wired together in series to create one 12-volt "battery."] If the price is right, they can still be useful if they can be moved. (We have two 250 amp-hour BP-Solar batteries that were bought used from someone else. The seller did not want to move them and gave us a terrific deal when he had to leave. They are BIG though.) You also need to check on their history and inspect them for damage, sediment (if the case if clear), and evidence of abuse. (Paul Kroening—E. Congo Group)

Automotive batteries

We have been suggesting that deep-cycle batteries are the type most appropriate for solar-electric systems. Now take a look at some differing experiences and special applications where automotive batteries may have a beneficial role:

Laurie Maskell, a technician in Papua New Guinea, tends to sell mostly automotive batteries to language and development workers he services. His thinking boils down to the fact that many of these users leave their batteries uncharged for long enough periods that they end up failing prematurely. In Papua New Guinea deep-cycles cost twice as much as automotive batteries, so they are not cost effective; both types tend to fail in about two years.

Back-up power for our telephone system and our computer network server here is provided by auto batteries. We replace them after six to seven years, not because the old ones are failing but because we want to be sure that they do not. They are floated at the equivalent of 13.5 volts for an auto battery. They rarely discharge more than 10%, so why pay premium prices for deep-discharge which is almost never used? Floating at 13.5 volts is very comfortable for a lead-acid battery. (Laurie Maskell—Papua New Guinea)

Car batteries have a much shorter life in solar applications. Assuming a deep-cycle battery can be bought for a similar price, a car battery is definitely not economical except in one very narrow application: where you use the vast majority of the charge in the daytime and at a rate which does not exceed the charging rate of the panel. Then the battery is acting only as a buffer. (Paul Kroening—E. Congo Group)

One last discussion of automotive versus deep-cycle batteries from Paul Thomas, formerly with E. Congo Group:

Go with deep-cycle if

- *there are many cloudy days during which you want to work,*
- *you have long printer runs,*
- *you run large loads at night, or*
- *deep-cycles are available for a reasonable cost.*

Go with automotive batteries if

- *you have low nighttime loads,*
- *you do printer runs on sunny day,*
- *automotive batteries are significantly less expensive,*

- *you prefer not to wait for shipment/customs, or*
- *you are using a backup generator.*

Replacing batteries

At some point you will need to add another battery or replace one of your batteries earlier than the rest. The most efficient method electrically, though perhaps impractical economically, is to replace all your batteries at the same time. (See the following field note.)

It is expensive to change out all your batteries at one time. Or sometimes, you just can not get a replacement battery for months. Say you have one that is a couple years old and about 60– 75% efficient and you want to add another to increase capacity. How do you use that old battery? I think the only practical way is to split off one panel to charge only that old battery and use the other one or two panels for the new battery. This way each battery is used as efficiently as it can be. Different appliances should then be tied to each separate system: inverter and lights on one, radio on the other, for example. I knew a guy who had three panels and two batteries. Not realizing he could use two panels on one battery, he used one panel and one battery for his radio. He used another panel and battery for his lights, and the third 14V panel he wired directly to the ceiling fan in the kitchen with no battery because he did not have one. The fan started to spin slowly at 9 in the morning, was really going during the heat of the day, and would quit about 4 PM! Necessity is the mother of invention. Caution: don't try this with a 17V panel as the higher voltage will probably damage the fan motor. (Paul Kroening—E. Congo Group)

Special batteries: Nicads and Gel-cells

More and more aircraft have nicad batteries. A nicad is very finicky and should not be used in a village solar-electric system (even if you could afford them!). They require specialized charge controllers.

Certain types of gel-cell and other new technology batteries may be attractive, but the main consideration is not the type of battery so much as the intended application. Any battery used for starting vehicles and being recharged by the on-board alternator is probably not intended for normal deep-cycle solar panel use. (Paul Kroening—E. Congo Group)

Buying inverters

Most small system users will buy an inverter to power their computer and printer. However, larger inverters may be appropriate for some applications. They offer many options and are worth some comparison shopping.

Please note that some kinds of appliances are inefficient and should not be powered by an inverter in a solar-electric system. Electric heaters (space heaters, ovens) and air conditioners are highly inefficient.

Surge capacity

If an inverter will be used to power induction motors (washing machines, refrigerators, power tools), it must have the capability to provide a larger amount of power for short periods. For this purpose, the surge rating should be a multiple of the wattage of your largest motor.

Motor type	**Surge capacity multiple** (inverter must have watt rating of many times the watt rating of the motor)
Refrigerator, tools	3–4X
Air compressor	5X
Well pump	6X

I once owned a 1,000-watt inverter that could provide 1,500-watts of surge capacity for a short time (20 minutes). It could power a microwave (a small, simple one), an air popcorn popper, or a blow dryer for a few minutes, which is all any of these items usually need to run. (David Colborn—SIL Dallas)

Today's smaller inverter usually has a similar surge capacity of 24–50% for 3–10 minutes. Most high frequency switching inverters (Exeltech and Statpower) can surge 200%. Most transformer inverters (Trace and Heart) can surge 300–500%.

Waveform

Standard 120 or 220-volt utility supplied electricity is in the form of a pure sine wave.

Inverters vary in their ability to supply a sine wave, and they cost accordingly.

- Square wave inverters are the least expensive type of inverter, but will not run induction motors or fluorescent lights. Square wave inverters will power some electronic equipment (not all) and universal motors commonly found in kitchen appliances, vacuum cleaners, and small power tools. They are not recommended for powering computers, color TVs, or VCRs. Square wave inverters are not efficient, with better models varying between 20% and 75% efficiency, depending on loading.
- Medium quality inverters provide a modified sine wave or quasi sine wave. Some are capable of powering most computers, TVs, VCRs, stereos, microwaves, and standard motors devices, but cannot supply power clean enough for equipment like clocks, timers, cordless tool rechargers[47], laser printers, photocopiers, bread makers and other sensitive devices. Some will power refrigerators. Modified sine wave inverters range from 85% to 95% efficiency.
- Pure sine wave inverters have become more affordable, and currently cost US$250–4,500. They are able to supply power clean enough for equipment like clocks, timers, cordless tool rechargers, laser printers, photocopiers, bread makers, and other sensitive equipment. They are usually capable of powering capacitor start and induction motors. These inverters start at 90% efficiency and reach 96%.

Devices with variable speeds and devices with chargers (cordless drills and screwdrivers) may not react correctly when used with square wave or modified sinewave inverters. In the case of variable speed tools, a tool may only run when its trigger is fully pulled (it will not provide a variable speed). In the case of chargers, inadequate or no charging will take place. Some chargers, especially cubes you plug in, may overheat or overcharge their rechargeable batteries. The only way to determine what will work with these inverters is to try the device and, if they do not work correctly, return them and try another.

Voltage and frequency regulation

Inverters can be ordered for 120 or 220-volt AC and at 50Hz or 60Hz.

Some inverters maintain the AC voltage at + or – 1% regardless of the input voltage of the batteries. They may also regulate the frequency of the AC waveform within .5% at 50 or 60 Hertz. Regulation of this precision may be necessary for sensitive loads such as computers, VCRs, stereos, some motors, and similar items.

Efficiency

See "Waveform" section, above.

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[47] If nicads in the cordless device (or nicad recharger) add up to 12V or less, you may be able to rewire around the electronics and charge the nicad batteries directly from your DC solar-electric system. Radio Shack sells a converter for dropping 12V to a range of DC voltages (9V, 7.5V, 6V, 4.5V, and 3V). You can also build your own voltage converter using a resistor of the correct ohm and watt rating.

Idle current

Modified sine wave and sine wave inverters use some current to remain ready to supply AC power at the flick of a switch. In some inverters this is very low, only a fraction of an amp; in others 1.5 amps may be used.

Battery charging

Many medium to large inverters include a built-in 3-stage battery charger. This is not a charge controller for your solar-electric panels, but rather a charger designed to be powered by a generator or AC power. Having a battery charger is valuable in situations where you have part-time access to AC power and depend on batteries the rest of the time.

Low/high battery voltage

Some inverters offer alarms or automatic shutdown for low or even high battery voltage conditions. Some allow adjustment of these threshold voltages.

Guarantees

Modern inverters offer high reliability, yet it pays to compare guarantees. Look for one to two years on parts and labor as the standard. Some inverter manufacturers have established a reputation for reliability, fast service, and a no-hassle warrantee policy.

Inverter buying checklist

- Does it have a continuous wattage rating that is greater than the sum of all the loads that you might be running at the same time?
- Does it have a surge rating 4–6 times the wattage of your largest induction motor?
- Does it have the features you will need? For example, frequency regulation, voltage regulation, low-voltage cutout, etc.?
- Does it have the AC output voltage and frequency you need (120 or 220 volt/ 50Hz or 60Hz)?
- Does the manufacturer have a reputation for reliability, service and warrantee fulfillment?

What not to power with an inverter

Most inverters do not like large inductive loads and may fail if used to power transformers. Check the documentation carefully before purchase.

Doing the math

Contributed by Paul Kroening—E. Congo Group

I love inverters. I recommend them to everyone. But just like learning to ration water in a drought, rationing electricity is a learned skill. And inverters test that skill.

Inverters also put our mathematical knowledge of electricity to the test. In principle, the power input (in watts) required for a given amount of output remains the same no matter what voltage it uses, but the current (amps) changes proportionally. So a 60 watt light bulb at 120 volts requires half an amp of current (volts x amps = watts). To drive a 60 watt bulb with 12 volts will require 5 amps! Both still use the same power, 60 watts.

An inverter gives the beginning user the false sense that he can use high-power appliances "for free." For example, a 250 watt inverter lets him use a dot matrix printer at 50 watts. He has been using a smaller bubble jet, but needs the dot matrix to cut stencils for the mimeograph machine. Before, he was used to *using his laptop computer at 1.5 amps, his 3 lamps in the evening at 2 amps each, and listening to the transceiver for a half-hour a day, transmitting for a total of 5 minutes at 10 amps. Now he has this inverter and plugs in the printer. It works fine! It draws only half an amp from the output side of the inverter. He forgets that to create that 50 watts inside he needs 50 divided by 12 = 4.5 amps for the duration of the print job (at 90% efficiency). It runs so well he decides to plug in his wife's little hand mixer. Now he is drawing 150 watts divided by 12 = 13 amps. So he plugs in his little power drill at 250 watts. Now he is drawing less than 2 amps at the output side, but the required input is drawing 250 divided by 12 = 22 amps! He can run through a lot of panel production in a short time! In addition, he needs large cables to carry the 20 amps from the battery to the inverter.*

Refrigeration

When you add refrigeration to a village home system, a significant number of additional panels and batteries are required. Conventional refrigerators require a powerful motor to run the compressor.

If you prefer 12-volt refrigeration, the SunFrost Model R10 (about US$1,740) provides 10 cubic feet of refrigeration (no freezer), draws 15 amps a day (24 hours) at 70 degrees F (21°C) and 25 amps a day at 90 degrees F (32°C). For those really hot days of 110 degrees F (43°C), expect to use about 38 amps. Alternative Energy Engineering, Sierra Solar Systems, and Sunbeam Solutions carry these refrigerators (see "Sources" at the end of the appendix).

If you can buy a large inverter and power a 120 or 220-volt model, you have a wider choice of units. Keep in mind that you should look carefully for an energy efficient model. Also be sure your inverter can handle the startup load of the refrigerator's compressor.

Cooling

Fans

If you use 12 volts, and not a large inverter, there are several 12-volt fans to choose from.

Probably the most popular is an 8 inch oscillating fan with two speeds (US$35). At high speed it draws 2 amps, on low it draws 1.2 amps. JAARS carries these and other fans.

The marine market carries high-efficiency fans that draw much less current. The SeaFit oscillating 7-inch fan draws 1.0 amp and costs about US$20. The Hella Turbo is a fixed, 7-inch fan that draws 0.2 amps (that is two-tenths of an amp) and costs about US$55. You need to mount these marine fans to a base (such as a ¾" x 6" x 6" board) or permanently mount to a surface. Check local sources or look for West Marine in "Sources" at the end of the appendix.

Ceiling fans that draw 0.5 amps are also available. They cost about US$155. They work best on low ceilings, as they are not overly powerful.

Evaporative coolers

In areas where the humidity is below 70%, evaporative coolers can effectively and economically cool and clean the air. Some 12-volt models draw about 3.0 amps on low and 4.5 amps on high and cost around US$500.

Water pumping

There are three ways you can use solar electricity to supply water:

- Solar-electric panels direct to a pump
- Solar-electric panels to batteries to a pump
- Solar-electric panels to batteries to an inverter to a pump

Usually the direct panels to a pump is the easiest system and both surface water and submersible pumps are made for this application.

Direct from panel

Without using batteries, the sun shines on a dedicated *PV* installation, the electricity is boosted in amperage by a linear current booster, and a DC pump runs according to how much sunshine is reaching the PVs. The pump is usually pumping to a storage tank placed above the level of the house so as to provide gravity flow.

When using one 60 watt dedicated panel, a low flow surface water pump (about US$110) can provide 1.66 gallons per minute (6.28lpm) at 10PSI. By using a linear current booster, the pump keeps operating, though more slowly, when there is less sunshine (the pump would normally stall without the current booster). Current boosters cost around US$90. (See “Sources” at the end of the appendix.)

Battery assisted

By using batteries, you can pump water on demand and do not need a linear current booster. Instead, water is pressurized in a small storage tank and a water pressure switch turns the pump on and off, eliminating the need for a large storage tank. However, batteries give up some efficiency when compared to direct PV-to-pump systems.

You can also use batteries to pump water to a gravity-feed storage tank equipped with a float switch. The float switch turns the pump off when the tank is full. As the tank empties during water use, the float switch turns the pump back on and refills the tank.

Inverter assisted

You can use large inverters to supply AC power to standard AC well pumps. As with the battery assisted system, inverter assisted systems do not need current boosters or large storage tanks, but provide pressurized water on demand. On the other hand, inverters give up some efficiency in their operation. If you plan to use a washing machine and a water pump at the same time, make sure the inverter has enough surge capacity to handle the total load.

Other direct from panel to load systems

Evaporative coolers are candidates for dedicated solar-electric panel to load systems (see “Evaporative coolers” above). Ceiling fans also fall into this category, although they do not require as many amps (less than 1 amp) as an evaporative cooler (3–5 amps); perhaps you can use a panel that has lost much of its output or a small panel.

He wired a single panel directly to the ceiling fan in the kitchen. The fan started to spin slowly at 9 in the morning, was really going during the heat of the day, and would quit about 4 PM. (Paul Kroening—E. Congo Group)

Hybrid systems

For devices mentioned in this section, please refer to catalogs mentioned in “Sources” at the end of the appendix.

Solar-electric plus wind

A PV and wind hybrid system makes sense if there are strong, consistent winds during seasons of low sunlight. Most people are too optimistic about the amount of reliable wind available. Minimum winds of 9 mph (14.5 km/h) average are the starting point; 15 mph (24 km/h) average winds are very useful; 25–30 mph (40–48 km/h) are the peak for most wind generators.

If leaves do not regularly blow around, forget it. There is not enough wind. Most wind generators will not produce anything in winds less than 13km/h (8 mph). (Laurie Maskell—Papua New Guinea)

Place wind generators at least 30 feet (9 meters) higher than any trees, buildings, or other obstructions within a 200-foot (61 meter) radius. The Southwest Windpower AIR403 provides about 6 amps at windspeeds of 15 mph (24 km/h) and costs about US$600.

Solar-electric plus hydro

A PV and hydro hybrid system may make sense if there is good water flow from a higher elevation during seasons of low sunlight. If there is year-round water flow, hydro may be a better source of power than PV.

If you can collect water high on a slope and pipe it down to a much lower location, consider a pelton wheel turbine. The higher the vertical drop, the more power you can harvest from a given volume of water. Conversely, the greater the volume of water, the lower a vertical drop will be needed for a given amount of power. Prices for Pelton wheel generators run about US$750–1,000.

For flatter sites with swift streams, a submersible prop and generator unit (Jack Rabbit Hydro Generator) can provide useful power from a low stream flow with minimal installation. A stream flowing at only 6 mph / 9.6 km/h can provide 8 amps per hour. The price for a Jack Rabbit hydro generator is about US$1,150 and is available through Real Goods (See “Sources” at the end of the appendix).

Solar-electric plus generator

A small generator is often used to back up a PV system. This is especially true when power must not be interrupted during periods of overcast or high loads. Usually, hybrid PV-generator systems are designed so that PV provides 80–90% of the annual power needs. The remaining 10–20% is economically provided by the generator.

This is a very efficient use of a generator, since generators age more and waste fuel when not powering a full load. By working a generator at full capacity for short periods to recharge batteries (plus washing clothes, pumping water, and using shop tools, etc.) and then shutting it down, efficiency is maximized.

A battery charger is a necessity in this type of system. Some generators and inverters incorporate battery chargers. In any case, make sure the battery charger is sized to match the output of the generator (and any other loads) when designing the system.

Buy a dual voltage (120V/240V) generator with a built-in battery charger that is big enough to run tools and other things while you are charging. The dual voltage allows you to run United States tools as well as tools from your local area. I would buy a 60-cycle generator since 50-cycle tools will run with 60-cycle power, though they run a little fast. Do not try to run 60-cycle tools with 50-cycle power. They will normally burn out their motors unless they are specifically marked as able to run with either 50 or 60 cycle power.

Do not wait to purchase your generator until you are on the field. They cost three to four times as much overseas. Even with shipping and customs charges factored in, they are cheaper to buy at home. (Mike Sweeney—Pioneer Bible Translators, Papua New Guinea)

Installation

Wire sizing formulas

There is a wire sizing chart in the earlier "Install your system" section, but you may enjoy the flexibility of calculating your wire sizes using formulas.

First, you must know the resistance of particular wire sizes in ohms for particular distances:

Wire diameter in mm^2	**Ohms per meter**	**American Wire Gauge**	**Ohms per meter**
0.75	0.024	20	0.0353
1.0	0.018	18	0.0222
1.5	0.012	16	0.0140
2.5	0.0072	14	0.0879
4.0	0.0045	12	0.00554
6.0	0.003	10	0.00348
10	0.0018	8	0.00218
16	0.001125	6	0.00138
25	0.00072	4	0.000866
35	0.0005142	2	0.000544

Resistance in 1 meter of stranded copper wire

Distance

The formula in descriptive form to discover distance for a 2.5% voltage drop is as follows:

Maximum wire length in meters = Acceptable voltage drop ÷ Amps being carried x Ohms for selected wire size x 2 (for two way distance)

The formula: D = .25 ÷ A x Ohms x 2

Ohms

The formula in descriptive form to discover ohms (and then wire size via table above) for a 2.5% voltage drop is as follows:

Ohms for selected wire size = Acceptable voltage drop ÷ Maximum wire length in meters x Amps being carried x 2 (for two way distance)

The formula: Ohms = .25 ÷ D x A x 2

Amps

The formula in descriptive form to discover the maximum amps that can be carried for a 2.5% voltage drop is as follows:

Maximum amps = Maximum wire length in meters x Ohms for selected wire size x 2 (for two way distance)

The formula: A = .25 ÷ D x Ohms x 2

Panel installation and wiring

You can wire up to four panels in parallel using the junction boxes on the back of the panels. If you are wiring more than four panels, break them into two groups and join the two groups in a separate junction box. Here is why: when a connection loosens at the junction box of one of the panels, arcing occurs. If more than four panels are wired in parallel, the higher current can cause a lot of heat and the junction box, even the panel, may be ruined.

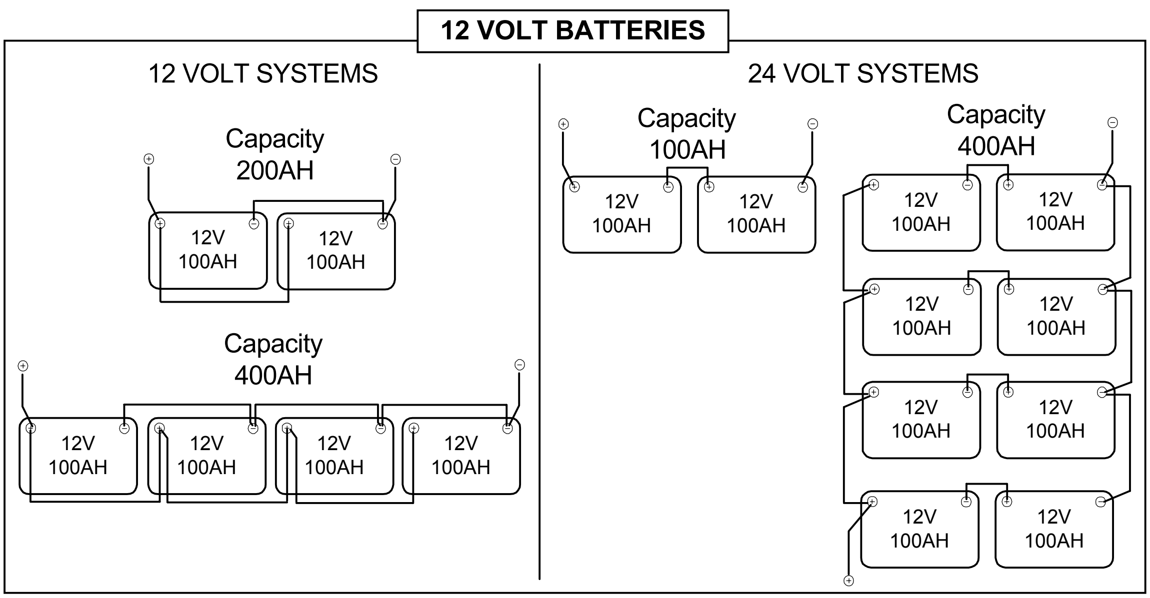
If your panels are mounted away from your house, you may wish to run your wires overhead. In that case, you will need some way to anchor the wires at each end so extra weight from wind or falling branches will not stress the connections. Electrical supply houses or your local technician should be able to provide the appropriate strain-relief hardware. Adding a spring at one end will add to the survival of your wire run.

If you wish to bury your wires, you can buy wire rated for direct burial (very expensive) or pull wire through inexpensive black PVC pipe and bury it. To pull wire through PVC pipe, tie a small styrofoam ball (loose fit) or a ball of rag to some string and suck it through using a vacuum cleaner (or blow it through using lung power). Pull heavier, stronger twine through using string. Finally, pull wire through using twine.

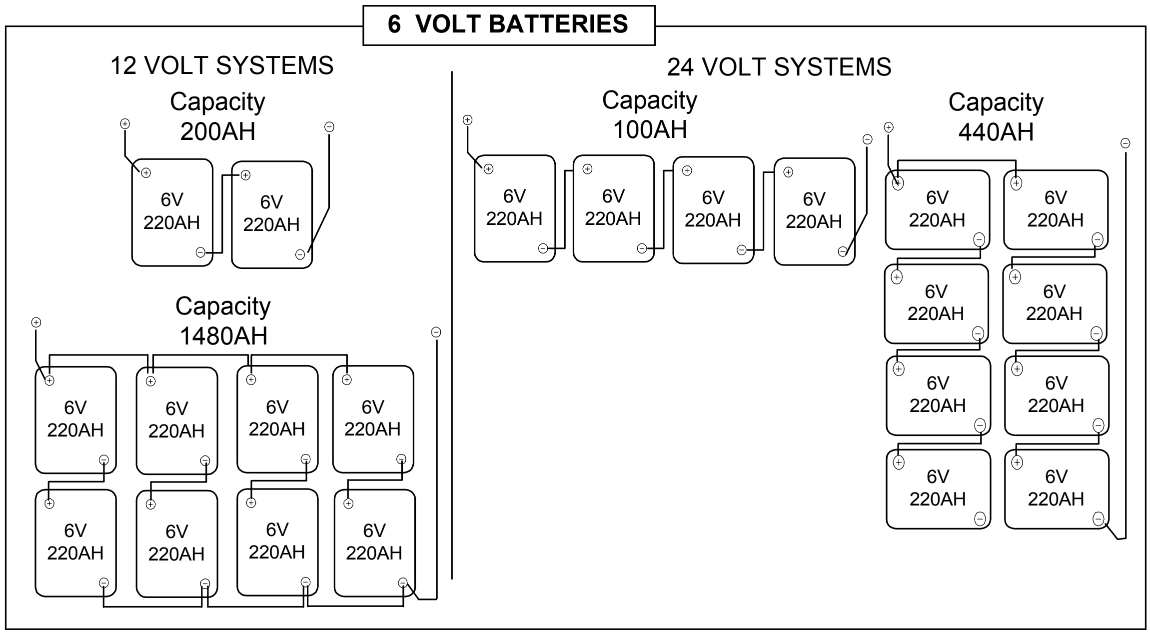
If you use solid wire (instead of stranded) for the run from panels to house, its stiffness has been known to pull off panel terminal posts. To avoid this, mechanically anchor the wire to one of your panels as a strain relief and connect (solder) the solid wire to a short piece of stranded wire which is in turn connected to the panel terminal.

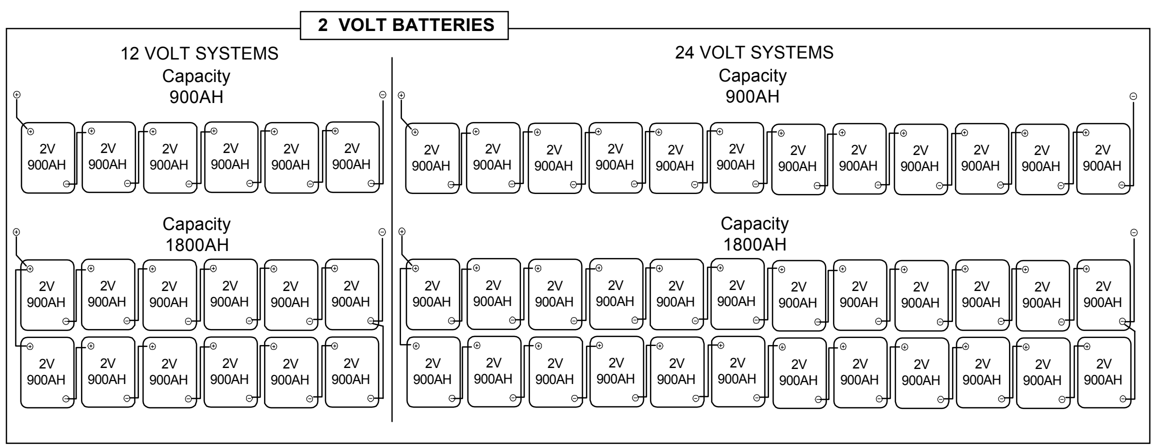
Battery installation and wiring

Some users will opt for a split system: one (or more) panel(s) feeds a battery and another panel(s) separately feeds a different battery. But for unified systems, note the layout and wiring for various voltages and battery connections below:



Battery bank composed of 6-volt batteries wired to produce 48 volts. (Do not try this at home.)





Monitors including shunts

While smaller systems might only monitor battery condition, medium and large systems should have monitors for incoming power, outgoing power, and battery voltage.

Tip: when you first install your system, log the current (amp) reading when the full sun is directly overhead. Years later, you can compare to determine if your system continues to produce well. If your output has fallen, use the maintenance section of this guide to attempt to eliminate any problems.

While most monitors report amperage or voltage at a particular point in time, cumulative monitors are available for measuring incoming and outgoing amperage over time. Currently, cumulative monitors are expensive (around US$200). Whichever type you use, there is still a need for logging the data to accurately understand what is coming into and going out of a system.

A shunt is a device used to measure many amps of DC current. Usually you place a shunt between a battery bank and a large inverter. A shunt is a precision resistor producing an accurate voltage drop when current is passed through it. You use it in conjunction with a specific monitor to give an accurate reading of amps used. Select shunts to correspond with the maximum continuous amp load of a system.

Plugs and receptacles

You may need to plug and unplug a large appliance; in that case, you may need connectors that can carry higher *current* loads. Unfortunately, there is no standard for high-current DC connectors. Basically, a plug-and-receptacle combination must provide enough metal surface for good conductivity at higher *amp loads.* They also must provide a way to maintain *polarity*.

Some people from the United States have used 220-volt connectors because of their robustness and *polarity* assurance, with the assumption that they will not confuse the 220-volt connectors with 120-volt connectors in an inverter system (the connectors would not allow one to accidentally plug a 120-volt appliance into a 220-volt receptacle).

Special switches

Digital timers are available for switching appliances (even pumps) on and off. Available through United States catalogs (and probably elsewhere), they

- cost about US$60,
- handle up to six on/off operations per day,
- draw only 10 mA, and
- can control up to 15 amps of resistive load or 10 amps of inductive load.

For larger loads, use a relay.

I have discovered that relays are useful when you need to switch heavy-current appliances on and off. Relays can reduce long runs of heavy wire. Thin wires (#22) can control relays over long distances. (Bob Ulfers—Cameroon)

Grounding tips and details

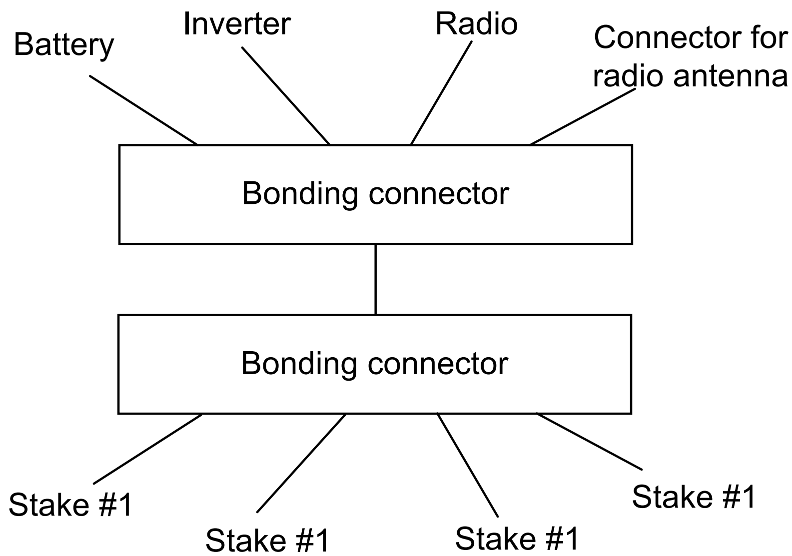
Run three separate wires to a common ground stake. NEVER tie these wires to different ground stakes. If a strike hits the ground 100 yards away, there would likely be as much as 1,000 volts between separate ground stakes for long enough to destroy equipment. If everything is tied to a single ground stake, then most equipment would survive such a strike. Two-way radio damage can be prevented by disconnecting the antenna from the radio and connecting it to the ground stake while the radio is not in use. [Connecting the antenna to the ground may not protect the antenna, but should help prevent fires and protect your radio.]

Most installations will need only one ground stake. If you do have several ground stakes, bond them together first and then connect the wires from the equipment to the SAME POINT on that ground system. Equipment connected as in the diagram below would be safe from ground potential differences.

In the event of a nearby strike, the high voltages and currents will be confined to the wires interconnecting the ground electrodes.

A lightning stroke does not travel all the way down to the ground. Rather, it is met, at about 150 feet (46 meters), by a "ground leader" coming upward from the ground. Where this ground leader comes from is determined by the voltage gradients near the surface under the charged cloud. Even a very poor conductor such as a dead tree (or timber house) will modify the nearby voltage gradient and may well become an origin of such a ground leader. Once the main descending stroke and the ascending ground leader have met, the path for the discharge is set to within a few feet.

Lightning is much more likely to follow a defined, non-destructive path through a house if there is a good conductor for it to follow, with no sharp turns. On the other hand, if the lightning is allowed to branch according to some indeterminate factor (such as the moisture content of various parts of the walls, floor and posts of the house), a great deal of destruction may be unleashed.



For really serious protection such as is needed for a Telephone Exchange, the building is surrounded by a ring of ground stakes bonded to each other and connected AT ONE POINT to the equipment common ground.

There is tremendous energy in a lightning strike. I have twice picked up the copper-coated remains of the housing of the 15 amp mains' fuses from the opposite side of the room to the switchboard in our own house after thunderstorms. (Laurie Maskell—Papua New Guinea)

Unfortunately, grounding for lightning protection is not universally accepted. Some techs have stated an entirely different view, saying system components should "float." I do not have enough information to know which view is correct, though I lean toward grounding. In addition, electrical codes in virtually every country require grounding.

My experience leads me to ground or "earth" solar panels, electronic equipment, and battery banks.

Nearby lightning strikes, in my experience, will not harm grounded panels. Direct strikes are usually taken by trees and roofs, but ungrounded panels in their vicinity often are damaged, leaving indications that, had they been grounded, they would have survived.

Lightning in the vicinity of electronic equipment can create enough electromotive force (EMF) to damage electronics. Grounding will usually, though not always, save electronics. (Paul Kroening—E. Congo Group)

When you ground, do it thoroughly and well.

The sociology, psychology and high-finance of being a technical advisor

Often after calculating their electrical needs, people will simply not buy enough batteries to avoid deep-cycling them, either because they are hard to transport all at once, they are expensive all at once, or they do not have the room. Another reason is that if they stay in a village 3 or 4 years, and then take a year's break, they like to be able to "use up" the batteries, because storing them is never good for them at that age. They almost always are ruined after the year.

I like people to buy enough batteries so that in the rainy season they are not tempted to discharge more than 60 to 70% of capacity. This gives a long life and reliability, but does not make you contend with a bank of batteries as big as the house. A three panel installation gives more or less 45 amp hours per day in the tropics. One 100 amp hour battery gives fine daily performance but less than one further day of independence. So for this house, two 100 amp hour batteries is better: 70% of 200 amp hour capacity is

140 amp hours, or nearly three days, a good moderate-length design. 20% discharge depth, however, requires over 200 amp hours of capacity per day for the 45 amp hour daily use, and thus just under 700 for three days independence, or 7 batteries. While I agree that it is the most efficient, it is hard to get people to shell out the money or not be overwhelmed by the maintenance or finding a place to put them. (Paul Kroening–E. Congo Group)

Glossary

Some terms below are not used in the text, but are useful in understanding catalogs and dealers.

absorption charge – The second stage of three-stage battery charging where voltage is constant and the current is allowed to rise to the level that the battery will accept.

AC – Alternating current. Regular household current as supplied by electric utilities (or inverters). The movement of electricity which reaches a maximum in one direction, decreases to zero, then reverses itself and reaches a maximum in the opposite direction. See *DC.*

amp or ampere – Unit of measurement for electric current.

amp hours – One amp used or produced in one hour = 1 amp hour; 3 amps in one hour = 3 amp hours. Batteries are rated in amp hours, as are solar-electric panels. This is a measure of charge capacity in batteries and measure of electrical production in solar-electric panels. See *watts*.

array – A group of solar-electric panels connected together.

battery bank – A group of batteries wired together.

battery loss allowance – Storing electricity involves some losses. The *battery loss allowance* is a method for considering these losses.

bulk charge – The first stage of multi-stage battery charging where current is constant and, as the batteries accept the current, the voltage is allowed to rise.

charge controller – An electronic device that regulates the current from solar-electric panels to your batteries.

current – A measurement of electrical movement in a conductor measured in amps.

DC – Direct current. The type of electrical current supplied by batteries and solar-electric panels. The movement of electricity in a conductor in only one direction. See *AC.*

deep-cycle battery – A battery capable of many deep discharge and recharge cycles. (As opposed to car batteries which are designed for shallow cycles.)

diode – A two terminal electronic device that will conduct electricity much more easily in one direction than in the other.

DOD – Depth of discharge is a term used to describe the status of a battery. A battery that has a 70% depth of discharge (DOD) is said to have a 30% state of charge (SOC). *See* SOS.

electrolysis – See *gassing.*

electrolyte – Sulfuric acid dissolved in water creates a conducting medium for the flow of current and the movement of ions.

float charge – The final stage in multi-stage charging where both voltage and current are reduced to a level approximately equal to the self-discharge rate of the battery. Also called a trickle charge; often .5 – 2 amps.

gassing – The product of overcharging or excessive charging of battery cells; also called electrolysis. If excessive, there will be water loss and premature aging of the battery. Too much gassing scrubs material off the plates, decreasing their capacity, overheating them; this leads to shortened battery life. Excessive gassing produces violent bubbling of the cell water. On the other hand, some gassing is normal; normal gassing produces slight bubbling in the cell water during charging.

Hertz or Hz – The unit of measurement for the number of cycles of a waveform in one second. One Hertz equals on cycle per second. Used in discussions of AC circuits and inverters.

hydrometer – A device used to draw fluid out of a battery cell to measure its *specific gravity*. See *specific gravity.*

inverter – A device used to convert DC electricity to AC electricity.

insolation – A measurement of solar radiation received at the earth's surface. As used in PV system sizing, insolation is a measurement of year-round average hours of peak sunlight.

kilowatt or kW – A unit of power equal to 1,000 *watts*. See *watts.*

line loss – The voltage drop over a length of electrical wire of a specific gauge. Line loss wastes power when the wire is too small for the current being run through it.

load – Appliances and other devices that use electricity.

low voltage disconnect or LVD – An electronic device that automatically disconnects all loads from a battery when that battery falls below a pre-set voltage.

module – The industry term for a solar-electric panel.

parallel (wiring) – Component (solar-electric panel or battery) connected with its positive terminal connected to the next related component's positive terminal (and negative to negative). Parallel wiring increase amperage while maintaining voltage at the same level. See *series (wiring)*.

Photovoltaic (PV) – The conversion of solar energy directly to electrical energy. Photo means *light*; voltaic means *electric*.

polarity – Having two opposite electrical paths: positive and negative. In direct current (DC) electricity, there is a positive (+) and a negative (-) electrical path. Since connecting the positive to the negative directly will cause a short (with sparks and heat and blown fuses), users of DC electricity try to maintain the *polarity* of the wiring by using wire colors and connectors that will assure that positive only gets connected to positive and negative only to negative.

PV – Abbreviation for *photovoltaic*.

Self-discharge – The natural tendency of a battery to slowly discharge. This is caused by unavoidable impurities in the chemicals used in their manufacture. These impurities cause an internal chemical reaction which slowly discharge the battery. New batteries self-discharge at about 1–2% of their amperage capacity per day. Older batteries and batteries at higher temperatures will self-discharge faster.

series (wiring) – Component (solar-electric panel or battery) connected with its negative terminal connected to the next related component's positive terminal. Series wiring increases voltage while maintaining amperage at the same level. See *parallel (wiring).*

solar cell – A single photovoltaic unit which typically produces .5 volts, but when many are wired in series in a solar-electric panel, produces voltages high enough to charge 12-volt batteries or power water pumps directly. Each *solar cell* produces a specific amperage, depending on its size and construction. Types of solar cells include: single crystal (mono crystalline), semi-crystalline, poly-crystalline, and amorphous film.

solar-electric panel – The industry calls these units *PV modules*.

specific gravity – The ratio of the density of any substance (sulfuric acid) to the density of some other substance taken as standard (such as water). See *hydrometer.*

SOS – State of charge is a term used to describe the status of a battery and is the opposite of depth of discharge (DOD). State of charge indicates the percentage that the battery is charged. A battery that has a 70% state of charge (SOC) is said to have a 30% depth of discharge (DOD). *See* DOD.

voltage or volts – voltage is the rating of the amount of electrical pressure that causes electricity to flow in a power line. If electricity were water, voltage would measure the amount of pressure at the faucet.

water – Refers to battery cell liquid (electrolyte) which is partly water and partly acid.

watt – A watt is a measurement of total electrical power; watts = volts x amps.

Appendixes

Appendix A: Size your system

While you can use the JAARS starter system as a guide and modify it to your needs, you can also size a solar-electric system by using the following tables. (Sizing forms based on publications of Atlantic Solar Products, Inc. Used by permission.)

Usage

DC appliance	Hours of daily use X	Appliance amps =	Total daily amp hrs used

Total DC daily energy budget ______________________

plus 20% battery loss allowance ______________________

net DC daily energy budget ______________________

AC appliance	Hours of daily use X	Appliance amps* =	Total daily amp hrs used

*If only watts are known, divide appliance watts by 120 to find amps.

Total AC daily energy budget ______________________

plus 30% inverter & battery loss allowance[48] ______________________

net AC daily energy budget ______________________

[48] If system is a combination of 12 volt DC and 120 volt AC, then you do both loss allowances: 20% for the DC component battery lose, 30% for the AC component inverter and battery loss. Both DC and AC appliances need battery lose compensation and AC also needs an extra 10% for inverter inefficiency.

Calculate usage and panel output to determine number of panels

Enter net DC daily energy budget		Example: 14 amps
Plus net AC daily energy budget	+	10 amps
Equals total daily energy budget	=	24 amps
Divided by average daily amps from a single specific module in a specific region[49]	÷	(3 amps x 5 hrs.=)15 amps
Equals number of modules needed	=	2

Table 1: Calculating battery storage needs

Note: Examples differ only in number of days of cloudy weather. Calculations are rounded.

Steps		**Example 1**	**Example 2**	**Calculations**
Daily energy budget in amps		24A	24A	
Multiplied by maximum number of continuous days of cloudy weather per year	x	5 days	15 days	
Equals gross amps needed for 5 days	=	120A	360A	
Divided by 0.7 to keep batteries at 30% *SOC*	÷	0.7	0.7	
Equals amount to keep the batteries at a minimum of 30% charge	=	171A	514A	
Multiplied by coldest season average ambient temperature (see Table 2). For example, 70° (21°C) which = 1.04.	x	1.04	1.04	
Equals amount adjusted for winter temperature	=	178A	535A	
Divided by amp-hours of chosen battery	÷	105A	105A	
Equals number of 12-volt, 105 amp hour batteries in parallel required	=	1.7 rounded up to 2	5	

If you use 6-volt batteries, multiply your number of 12-volt batteries by 2 to get the number of 6-volt batteries you will need (system voltage [12V] ÷ battery voltage [example: 6V] x number of 12V batteries in parallel required = total number of battery units required).

"Independence" is the number of days you can run your normal appliances without the sun. The amount of independence you want affects the number of batteries you need.

[49] To determine a module's output in a particular region, you must know the peak amps of the panel you plan to use (for example, 3 amps) and determine the average peak sun hours per day in your region (for example, 5 hours per day). See "Insolation maps" below to determine average peak sun hours.

To fill out Table 1, you need the coldest season average ambient temperature multiplier. Use Table 2 to find the multiplier.

Table 2: Battery temperature compensation

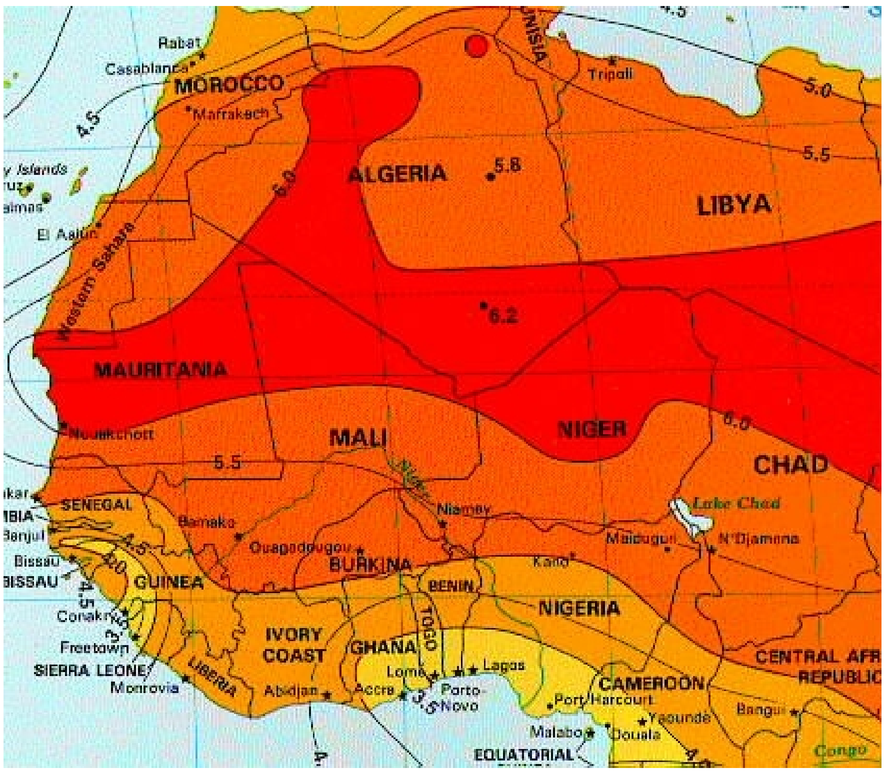
Battery temperature in coldest season	Multiplier
80°F/26.7°C	1.00
70°F/21.2°C	1.04
60°F/15.6°C	1.11
50°F/10.0°C	1.19
40°F/4.4°C	1.30
30°F/-1.1°C	1.40
20°F/-6.7°C	1.59

Appendix B: Insolation maps

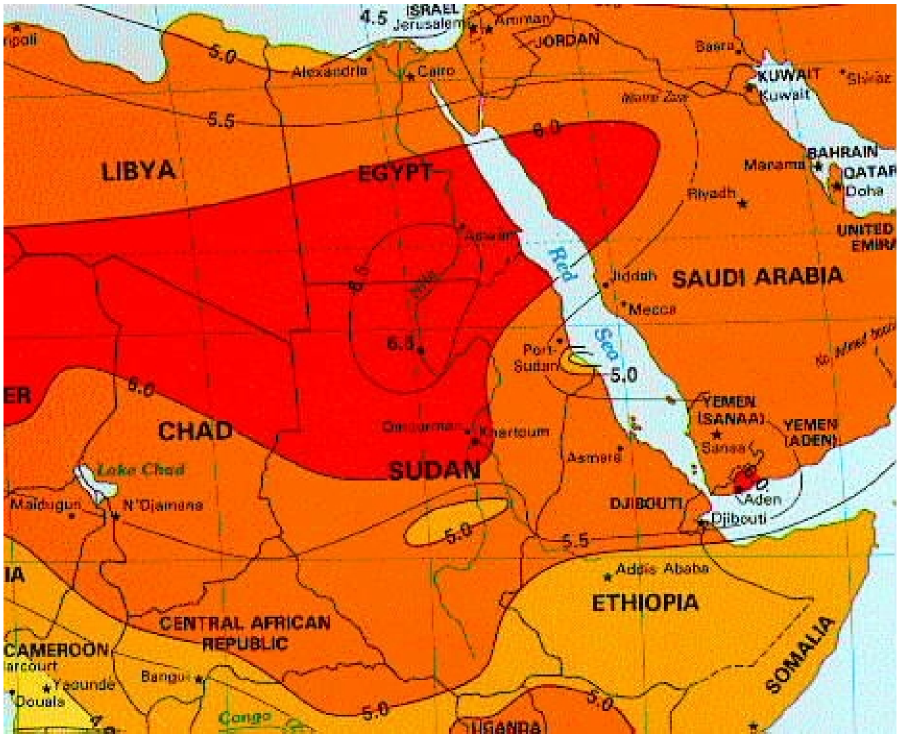
Insolation maps tell you how many average peak sun hours (equivalent full sun hours) are available in a particular region. Once you know that number, enter the peak sun hours into your sizing worksheets in the "Calculating usage and panel output to determine number of panels" section.

Initially, the insolation maps may be confusing to read. Start with the darkest area and look for an hours number like 6.2 in a central location (not on a line). This is the average (year round) peak sun hours. Then look at the line around the darkest area; somewhere on it you may find a number of 6.0. This indicates that closer to the line and away from the 6.2 area, the peak sun hours are about 6.0.

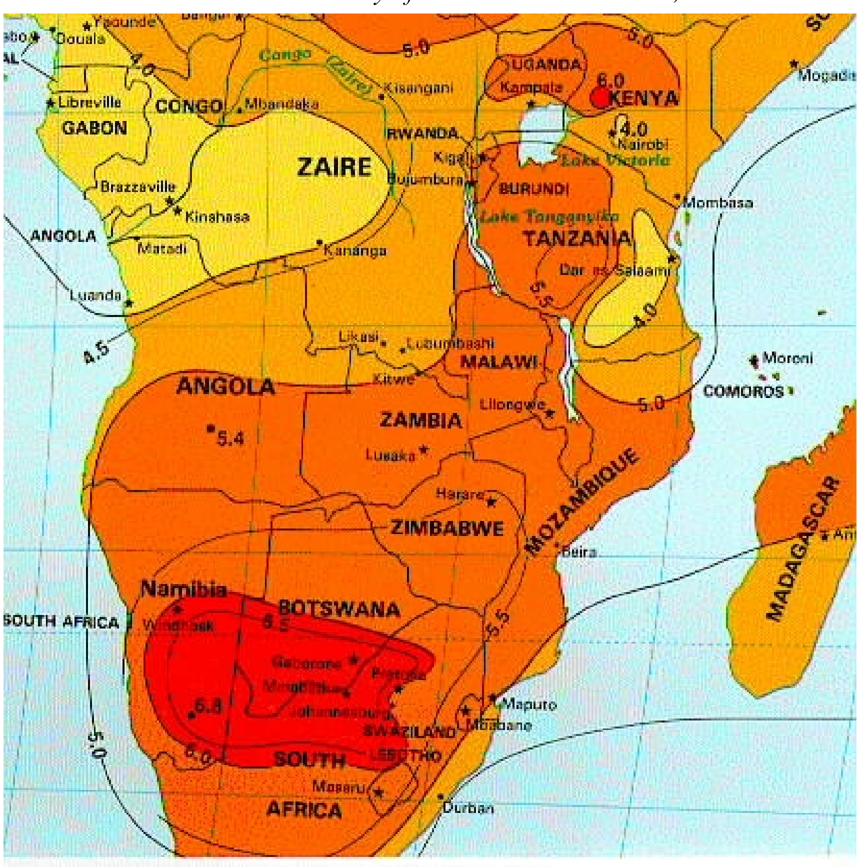
Unfortunately, insolation maps for most of Asia, Europe and the South Pacific are not available as of publication. We hope to add these in a future update.



Northwest Africa *Courtesy of Atlantic Solar Products, Inc.*

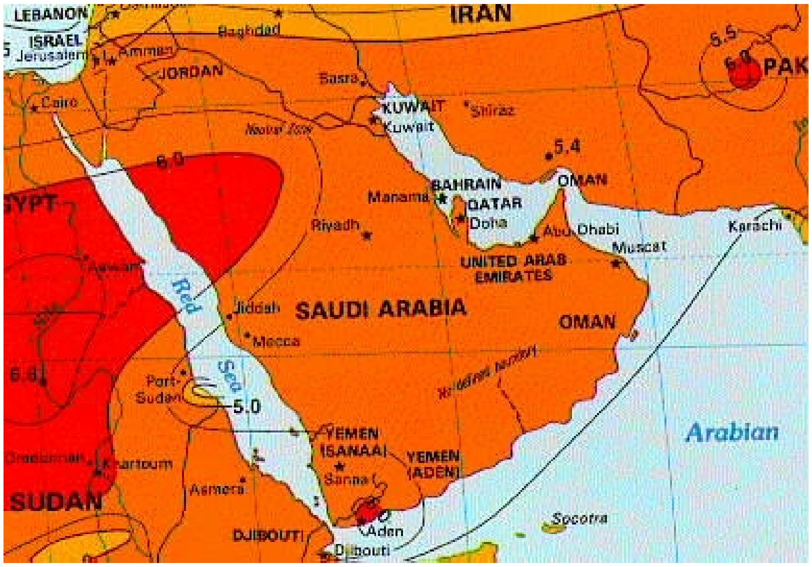


Northeast Africa *Courtesy of Atlantic Solar Products, Inc*

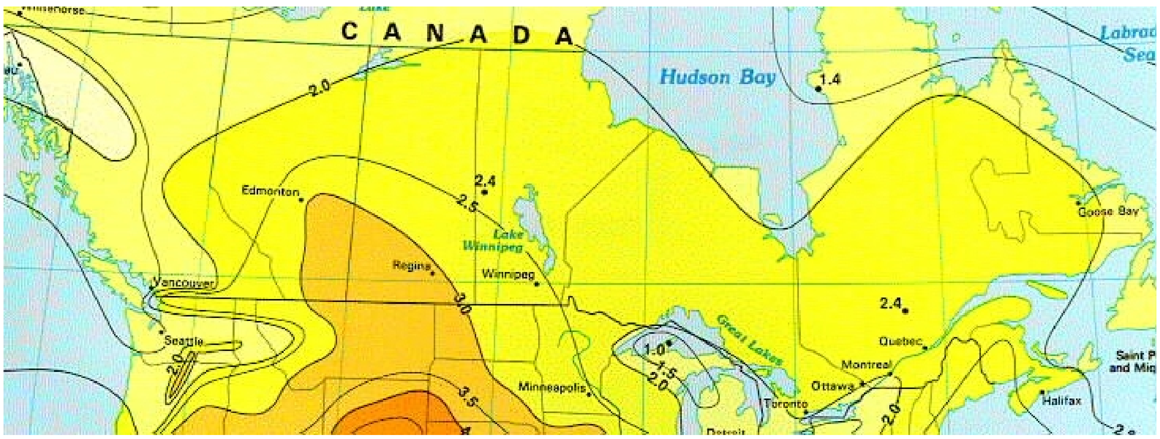


South Africa *Courtesy of Atlantic Solar Products, Inc*

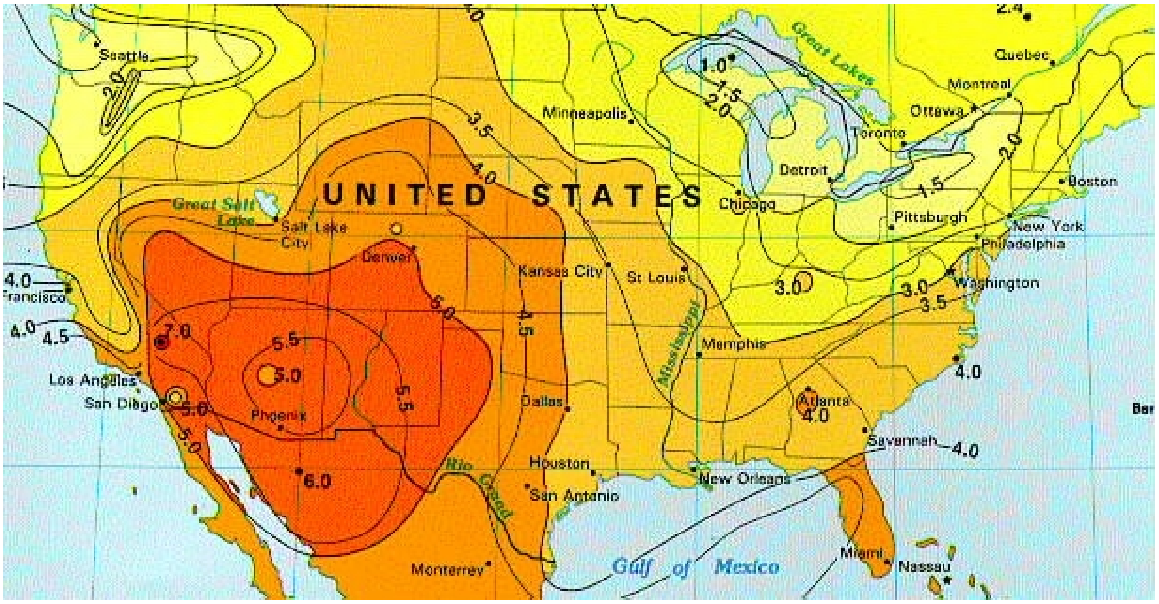
Note: the name of Zaire is changed to D.R. Congo.



Middle East *Courtesy of Atlantic Solar Products, Inc*



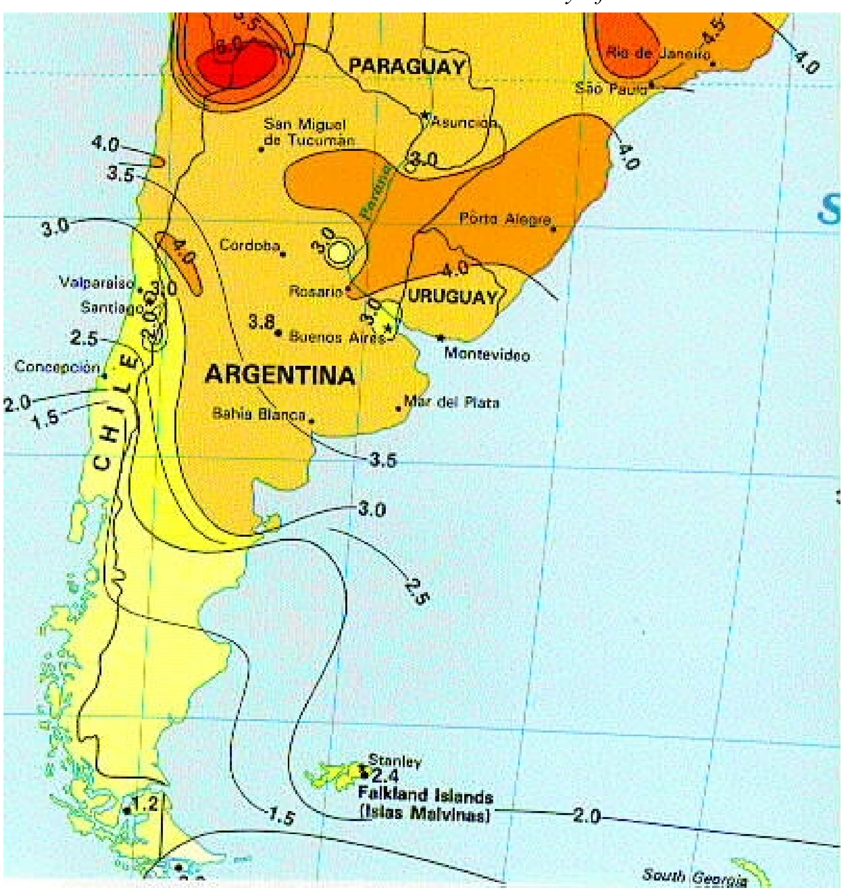
Canada *Courtesy of Atlantic Solar Products, Inc*



United States *Courtesy of Atlantic Solar Products, Inc*

Mexico and Central America *Courtesy of Atlantic Solar Products, Inc*

Northern South America *Courtesy of Atlantic Solar Products, Inc*



Southern South America *Courtesy of Atlantic Solar Products, Inc*

Indonesia *Courtesy of Atlantic Solar Products, Inc*

Appendix C: Sources

Alternative Energy Engineering (catalog), P.O. Box 339, Redway, CA 95560; orders 800-777-6609; tech support 800-800-0624; email: energy@alt-energy.com; Website: www.alt-energy.com

Atlantic Solar Products, Inc., 9351 J. Philadelphia Road, Baltimore, Maryland 21237; telephone: 410-686-2500; fax 410-686-6221; email: mail@atlanticsolar.com; Website: www.atlanticsolar.com

JAARS Inc. (Jungle Aviation And Radio Service): 7601 Davis Rd/ P.O. Box 284, Waxhaw, NC 28173; telephone: 704-843-6012; email: ernie_warnick@jaars.org; website: www.jaars.org

Jade Mountain (catalog), P.O. Box 4616, Boulder, CO 80306; orders 800-422-1972; tech support 303-449-6601; fax 303-449-8266; www.jademountain.com; discounts to missionaries.

Kyocera Solar, Inc. (catalog), 7812 E. Acoma Drive, Scottsdale, AZ 85260; Tel: 480-948-8003; Fax: 480-483-6431; Website: www.kyocera.com/solar/

Real Goods (catalog), 200 Clara Ave., Ukiah, CA 95482; telephone: 1-800-919-2400; fax: 707-462-4807; email: techs@realgoods.com; Website: www.realgoods.com/renew

Sierra Solar Systems (catalog) can be contacted by mail, email, fax, telephone, or you can view their website. 109-N Argall Way, Nevada City, CA 95959; tech info and foreign orders: (503) 265-8441; order line: (800) 51-SOLAR (USA only); fax: (530) 265-6151; email: solarjon@sierrasolar.com; Website: www.sierrasolar.com

Sunbeam Solutions (catalog plus); US$10 binder includes guidebook, brochures, tips and discount catalog: 537 E. Delano St., Tucson, AZ 85705-3911; phone: 520-882-9890; fax: 520-882-9556; email: leldeen@azstarnet.com

West Marine: (catalog) Catalog Sales, P.O. Box 50050, Watsonville, CA 95077; U.S.: 1-800-262-8464; United Kingdom: 0800-895473; France: 0800-908430; Germany: 0130-8-10427; Japan: 0066-33-812071; New Zealand: 0800-445-635; Australia: 1-800-1-43404 (fans and other 12V products)

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Battery Service Manual, by Battery Council International, 401 N. Michigan Ave, Chicago, IL 60611

Charging and Maintenance Brochure, by Trojan Battery, 12380 Clark Street, Santa Fe Springs, CA 90670

Remote Power Systems, by Atlantic Solar Products, Inc, P.O. Box 70060, Baltimore, MD 21237

Solar Electric Design Guide, by Photocomm (Photocomm merged with Golden Genesis Company, who recently merged with Kyocera Solar, Inc.). The new name and address is Kyocera Solar, Inc., 7812 E. Acoma Drive, Scottsdale, Arizona 85260; Website: www.kyocera.com/solar/

Solar Electric Systems for Africa, by Mark Hankins, Commonwealth Science Council, Marlborough House, Pall Mall, London SWIY 5HX, United Kingdom (Also available through Jade Mountain; see "Appendix C: Sources" above.)

Tech Notes, by Trace Engineering, 5916 – 195th N.E., Arlington, WA 98223

The Solar Electric Independent Home Book, by New England Solar Electric Inc., 3 South Worthington Road, Worthington, MA 01098