Independent Solar Electric Homes

Utility independent, or "remote," solar electric systems provide electricity for buildings that are not connected to an electric utility. Photovoltaics (PV) have been used to power remote homes in Montana for more than 20 years. Applications vary from simple systems that charge a trailer battery, to complete home power systems that run everything from power tools to microwave ovens. This brief covers the basics of what you need to get started; for more hands-on information and examples of remote solar homes, see *Home Power Magazine*.

When to Consider a PV Power System

The cost of extending a power line to a home depends on your local electric utility's line extension policy and the distance from the site to the existing electrical distribution lines. If the local utility has a generous line extension policy and the home site is close to existing distribution lines, a line extension may be your best option.

However, many electric utilities expect customers to pay the full cost of line construction. Utilities also are increasingly reluctant to build power lines to small loads in remote locations even if the customer is willing to pay, because the utility must pay for expensive maintenance once the line is built.

Your local electrical utility company can give you an estimate of the cost to extend a new line to a home site. With utility line construction costs typically ranging from $10,000 to $30,000 per mile, plus additional costs for maintenance, it may be to the utility's and your benefit to find an alternative source of power. Depending on your electricity requirements, a PV system could be the least-cost option even when the nearest utility is no more than one-half mile away.

Solar electric homes are generally energy efficient, but they don't necessarily require a change in lifestyle or standard of living. Unlike utility power, remote systems provide a limited amount of energy and have a fixed maximum power output. All remote systems rely on batteries to store energy for use when there is insufficient sunlight, and most are equipped with small generators for backup electricity during extended cloudy periods.

Another element of a remote home PV system is that space heating, water heating and food cooking is accomplished using either wood or gas. Using photovoltaics to power these systems would be expensive. The best option is to use

Solar electricity powers this home in the mountains independent of the utility grid. *(Dave Parsons, National Renewable Energy Laboratory)*

solar water heating and passive solar space heating to supplement conventional heating.

Here are the four most common reasons people choose a solar electric system for remote homes:

1) Increased reliability and power quality;
2) Quiet operation, compared to running a gas or diesel generator;
3) Cheaper than a line extension; and
4) Good environmental stewardship.

The Basics

Here are a few key terms you should know:

PV array	A collection of PV modules sized to provide enough power to your system on a typical December day.
Charge controller	A voltage regulator designed to control the charging of your batteries to assure maximum useful life.
Batteries	Deep-cycle batteries such as those used in RV's, golf carts, or lift trucks. These are sized to provide you with three to five days of backup power.

Inverter — A power converter that transforms the DC power from your array and batteries into standard household AC power.

Backup generator — A small gasoline or propane generator used to recharge your batteries under extended periods of poor sunlight. This is optional but recommended since it allows you to reduce the size of your battery bank.

Unlike utility power, a PV system provides a limited amount of energy and has a maximum power output. The amount of energy collected depends on the size of the array, and the maximum power output depends on the size of the inverter.

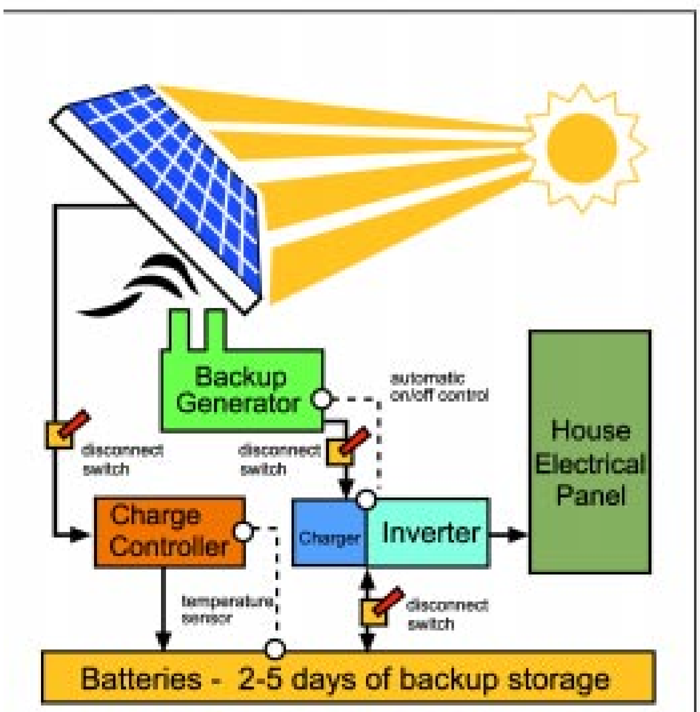
System Sizing

Properly sizing a utility-independent system is important, so you should consult with a PV provider to help you with this step. The goal is to determine a reasonable size for your system. A system that's too large will leave you with surplus power in the summer; too small of a system will force you to run your backup generator too much.

Before you call your PV provider, determine how much energy you'll need. Start by adding up the average daily energy use for every piece of electric equipment you plan on using in the winter. Energy use is calculated by multiplying the power consumption of the equipment (watts) by how long (hours) it is run on an average day. Because energy losses are different for alternating (AC) current than for direct current (DC) equipment, you'll need to keep these totals separate.

Once you've added up all your daily AC and DC energy use, you can estimate the size of the solar array by dividing this value by the number of equivalent full-sun hours for your location. See **Appendix 1** for an example load and sizing estimation. **Appendix 2** shows typical power consumption values for common household appliances.

Notice that the sizing column in **Appendix 1** is does not correspond to the amount of sun during any particular month. Using this value will assure that your system will not be significantly oversized during the summer, while keeping winter time backup recharging to a minimum. You might be able to get by with an even smaller system than determined by using the sizing column. However, doing so will require you to reduce your normal energy use during the winter.



Schematic of a remote system (NOT a wiring diagram).

Some (Very) Basic Electricity

The first step in understanding a photovoltaic system is to understand the end product. The following definitions of basic electrical terminology will help clarify the explanation of PV system design.

a. **Electricity** — the movement of electrons through a circuit.

b. **Current** — expressed in amperes (or amps), it's the number of electrons passing a given point per unit of time.

c. **Voltage** — pressure forcing electrons through a circuit.

d. **Power** — expressed in Watts, it is the product of voltage multiplied by the current:

Power = Volts (V) x Amps (I)

e. **Resistance** — load characterized by resistance to the flow of electrons, Ohm's Law:

Volts = Amps (I) x Resistance (R)

f. **AC and DC** — two ways in which electricity flows.

Direct current (DC) is produced by battery systems (such as in an auto) and by solar cells. It is a constant flow of electrons, at a set voltage, along a conductor. The current (amps) may vary.

Alternating current (AC) is usually of higher voltage and is typical of utility-supplied power. Alternating current flows through a conductor as a wave form. This wave form is usually of a constant voltage, cycling the current at a set frequency (usually 60 cycles per second)

Altair Energy Photo

Solar panels are mounted at an angle on the side of this remote home.

Efficiency and Phantom Loads

Although estimating your daily energy use is tedious, it'll give you an idea of where you can improve your home's electric efficiency. In the above example, replacing your clock with a battery-powered digital one, and the two incandescent lamps with fluorescent lamps, would lower your daily energy use by 504 watt-hours. Using the rule of thumb of $11 per watt for a professionally installed system, this translates to a reduction $1,000 in the initial cost!

Using readily available technology, you can reduce your electric energy needs to one-third of a typical home. Appliances should be selected for efficiency. Fluorescent lights are preferred over incandescents because they use a quarter of the energy. Refrigerators, dishwashers, water pumps and small loads that are run all day should be carefully selected. The extra $400 you spend on a highly efficient refrigerator will substantially reduce the amount you have to spend on your PV system. And most important, wood or gas (propane) should be used for all space heating, water heating and cooking.

It's also important to watch out for "phantom loads." A phantom load is an electric device that continues to draw power even though the device is not considered "on." A good example of this is a VCR or stereo. Even though it may not be in use, a small light or clock is running and drawing power. This might seem insignificant, but because it is running 24 hours a day, seven days a week, it can drain a noticeable amount of power from your batteries. To prevent phantom loads from draining your batteries, use power strips or make sure the appliances you buy do not draw power without your approval.

Inverter and Backup Power

Most remote homes today use inverters to transform the DC power of your PV array and batteries into standard household AC power. This is not to say that all your energy use will or should be in AC form. Inverters generally impose an efficiency penalty of 10 percent to 15 percent. Thus, you may get better performance by running some loads directly on DC power. Your PV provider can help you determine if this would be a good strategy. The most common loads run with DC power are refrigerators and pumps.

Once you've totaled all your energy consumption, your PV provider can help you determine how many PV modules you will need and the size of your inverter and battery backup system. An inverter for a remote system doesn't require the sophisticated electronics necessary to synchronize the power with a utility's power. It doesn't even have to be in the form of a pure sine wave. Inverters that produce "modified square wave" AC power are acceptable. The up-side of these inverters is that they will save you a considerable amount of money. The down-side is that some appliances such as motors, AC refrigerators, clothes washers and microwave ovens run hotter and sometimes noisier when powered by a modified square-wave inverter.

Another feature offered by many home-power inverters is the ability to start up a small generator when you've either been using too much energy or the skies have been dark or cloudy for an extended period. A backup generator allows you to size your battery backup reasonably. If you sized your battery storage to get you through the worst possible week of the worst winter, not only would it be enormous, it would also have higher losses and would require an even larger PV array to maintain it at full charge.

The generator you choose need not be designed to run continuously, since it will be used only to carry you through those very dark weeks of winter or "top off" your batteries. The generator does need to be large enough to both "bulk charge" your batteries and power your home's key electric needs at the same time. Buy a quality generator that has remote turn-on function so the inverter can automatically start the generator when the batteries get too low.

Deep-cycle batteries.

Batteries

Batteries come in a variety of different configurations and styles that are capable of storing tremendous amounts of energy. Unsealed, deep-cycle, lead-acid batteries are the most commonly used because they offer the best storage per dollar. Automobile batteries should never be used, because they are designed for quick infrequent discharges and won't last long if deeply discharged. Your PV provider can help you sort out the various trade-offs between different batteries and issues such as maintenance, temperature, ventilation, storage capacity, discharge rate, physical size and voltage configuration.

Batteries typically are sized to provide three to five days of power under "no-sun" conditions. A lead-acid battery about the size of a large truck battery (some are much larger) will hold about one kilowatt-hour. Thus, if your home uses five kilowatt-hours per day (5,000 wh), you would need about 20 batteries (5 kwh x 4 days of backup /1 kwh per battery = 20 batteries).

Because batteries will wear out, it's important to protect your investment. Your charge controller provides day-to-day battery protection. This electronic device can be set so that your PV array doesn't overcharge the batteries, and so that your batteries do not become too discharged. Unsealed batteries require that you check their water level every few months to prevent hydrogen gas buildup. Batteries should be kept between 60 and 80 degrees Fahrenheit for best performance. To ensure long life, most batteries should never discharged more than 70 percent.

Charge Controllers

Charge controllers are voltage regulators designed to control the charging of your batteries to assure maximum useful life. Power flowing from your solar array must not be allowed to flow directly into your batteries. The charge controller assures that energy is added to the battery at a rate that doesn't harm the battery. If the battery is already fully charged, the charge controller prevents overcharging. Most charge controllers also can be used to disconnect circuits when voltage gets too low, thus protecting your battery from being overly discharged.

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National Center for Appropriate Technology

Lyle Rawlings Photo

Appendix 1

Example load calculation — Medium-sized Home

AC Appliances (120/240 Volt)	Number	X	Watts	X	Avg. hrs/day	=	Avg. Daily EnergyUse
Coffee maker	1	X	600	X	0.2	=	120
60 W lamp	2	X	60	X	3.0	=	360
16 W fluorescent lamp	6	X	16	X	3.0	=	292
Dish washer	1	X	1,200	X	0.5	=	600
Microwave	1	X	900	X	0.1	=	90
Stereo	1	X	60	X	2.0	=	120
27" Color TV	1	X	250	X	1.0	=	250
VCR	1	X	40	X	1.0	=	40
Clock	1	X	10	X	24	=	240
Circulation fan	1	X	100	X	0.125	=	125
Clothes washer	1	X	430	X	0.5	=	215
Miscellaneous (vacuum, blender, etc)	few	X	some	X	a little	=	100
		X		X			
		X		X			
AC Load							2,552

DC Appliances (12/24/48 Volt)	Number	X	Watts	X	Avg. hrs/day	=	Avg. Daily EnergyUse
Refrigerator (16 c.f. Sunfrost)	1	X	120	X	10	=	1,200
Well pump	1	X	100	X	4.0	=	400
		X		X			
		X		X			
DC Load							1,600

Adjusted AC Energy	=	AC Load 2,552	x	1.6	=	4,083
Adjusted DC Energy	=	DC Load 1,600	x	1.4	=	2,240
Total estimated energy needs (add above two values)					=	6,323

Load and array sizing estimation worksheet.

Appendix 2

Typical power use of appliances

Appliances	Watts	Appliances	Watts
Blender	300	**Computer**	
Coffee maker (0.2)	600	Desktop	150
Toaster	800-1,500	Laptop	40
Deep Fryer	1,400	Inkjet Printer	100
Microwave	600-1,500	Monitor - 17"	150
Waffle iron	1,200		
Frying pan	1,200	TV- 20" color	150
Mixer	100	TV- 27" color	250
Slow cooker	200	VCR	40
		CD Player	35
Dish washer - standard	1,200	Stereo	80
Sink waste disposal	450	CB radio	10
Refrigerator (12)		Electric clock	10
24 c.f. w/ice maker 250	250	**Lights - CFL**	
20 c.f. energy efficient 150	150	Incandescent equivalent	
16 c.f. Sunfrost DC 120	120	40-watt equivalent	11
		60-watt equivalent	16
Clothes washer (1) 350	350	75-watt equivalent	20
Clothes dryer - electric	2,200	100-watt equivalent	28
Clothes dryer - gas	350		
		Electric mower	1,500
Garage door opener 350	350	Hedge trimmer or weed eater	450
Ceiling fan 85	85	3/8" drill	300
Table fan 50	50	Drill press	1,000
Electric blanket 800	800	Belt sander	1,200
Blow dryer 1,200	1,200	Electric chain saw	1,100
Shaver 20	20	Circular saw	1,400
Clothes iron 1,000	1,000		
Vacuum cleaner 200-700	200-700	Furnace blower	300-1,000
		Air conditioner - room	1,200
		Air conditioner - central	4,500
		Water heater - electric (2.2)	4,500

Power consumption of typical appliances.