Utility Grid-Tie System Design

Budget, roof dimensions and other site-specific factors often call for custom system design. If you are planning to mount your array on a roof, decide which module best fits into the available roof space, taking into consideration obstructions such as chimneys, plumbing vents and skylights. See Solar Modules, page 20, for dimensions of modules. A grid-connected PV system consists of PV modules, output cables, module mounting structures, AC and DC disconnect switches, inverter(s), grounding equipment and a metering system. This worksheet will help you decide what size PV array would be required to eliminate your electric bill. This will be the largest system that would be cost-effective to install. A smaller system can reduce part of your bill, or eliminate higher cost electricity in locations that have progressively increasing rates as consumption increases. Use this information and the amount of available space to get a rough idea of your PV array size.

PV Array Design Worksheet – Determine the array size for your grid-connected system.

Step 1 Find your monthly average electricity usage from your electric bill. ______

This will be in kilowatt-hours (kWh). Due to air conditioning, heating and other seasonal usage, it is a good idea to look at several bills. You can add the typical summer, fall, winter and spring bills and divide by four to find the average monthly usage.

Step 2 Find your daily average electricity use. ______

Divide the monthly average number of kWh use by 30 (days)

Step 3 Find your location's average peak sun hours per day. ______

See the maps and listings on page 14, and/or the insolation maps beginning page 194. For example, the average for California is 5 peak sun hours

Step 4 Calculate the system size (AC watts) to provide 100% of your electricity. ______

Divide your daily average electricity use by average sun hours per day. For example, if the daily average electricity use is 30 kWh, and the site is in California, system size would be: 30 kWh / 5 h = 6 kW AC. (Multiply kWh by 1000 to get AC watts.)

Step 5 Calculate the number of pv modules required for this system. ______

Divide the system AC watts in Step 4 by the CEC watt rating of the modules to be used, then divide by the inverter efficiency, usually 0.94, and you get the total number of modules required. (Round this number up)

Use table below (continued next page) to determine array size/inverter combinations

This table shows inverter and module combinations for common modules used in grid connected systems. For a given inverter and module combination, the table displays the acceptable number of series strings of modules and the number of modules per string for temperatures between 14ºF and 104ºF. Where the inverter will support more than one string of modules, the table shows the number of modules that can be used with multiple strings. Sizing is accurate in locations where the maximum temperature is lower than 104ºF or the minimum temperature is higher than 14ºF. In locations where the minimum temperature is lower than 14ºF, the maximum number of modules per string may be lower.

In the table on the next page, the line labeled CEC watts is the expected output of the modules at normal operating temperature, in full sun. The approximate power output of a system in full sun will be the number of modules times the CEC rating of the modules times the inverter efficiency from second column on the table. Other factors, such as high or low temperature, shading, array orientation, roof pitch and dirt on the modules, will affect the system's actual output.

			Module >	SolarWorld SW175	REC Solar SCM 220	Evergreen ES-190	Mitsubishi UD185MF5
Inverter		**CEC efficiency**	*CEC >*	**162.7**	**194.0**	**168.8**	**164.7**
Mfg	**Model**		*Ratio >*	**0.930**	**0.882**	**0.888**	**0.890**
			Recommended Number of Modules per String				
SMA	SB700U	91.5%	one string	3 to 5			
	SB3000US	95.5%	one string	7 to 10	9 to 12	10 to 13	11 to 14
			two strings	7 to 10		10	
	SB4000US	96.0%	one string	9 to 12	11 to 14	11 to 16	13 to 17
			two strings	9 to 12		11 to 13	
			three strings	9			
	SB5000US	95.5%	one string	9 to 12	11 to 14	12 to 16	13 to 17
			two strings	9 to 12	11 to 12	12 to 16	13 to 15
			three strings	9 to 10			
	SB6000US	95.5%	one string	9 to 12	11 to 14	12 to 16	13 to 17
			two strings	9 to 12	11 to 14	12 to 16	13 to 17
			three strings	9 to 12		12 to 13	
			four strings	9			
	SB7000US	96.0%	one string	9 to 12	11 to 14	12 to 16	13 to 17
			two strings	9 to 12	11 to 14	12 to 16	13 to 17
			three strings	9 to 12	11	12 to 15	13 to 14
			four strings	9 to 10			
Fronius	IG2000	93.5%	one string	5 to 9	7 to 11	8 to 13	8 to 13
			two strings	5 to 7			
	IG3000	94.0%	one string	5 to 9	7 to 12	8 to 13	8 to 14
			two strings	5 to 9	7	8	8 to 9
			three strings	5 to 6			
	IG4000	94.0%	one string	5 to 9	7 to 12	8 to 13	8 to 14
			two strings	5 to 9	7 to 11	8 to 13	8 to 12
			three strings	5 to 8	7	8	8
			four strings	5 to 6			
			five strings	5			
	IG5100	94.5%	one string	5 to 9	7 to 12	8 to 13	8 to 14
			two strings	5 to 9	7 to 12	8 to 13	8 to 14
			three strings	5 to 9	7 to 9	8 to 10	8 to 10
			four strings	5 to 8	7	8	8
			five strings	5 to 6			
			six strings	5			

			Module >	SolarWorld SW175	REC Solar SCM 220	Evergreen ES-190	Mitsubishi UD185MF5
Inverter		CEC efficiency	*CEC >*	162.7	194.0	168.8	164.7
Mfg	Model		*Ratio >*	0.930	0.882	0.888	0.890
			Recommended Number of Modules per String				
Xantrex	GT 2.8	94.0%	one string	7 to 12	9 to 14	10 to 15	11 to 17
			two strings	7 to 9			
	GT 3.3	94.5%	one string	7 to 12	9 to 14	10 to 15	11 to 17
			two strings	7 to 11	9	10 to 11	
			three strings	7			
	GT 4.0	95.5%	one string	7 to 12	9 to 14	10 to 15	13 to 17
			two strings	7 to 12	9 to 10	10 to 12	13
			three strings	7 to 8			
	GT 5.0	95.5%	one string	9 to 12	9 to 14	12 to 15	13 to 17
			two strings	9 to 12	9 to 13	12 to 15	13 to 16
			three strings	9 to 10			
PV Powered	PVP1100EVR	92.0%	one string	4 to 7	5 to 6	6	6 to 7
	PVP1100SVR	92.5%	one string	5 to 7			
	PVP2000EVR	92.5%	one string	4 to 10	5 to 10	6 to 12	6 to 12
			two strings	4 to 6		6	6
	PVP2000SVR	93.0%	one string	5 to 10	7 to 10	8 to 12	8 to 12
			two strings	5 to 6			
	PVP 2500	93.5%	one string	5 to 10	6 to 12	7 to 13	8 to 14
			two strings	5 to 9		7 to 8	8
	PVP3000SVR	93.0%	one string	6 to 10	8 to 12	9 to 13	9 to 14
			two strings	6 to 10	8	9	9
	PVP 3500	94.0%	one string	7 to 10	9 to 12	10 to 13	11 to 14
			two strings	7 to 10	9	10 to 11	11
			three strings	7 to 8			
	PVP 4800	94.0%	one string	7 to 10	9 to 12	10 to 13	11 to 14
			two strings	7 to 10	9 to 12	10 to 13	11 to 14
			three strings	7 to 10			
			four strings	7 to 8			
	PVP 5200	94.5%	one string	8 to 10	11 to 12	12 to 13	13 to 14
			two strings	8 to 10	11 to 12	12 to 13	13 to 14
			three strings	8 to 10			
			four strings	8			
KACO	1501xi	94%	one string	5 to 8	6 to 9	6 to 10	7 to 11
			two strings	5			
Solectria	PVI1800	92.5%	one string	5 to 8	6 to 9	7 to 10	7 to 11
			two strings	5 to 6			
	PVI2500	93%	one string	5 to 8	6 to 9	7 to 10	7 to 11
			two strings	5 to 8	6 to 7	7 to 9	7 to 8
			three strings	5			

Grid-tie systems with battery backup are configured differently and are much more complex than standard grid-tie systems without batteries. They need to be custom designed. If you need a backup system, consult with us to determine all the system components that you will need.

Inverters for Grid-Tie with Battery Backup

OutBack also makes inverters and switchgear that can be assembled into larger grid-tie w/ battery backup systems.

The new Xantrex XW series of inverters offers grid-tie inverters with battery backup capability in 6000-watt increments. Several can be stacked for 12kW or 18kW battery backup systems.

You can use the following steps to determine the dual-function inverter size and the battery capacity that your system will require. Follow steps 1-5 on the PV Array Design Worksheet on page 8 to determine the size of the array required to provide the desired percentage of total power. Then calculate the inverter size and battery capacity needed using the worksheet below.

Worksheet: Inverter and Batteries for Grid-Tie w/ Backup System

Step 1 Find the power requirements (watts) for the appliances you need to power during a black-out.

Make a list of the loads and appliances that you absolutely need to power during an outage. Only list the essential items since the system size (and cost) will vary widely with power needed. The wattage of individual appliances can usually be found on the back of the appliance or in the owners manual. You can use a Kill-a-Watt meter for better measurements (page 120). If an appliance is rated in amps, multiply amps by the operating voltage (120 or 240) to find watts. Add up the wattage of all the items on your list to arrive at the total amount of watts that you need to run all at the same time. This will determine the size of the dual-function inverter that you will need.

Step 2 Decide the blackout duration you want to be prepared for.

Power outages last from a portion of an hour to a day (or more). Again, this decision will greatly affect the system size and cost, so it is more cost-effective to stay on the conservative side.

Step 3 Find the amount of stored power required.

Multiply the power requirements (in step 1) by duration in hours (in step 2). The result will be in watt-hours. For instance, if you need to power 1000 watts of appliances for 2 hours, you would need to have 2000 watt-hours (or 2 kWh) of stored power.

Step 4 Calculate the power storage needed.

Multiply the figure arrived at in step 3 by 1.7. In the example, 2 kWh X 1.7 = 3.4 kWh of stored power needed.

Step 5 Calculate battery capacity needed.

Divide the power storage requirement needed from step 4 by the DC voltage of the system (usually 48V, but sometimes 24V) to get battery amp-hour (Ah) capacity. See the battery section on page 126 for more information on batteries. Most backup systems use sealed batteries due to their greatly reduced maintenance requirements, and because they can be more easily placed in enclosed battery compartments.

System Sizing Information

The size of a solar electric system depends on the amount of power that is required (watts), the amount of time it is used (hours) and the amount of energy available from the sun in a particular area (sun-hours per day). The user has control of the first two variables, while the third depends on the location.

Conservation

Conservation plays an important role in keeping down the cost of a photovoltaic system. The use of energy-efficient appliances and lighting, as well as non-electric alternatives wherever possible, can make solar electricity a cost-competitive alternative to gasoline generators and, in some cases, utility power.

Cooking, Heating and Cooling

Conventional electric cooking, space heating and water heating equipment use a prohibitive amount of electricity. Electric ranges use 1500 watts or more per burner, so bottled propane or natural gas is a popular alternative to electricity for cooking. A microwave oven has about the same power draw, but since food cooks more quickly, the amount of kilowatt hours used may not be large. Propane and wood are generally better alternatives for space heating. Good passive solar design and proper insulation can reduce the need for winter heating. Evaporative cooling is a more reasonable load than air conditioning and in locations with low humidity, the results are almost as good. One big plus for solar cooling: the largest amount of solar energy is available when the need for cooling is the greatest.

Lighting

Lighting requires the most study since many options exist in type, size, voltage and placement. The type of lighting that is best for one system may not be right for another. The first decision is whether your lights will be run on low voltage direct current (DC) or conventional 110 volt alternating current (AC). In a small home, an RV, or a boat, low voltage DC lighting is often the best choice. DC wiring runs can be kept short, allowing the use of fairly small gauge wire. Since an inverter is not required, the system cost is lower. When an inverter is part of the system, and the lights are powered directly by the battery, a home will not be dark if the inverter fails. In addition to conventional-size medium-base low voltage bulbs, the user can choose from a large selection of DC fluorescent lights, which have 3 to 4 times the light output per watt of power used compared with incandescent types. Halogen bulbs are 30% more efficient and actually seem almost twice as bright as similar wattage incandescents given the spectrum of light they produce. High quality fluorescent lights are available for 12 and 24 volt systems.

In a large installation or one with many lights, the use of an inverter to supply AC power for conventional lighting is cost-effective. AC compact fluorescent lights will save a tremendous amount of energy. It is a good idea to have a DC-powered light in the room where the inverter and batteries are in case there is a problem. AC light dimmers will only function properly on AC power from inverters that have pure sine wave output.

Refrigeration

Gas powered absorption refrigerators are a good choice in small systems if bottled gas is available. Modern absorption refrigerators consume 5-10 gallons of LP gas/month. If an electric refrigerator will be used in a standalone system, it should be a high-efficiency type. Some high-efficiency conventional AC refrigerators use as little as 1200 watt-hours of electricity/day at a 70º average air temperature. A comparably sized Sun Frost refrigerator/freezer uses half that amount of energy and a SunDanzer refrigerator (without a freezer) uses less than 100 watt-hours per day. The higher cost of good quality DC refrigerators is offset by savings in the number of solar modules and batteries required.

Major Appliances

Standard AC electric motors in washing machines, larger shop machinery and tools, swamp coolers, pumps, etc. (usually 1/4 to 3/4 horsepower) require a large inverter. Often, a 2000 watt or larger inverter will be required. These electric motors are sometimes hard to start on inverter power, they consume relatively large amounts of electricity, and they are very wasteful compared to high-efficiency motors, which use 50% to 75% less electricity. A standard washing machine uses between 300 and 500 watt-hours per load, but new front-loading models use less than 1/2 as much power. If the appliance is used more than a few hours per week, it is often cheaper to pay more for a high-efficiency appliance rather than make your electrical system larger to support a low-efficiency load. Vacuum cleaners usually consume 600 to 1,000 watts, depending on how powerful they are, about twice what a washer uses, but most vacuum cleaners will operate on inverters larger than 1,000 watts since they have low-surge motors.

Small Appliances

Many small appliances such as irons, toasters and hair dryers consume a very large amount of power when they are used but by their nature require very short or infrequent use periods. If the system inverter and batteries are large enough, they will be usable. Electronic equipment, such as stereos, televisions, VCRs and computers have a fairly small power draw. Many of these are available in low voltage DC as well as conventional AC versions. In general, DC models use less power than their AC counterparts.

Off-Grid Load Worksheet

Determine the total energy in amp-hours per day used by all the AC and DC loads in your system.

Calculate your AC loads

If there are no AC loads, skip to Step 5

1. List all AC loads, wattage and hours of use per week in the spaces provided. Multiply watts by hours/week to get watt-hours per week (WH/Wk). Add up all the watt hours per week to determine AC watt-hours per week. Use a separate sheet of paper if you need to list more loads than the space below allows

NOTE: Wattage of appliances can usually be determined from tags on the back of the appliance or from the owner's manual. If an appliance is rated in amps, multiply amps by operating voltage (120 or 240) to find watts.

Description of AC loads run by inverter	watts	x	hours/week	=	watt-hours/week
	Total watt-hours/week				

2. Convert to DC watt-hours per week. Multiply line 1 by 1.15 to correct for inverter loss. ______________
3. Inverter DC input voltage; usually 12-, 24- or 48-volts. This is DC system voltage. ______________
4. Divide line 2 by line 3. This is total DC amp-hours per week used by AC loads. ______________

Calculate your DC loads

5. List all DC loads in the table below. If you have no DC loads, enter "0" in line 7 and proceed to line 8. ______________
6. DC system voltage. Usually 12, 24, or 48 volts. ______________
7. Find total amp-hours per week used by DC loads: divide line 5 by line 6. ______________
8. Total amp-hours per week used by AC loads from line 4. ______________
9. Add lines 7 and 8. This is total amp-hours per week used by all loads. ______________
10. Divide line 9 by 7 days. This is total average amp-hours per day that needs to be supplied by the battery. ______________

Enter this number on line 1 on the Number-of-Modules Worksheet on page 14, and on line 1 of the Battery Sizing Worksheet on page 129.

Description of DC loads	watts	x	hours/week	=	watt-hours/week
	Total watt-hours / week				

Solar Array Sizing Worksheet - Off-Grid Systems

Use this worksheet to calculate the total number of solar modules required for your system if you are using a non-MPPT charge controller. If you are using an MPPT type charge controller, do steps 1-4 on this worksheet, then move to step 5 on the next page.

To find average sun-hours per day in your area (line 3), check local weather data, look at the map below or find a city on the page 194 that has similar weather to your location. If you want year- round autonomy, use the lower of the two figures. If you want 100% autonomy only in summer, use the higher figure. If you have a utility grid-tie system with net metering, use the yearly average figure. The peak amperage of the module you will be using can be found in the module specifications. You can also get close enough if you divide the module's rated wattage by the peak power point voltage, usually 17 to 17.5 for a 12-volt module or 34 to 35 volts for a 24-volt module.

Step 1 Total average amp-hours per day needed (line 10 of the Off-Grid Loads Worksheet, page 13) ________

Step 2 Multiply line 1 by 1.2 to compensate for loss from battery charge / discharge ________

Step 3 Average sun-hours per day in your area ________

Step 4 Divide line 2 by line 3. This is the total solar array amps required ________

Step 5 Peak-Power amps of solar module used. See module specifications ________

Step 6 Total number of solar modules in parallel required. Divide line 4 by 5 ________

Step 7 Round off to the next highest whole number ________

Step 8 Number of modules in each series string to provide DC battery voltage – see table below ________

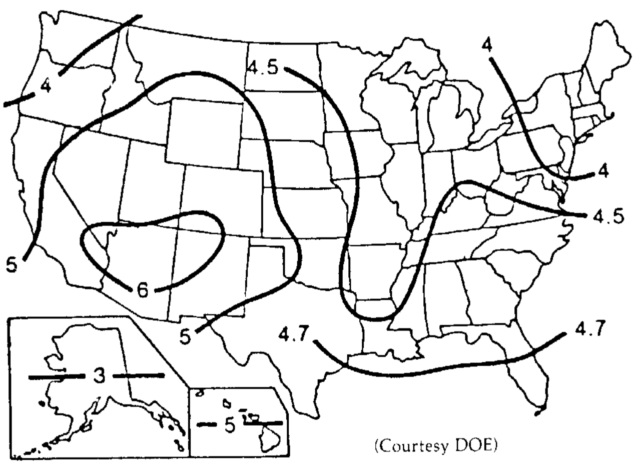
Step 9 Multiply line 7 by line 8 to get the total number of solar modules required. ________

Nominal System Voltage	Number of Series Connected Modules per String	
Volts	12V module	24V module
12	1	N/A
24	2	1
48	4	2

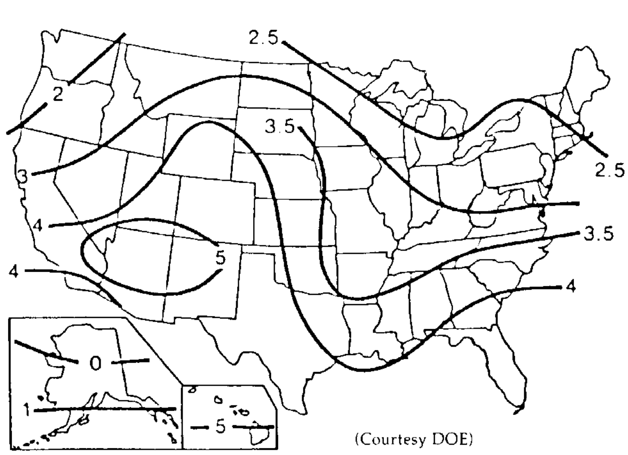
The maps below show sun-hours per day for the U.S.

See world insolation maps (and a larger version of the USA map) beginning page 194.

Yearly Average



Four-Week Average, 12/7-1/4



Solar Array Sizing Worksheet for use with MPPT Charge Controllers

Begin on page 14, steps 1 - 4 before starting on this page.

Step 5 Total solar array amps required from Step 4 of module worksheet for standard controllers. ________

Step 6 Enter average changing voltage: use 13.5V for 12V systems; use 27V for 24V systems; use 54V for 48V systems. ________

Step 7 Multiply Step 5 result by Step 6 result. This is the total PV array wattage required. ________

Step 8 Enter the peak power wattage of the chosen PV module. (Use the module's Peak Power wattage at STC.) ________

Step 9 Divide the wattage on Step 7 by the wattage on Step 8. **This is the total number of modules needed**. Round up to the nearest whole number. (NOTE: this number may need to be adjusted in Step 11.) ________

Step 10 Number of modules in each series string. See table below, and add number here. ________

Table for 150VDC maximum controllers. (For controllers with other max voltages, see controller instructions.)			
Module	**12V**	**24V**	**48V**
Evergreen ES	1 to 3	2 or 3	3
REC SCM-210	1 to 3	2 or 3	3
SolarWorld SW175	1 to 2	1 to 2	2
Mitsubishi UD185MF5	1 to 3*	2 to 3*	3*
12V nominal modules	1 to 5	3 to 5	4 to 5
12V nominal modules w/ Apollo controllers	2 to 5	3 to 5	5

*In climates that never have freezing temperatures below 10°F, four Mitsubishi 185UD5 modules may be used in series

Step 11 Divide the number of total modules in Step 9 by the number of modules per series string from Step 10. This is the total number of array series strings. If this is not a whole number, either increase or decrease the number of modules in Step 9 to obtain a whole number of series strings. CAUTION: decreasing the total number of modules may result in insufficient power production. ________

Step 12 Determine wattage of each series string. Multiply module wattage from Step 8 by number of modules per string on Step 10. This is the total wattage per string. ________

Step 13 Determine number of module strings per controller. Divide appropriate wattage figure from the chart below by the wattage per string from Step 12. Round down to a whole number. This is the total number of module strings per controller. If you have more module strings (from Step 11) than can be handled by the chosen controller, either use a larger controller, or use multiple controllers. ________

Step 14 Divide total number of strings from Step 11 by the number of strings per controller from Step 13. Round up to a whole number. This is the total number of chosen controllers needed. ________

Maximum watts that can be used with an MPPT controller			
Controller amp rating	**System nominal voltage**		
	12V	**24V**	**48V**
15A	200W	400W	800W
30A	400W	800W	1600W
50A	650W	1300W	2600W
60A	750W	1500W	3000W
80A	1000W	2000W	4000W