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Solar Basics

PV power generation systems are made up of interconnected components, each with a specific function. One of the major strengths of PV systems is modularity. As your needs grow, individual components can be replaced or added to provide increased capacity. Following is a brief overview of a typical PV system.

Solar Array – The solar array consists of one or more PV modules which convert sunlight into electric energy. The modules are connected in series and/or parallel to provide the voltage and current levels to meet your needs. The array is usually mounted on a metal structure and tilted to face the sun.

Charge Controller – Although charge controllers can be purchased with many optional features, their main function is to maintain the batteries at the proper charge level, and to protect them from overcharging.

Battery Bank – The battery bank contains one or more deep-cycle batteries, connected in series and/or parallel depending on the voltage and current capacity needed. The batteries store the power produced by the solar array and discharge it when required.

Inverter – An inverter is required when you want to power AC devices. The inverter converts the DC power from the solar array/batteries into AC power.

AC and DC Loads – These are the appliances (such as lights or radios), and the components (such as water pumps and microwave repeaters), which consume the power generated by your PV array.

Balance of System – These components provide the interconnections and standard safety features required for any electrical power system. These include: array combiner box, properly sized cabling, fuses, switches, circuit breakers and meters.

Five Steps to Sizing a PV System

We have provided you with an easy-to-follow, step-by-step guide for sizing your photovoltaic (PV) system. Follow these five steps to determine your requirements and specify the components you will need.

1. Determine Your Power Consumption Demands

Make a list of the appliances and/or loads you are going to run from your PV system. Find out how much power each item consumes while operating. Most appliances have a label on the back which lists the wattage. Specification sheets, local appliance dealers, and the product manufacturers are other sources of information. Once you have the wattage ratings, fill out the load sizing worksheet.

Load-Sizing Worksheet

List all of the electrical appliances to be powered by your PV system. Separate AC and DC devices and enter them in the appropriate table. Record the operating wattage of each item. Most appliances have a label on the back that lists the wattage. Local appliance dealers and the product manufacturers are other sources of this information. Specify the number of hours per day each item will be used. Multiply the first three columns to determine the watt-hour usage per day. Enter the number of days per week you will be using each item to determine the total watt-hours per week each appliance will require.

	DC Appliance	Watts	X	Qty	X	Hrs/Day	=	Wh/Day	X	Days/Wk	=	Wh/Wk
A.												
B.												
C.												
D.												
E.												

Total the numbers in the last column. This is your DC power requirement. Total _______

Multiply the total by 1.2 to compensate for system losses during battery charge/discharge cycle. DC WH/WK _______

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... Power Consumption *continued*

Load Sizing Worksheet

	AC Appliance	Watts	X	Qty	X	Hrs/Day	=	Wh/Day	X	Days/Wk	=	Wh/Wk
A.												
B.												
C.												
D.												
E.												

Total the numbers in the last column. This is your AC power requirement. Total ______

Multiply the total by 1.2 to compensate for system losses during battery charge/discharge cycle. AC WH/WK ______

1. Add AC WH/WK and DC WH/WK together. This is your total power requirement per week. Total _______
2. Enter the voltage of your battery bank (usually 12 or 24 volts) VOLTS _______
3. Divide line 1 by line 2. This is your amp-hour requirement per week. AH/WK _______
4. Divide line 3 by 7 days. This is your average amp-hour requirement per day that will be used to size your battery bank and your PV module array. AH/DAY _______

2. Optimize Your Power System Demands

At this point, it is important to examine your power consumption and reduce your power needs as much as possible. (This is true for any system, but it is especially important for home and cabin systems, because the cost savings can be substantial.) First identify large and/or variable loads (such as water pumps, outdoor lights, electric ranges, AC refrigerators, clothes washers, etc.) and try to eliminate them or examine alternatives such as propane or DC models. The initial cost of DC appliances tends to be higher than AC, but you avoid losing energy in the DC to AC conversion process, and typically DC appliances are more efficient and last longer. Replace incandescent fixtures with fluorescent lights wherever possible. Fluorescent lamps provide the same level of illumination at lower wattage levels. If there is a large load that you cannot eliminate, consider using it only during peak sun hours or only during the summer. (In other words, be creative!) Revise your Load Sizing Worksheet now with your optimized results.

3. Size Your Battery Bank

Read “Characteristics of Batteries” and then choose the appropriate battery for your needs.
Fill out the Battery Sizing Worksheet.

Characteristics of Batteries

Sizing Your Battery Bank
The first decision you need to make is how much storage you would like your battery bank to provide. Often this is expressed as “days of autonomy,” because it is based on the number of days you expect your system to provide power without receiving an input charge from the solar array. In addition to the days of autonomy, you should also consider your usage pattern and the criticality of your application. If you are installing a system for a weekend home, you might want to consider a larger battery bank, because your system will have all week to charge and store energy. Alternatively, if you are adding a PV array as a supplement to a generator-based system, your battery bank can be slightly undersized since the generator can be operated if needed for recharging.

Temperature Effects
Batteries are sensitive to temperature extremes, and you cannot take as much energy out of a cold battery as a warm one. Use the chart on the Battery-Sizing Worksheet to correct for temperature effects. Although you can get more than rated capacity from a hot battery, operation at hot temperatures will shorten battery life.

■■■ Battery Bank *continued*

Temperature Effects *continued*
Try to keep your batteries near room temperature. Charge controllers can be purchased with a temperature compensation option to optimize the charging cycle at various temperatures and lengthen your battery life.

Depth of Discharge
Depth of Discharge is the percentage of the rated battery capacity that is withdrawn from the battery. The capability of a battery to withstand discharge depends on its construction. Two terms, shallow-cycle and deep-cycle, are commonly used to describe batteries. Shallow-cycle batteries are lighter, less expensive and have a short lifetime. For this reason, we do not sell shallow-cycle batteries. Deep-cycle batteries should always be used for stand-alone PV systems. These units have thicker plates and most will withstand daily discharges up to 80% of their rated capacity. Most deep-cycle batteries are flooded electrolyte which means the plates are covered with the electrolyte and the level of fluid must be monitored and distilled water added periodically to keep the plates fully covered. We also offer sealed, lead-acid batteries that do not require liquid refills. There are other types of deep-cycle batteries such as nickel cadmium used in special applications. The maximum depth of discharge value used for sizing should be the worst case discharge that the battery will experience. The system control should be set to prevent discharge below this level.

Rated Battery Capacity
The ampere-hour capacity of a battery is usually specified together with some standard hour reference such as ten or twenty hours. For example, suppose the battery is rated at 100 ampere-hours and a 20-hour reference is specified. This means the battery is fully charged and will deliver a current of 5 amperes for 20 hours. If the discharge current is lower, for example 4.5 amperes, then the capacity will go to 110 ampere-hours. The relationship between the capacity of a battery and the load current can be found in the manufacturer's literature.

Battery Life
The lifetime of any battery is difficult to predict, because it is dependent on a number of factors such as charge and discharge rate, depth of discharge, number of cycles and operating temperature extremes. It would be unusual for a lead-acid battery to last longer than fifteen years in a PV system but many last for five to eight years.

Maintenance
Batteries require periodic maintenance. Even the sealed battery should be checked to make sure connections are tight and there is no indication of overcharging. For flooded batteries, the electrolyte level should be maintained well above the plates and the voltage and specific gravity of the cells should be checked for consistent values. Wide variations between readings may indicate cell problems. The specific gravity of the cells should be checked with a hydrometer particularly before the onset of winter. In cold environments, the electrolyte in lead-acid batteries may freeze. The freezing temperature is a function of a battery state of charge. When a battery is completely discharged, the electrolyte becomes water and the battery may freeze.

Battery Sizing Worksheet

1. Enter your daily amp-hour requirement. (From the Load Sizing Worksheet, line 4)	AH/Day	_______________
2. Enter the maximum number of consecutive cloudy weather days expected in your area, or the number of days of autonomy you would like your system to support.		_______________
3. Multiply the amp-hour requirement by the number of days. This is the amount of amp-hours your system will need to store.	AH	_______________
4. Enter the depth of discharge for the battery you have chosen. This provides a safety factor so that you can avoid over-draining your battery bank. (Example: If the discharge limit is 20%, use 0.2.) This number should not exceed 0.8.		_______________
5. Divide line 3 by line 4.	AH	_______________

■■■ Battery Bank *continued*

Battery-Sizing Worksheet

6. Select the multiplier below that corresponds to the average wintertime ambient temperature your battery bank will experience. _______________

Ambient Temperature		Multiplier
80F	26.7C	1.00
70F	21.2C	1.04
60F	15.6C	1.11
50F	10.0C	1.19
40F	4.4C	1.30
30F	-1.1C	1.40
20F	-6.7C	1.59

7. Multiply line 5 by line 6. This calculation ensures that your battery bank will have enough capacity to overcome cold weather effects. This number represents the total battery capacity you will need. AH _______________

8. Enter the amp-hour rating for the battery you have chosen. _______________

9. Divide the total battery capacity by the battery amp-hour rating and round off to the next highest number. This is the number of batteries wired in parallel required. _______________

10. Divide the nominal system voltage (12V, 24V or 48V) by the battery voltage and round off to the next highest number. This is the number of batteries wired in series. _______________

11. Multiply line 9 by line 10. This is the total number of batteries required. _______________

4. Determine The Sun Hours Available Per Day

Several factors influence how much sun power your modules will be exposed to:

- When you will be using your system – summer, winter, or year-round.
- Typical local weather conditions.
- Fixed mountings vs. trackers.
- Location and angle of PV array.

We have provided the following charts which show ratings that reflect the number of hours of full sunlight available to generate electricity. Your solar array's power generation capacity is dependent on the angle of the rays as they hit the modules. Peak power occurs when the rays are at right angles or perpendicular to the modules. As the rays deviate from perpendicular, more and more of the energy is reflected rather than absorbed by the modules. Depending on your application, sun tracking mounts can be used to enhance your power output by automatically positioning your array.

The charts reflect the difference in sunlight during spring, summer, autumn and winter. It is more difficult to produce energy during the winter because of shorter days, increased cloudiness and the sun's lower position in the sky. The charts list the sun hour ratings for several cities in North America for summer, winter and year round average. If you use your system primarily in the summer, use the summer value; if you are using your system year-round, especially for a critical application, use the winter value. If you are using the system most of the year (spring, summer and fall) or the application is not critical, use the average value. Between the chart and the map, you should be able to determine a reasonable estimate of the sun's availability in your area.

SUN HOURS PER DAY - NATIONAL

State, City	Summer Avg.	Winter Avg.	Yr. Round Avg
AL, Montgomery	4.69	3.37	4.23
AK, Bethel	6.29	2.37	3.81
AK, Fairbanks	5.87	2.12	3.99
AK, Mantanuska	5.24	1.74	3.55
AZ, Page	7.30	5.65	6.36
AZ, Phoenix	7.13	5.78	6.58
AZ, Tucson	7.42	6.01	6.57
AR, Little Rock	5.29	3.88	4.69
CA, Davis	6.09	3.31	5.10
CA, Fresno	6.19	3.42	5.38
CA, Inyokem	8.70	6.97	7.66
CA, La Jolla	5.24	4.29	4.77
CA, Los Angeles	6.14	5.03	5.62
CA, Riverside	6.35	5.35	5.87
CA, Santa maria	6.52	5.42	5.94
CA, Soda Springs	6.47	4.40	5.60
CO, Boulder	5.72	4.44	4.87
CO, Granby	7.47	5.15	5.69
CO, Grand Junction	6.34	5.23	5.86
CO, Grand Lake	5.86	3.56	5.08
D.C. Washington	4.69	3.37	4.23
FL, Apalachicola	5.98	4.92	5.49

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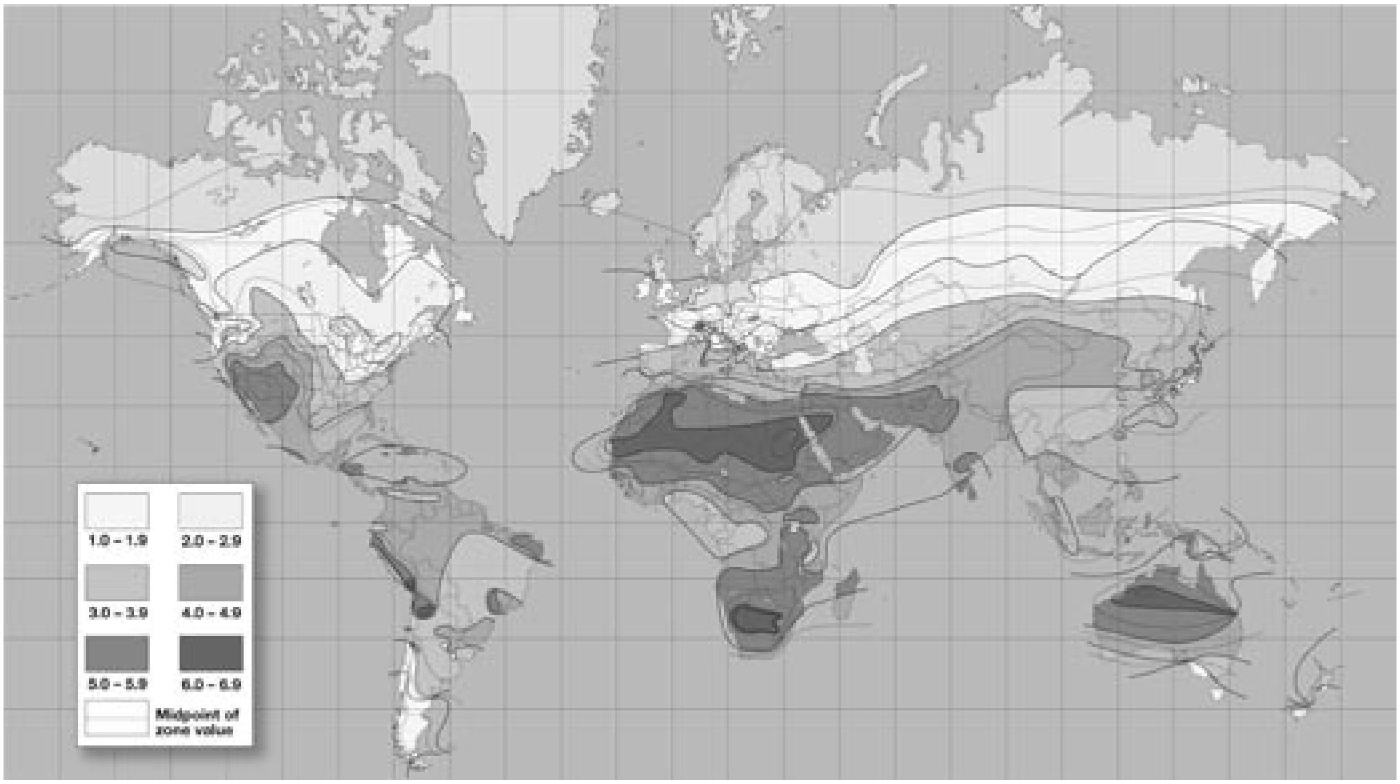
Sun Hours Per Day - National *continued*

State, City	Summer Avg.	Winter Avg.	Yr Round Avg.
FL, Belle Island	5.31	4.58	4.99
FL, Gainsville	5.81	4.71	5.27
FL, Miami	6.26	5.05	5.62
FL, Tampa	6.16	5.26	5.67
GA, Atlanta	5.16	4.09	4.74
GA, Griffin	5.41	4.26	4.99
HI, Honolulu	6.71	5.59	6.02
IA, Ames	4.80	3.73	4.40
ID, Twin Falls	5.42	3.41	4.70
ID, Boise	5.83	3.33	4.92
IL, Chicago	4.08	1.47	3.14
IN, Indianapolis	5.02	2.55	4.21
KS, Dodge City	4.14	5.28	5.79
KS, Manhattan	5.08	3.62	4.57
KY, Lexington	5.97	3.60	4.94
LA, Lake Charles	5.73	4.29	4.93
LA, New Orleans	5.71	3.63	4.92
LA, Shreveport	4.99	3.87	4.63
MA, Blue Hill	4.38	3.33	4.05
MA, Boston	4.27	2.99	3.84
MA, E. Wareham	4.48	3.06	3.99
MA, Lynn	4.60	2.33	3.79
MA, Natick	4.62	3.09	4.10
MD, Silver Hill	4.71	3.84	4.47
ME, Caribou	5.62	2.57	4.19
ME, Portland	5.2	3.56	4.51
MI, E. Lansing	4.71	2.70	4.00
MI, Sault Ste. Marie	4.83	2.33	4.20
MN, St. Cloud	5.43	3.53	4.53
MO, Columbia	5.5	3.97	4.73
MO, St. Louis	4.87	3.24	3.78
MS, Meridian	4.86	3.64	4.44
MT, Glasgow	5.97	4.09	5.15
MT, Great Falls	5.70	3.66	4.93
MT, Summit	5.17	2.36	3.99
NC, Cape Hatteras	5.81	4.69	5.31
NC, Greensboro	5.05	4.00	4.71
ND, Bismark	5.48	3.97	5.01
NE, Lincoln	5.40	4.38	4.79
NE, North Omaha	5.28	4.26	4.90
NJ, Sea Brook	4.76	3.20	4.21
NM, Albuquerque	7.16	6.21	6.77
NV, Ely	6.48	5.49	5.98
NV, Las Vegas	7.13	5.83	6.41
NY, Bridgehampton	3.93	1.62	3.16
NY, Ithaca	4.57	2.29	3.79
NY, New York	4.97	3.03	4.08
NY, Rochester	4.22	1.58	3.31
NY, Schenectady	3.92	2.53	3.55
OH, Cleveland	4.79	2.69	3.94
OH, Columbus	5.26	2.66	4.15
OK, Oklahoma City	6.26	4.98	5.59
OK, Stillwater	5.52	4.22	4.99
OR, Astoria	4.76	1.99	3.72
OR, Corvallis	5.71	1.90	4.03
OR, Medford	5.84	2.02	4.51

State, City	Summer Avg.	Winter Avg.	Yr Round Avg.
PA, Pittsburgh	4.19	1.45	3.28
PA, State College	4.44	2.78	3.91
RI, Newport	4.69	3.58	4.23
SC, Charleston	5.72	4.23	5.06
SD, Rapid City	5.91	4.56	5.23
TN, Nashville	5.20	3.14	4.45
TN, Oak Ridge	5.06	3.22	4.37
TX, Brownsville	5.49	4.42	4.92
TX, El Paso	7.42	5.87	6.72
TX, Port Worth	6.00	4.80	5.83
TX, Midland	6.33	5.23	5.83
TX, San Antonio	5.88	4.65	5.30
UT, Flaming Gorge	6.63	5.48	5.83
UT, Salt Lake City	6.09	3.78	5.26
VA, Richmond	4.50	3.37	4.13
WA, Prosser	6.21	3.06	5.03
WA, Pullman	6.07	2.90	4.73
WA, Richland	6.13	2.01	4.43
WA, Seattle	4.83	1.60	3.57
WA, Spokane	5.53	1.16	4.48
WV, Charleston	4.12	2.47	3.65
WI, Madison	4.85	3.28	4.29
WY, lander	6.81	5.50	6.06
Province, City			
Alberta, Edmonton	4.95	2.13	3.75
Alberta, Suffield	5.19	2.75	4.10
British Columbia, Kamloops	4.48	1.46	3.29
British Columbia, Prince George	4.13	1.33	3.14
British Columbia, Vancouver	4.23	1.33	3.14
Manitoba, The Pas	5.02	2.02	3.56
Manitoba, Winnipeg	5.23	2.77	4.02
New Brunswick, Fredericton	4.23	2.54	3.56
Newfoundland, Goose Bay	4.65	2.02	3.33
Newfoundland, St. Johns	3.89	1.83	3.15
Northwest Territory, Fort Smith	5.16	0.88	3.29
Northwest Territory, Norman Wells	5.04	0.06	2.89
Nova Scotia, Halifax	4.02	2.16	3.38
Ontario, Ottawa	4.63	2.35	3.70
Ontario, Toronto	3.98	2.13	3.44
Prince Edward Isl., Charlottetown	4.31	2.29	3.56
Quebec, Montreal	4.21	2.29	3.50
Quebec, Sept-Isles	4.29	2.33	3.50
Saskatchewan, Swift Current	5.25	2.77	4.23
Yukon, Whitehorse	4.81	0.69	3.10

World Insolation Map



This map divides the world into six solar performance regions based on winter peak sun hours in the worst case month. A larger map in full color is located on the back cover of this catalog.

5. Size Your Array

1. Enter your daily amp-hour requirement (from your Load Sizing Worksheet, line 4) AH/Day _______________
2. Enter the sun-hours per day for your area. Refer to chart. H/Day _______________
3. Divide line 1 by line 2. This is the total amperage required from your solar array. _______________
4. Enter the peak amperage of the solar module you have selected Peak A _______________
5. Divide line 3 by line 4. This is the number of solar modules needed in parallel. _______________
6. Select the required modules in series from the following chart. _______________

Battery Bank Voltage	No. of Modules in Series
12V	1
24V	2
48V	4

7. Multiply line 5 by line 6 to find the total number of modules needed in your array. Total _______________
8. Enter the nominal power rating (in watts) of the module you have chosen. W _______________
9. Multiply line 7 by line 8. This is the nominal power output of your system. W _______________