Battery Information And Sizing

All stand-alone and battery backup PV systems require battery storage. Photovoltaic modules charge the batteries during daylight hours and the batteries supply the power when it is needed, often at night and during cloudy weather. Utility intertie systems supply power directly to the utility grid; no battery storage is needed. The two most common types of rechargeable batteries in use today are lead-acid and alkaline. Lead acid batteries have plates made of lead, mixed with other materials, submerged in a sulfuric acid solution. We do not list nickel-cadmium batteries in this catalog because of their high cost and environmental problems related to disposal. Nickel-Metal Hydride and Lithium Ion batteries look promising for the future, but at this time their price is much too high for the size needed for all but the smallest of remote lighting systems.

Battery Size

The size of the battery bank required depends on the storage capacity required, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used. When designing a power system, all of these factors are looked at and the one requiring the largest capacity will dictate battery size.Temperature has a significant effect on lead-acid batteries. At 40°F they will have 75% of rated capacity, and at 0°F their capacity drops to 50%. The storage capacity of a battery, the amount of electrical energy it can hold, is usually expressed in amp-hours. If one amp is used for 100 hours, then 100 amp-hours have been used. A battery in a PV power system should have sufficient amp-hour capacity to supply needed power during the longest expected period of cloudy weather. A lead-acid battery should be sized at least 20% larger than this amount. If there is a source of backup power, such as a standby generator with a battery charger, the battery bank does not have to be sized for worst-case weather conditions.

Lead-Acid Batteries

Lead-acid batteries are the most common in PV systems because their initial cost is lower and because they are readily available nearly everywhere in the world. There are many different sizes and designs of lead-acid batteries, but the most-important designation is whether they are deep-cycle batteries or shallow-cycle batteries. Shallow cycle batteries, like the starting batteries in automobiles, are designed to supply a large amount of current for a short time and to stand mild overcharge without losing electrolyte. But they cannot tolerate being deeply discharged. If they are repeatedly discharged more than 20% their life will be very short. These batteries are not a good choice for a PV system. Deep cycle batteries are designed to be repeatedly discharged by as much as 80% of their capacity so they are a good choice for PV systems. Even though they are designed to withstand deep cycling, these batteries will have a longer life if the cycles are shallower. All lead-acid batteries fail prematurely when they are not recharged completely after each cycle. Letting a lead-acid battery stay in a discharged condition for days at a time will cause a permanent loss of capacity. Sealed deep-cycle lead-acid batteries (gel cells and absorbed glass mat) are maintenance free. They never need watering or an equalization charge. Sealed batteries require very accurate regulation to prevent over-charge and overdischarge. Either of these conditions will drastically shorten their lives. We recommend sealed batteries for remote, unattended power systems.

Caring For Lead-Acid Batteries

Always use extreme caution when handling batteries and electrolyte . Wear gloves, goggles and old clothes. “Battery acid” will burn skin and eyes and destroy cotton and wool clothing.

The quickest way to ruin lead-acid batteries is to discharge them deeply and let them stand “dead” for an extended period of time. The positive plates change from lead oxide when charged to lead sulfate when discharged. If they remain in the lead sulfate state for a few days, part of the plate does not return to lead oxide when the battery is recharged. The parts of the plates that become “sulfated” no longer store energy.

Batteries that are deeply discharged and then charged partially on a regular basis can fail in less than one year. Check your batteries on a regular basis to be sure they are getting charged. Use a hydrometer to check the specific gravity of your lead-acid batteries. If batteries are cycled very deeply and then recharged slowly, the specific gravity reading will be lower because of incomplete mixing of electrolyte. Check the electrolyte level in wet-cell batteries at least four times a year and top-off each cell with distilled water. Do not add water to discharged batteries. Electrolyte is absorbed when batteries are discharged. If you add water at this time and then recharge the battery, electrolyte will overflow and make a mess. Keep the tops of your batteries clean and check that cables are tight. Do not tighten or remove cables while charging or discharging. Any spark around batteries can cause a hydrogen explosion inside, and ruin one of the cells, and you. It is a good idea to do an equalizing charge when some cells show a variation of 0.05 specific gravity from each other. This is a long steady overcharge, bringing the battery to a gassing or bubbling state. Do not equalize sealed or gel-type batteries.

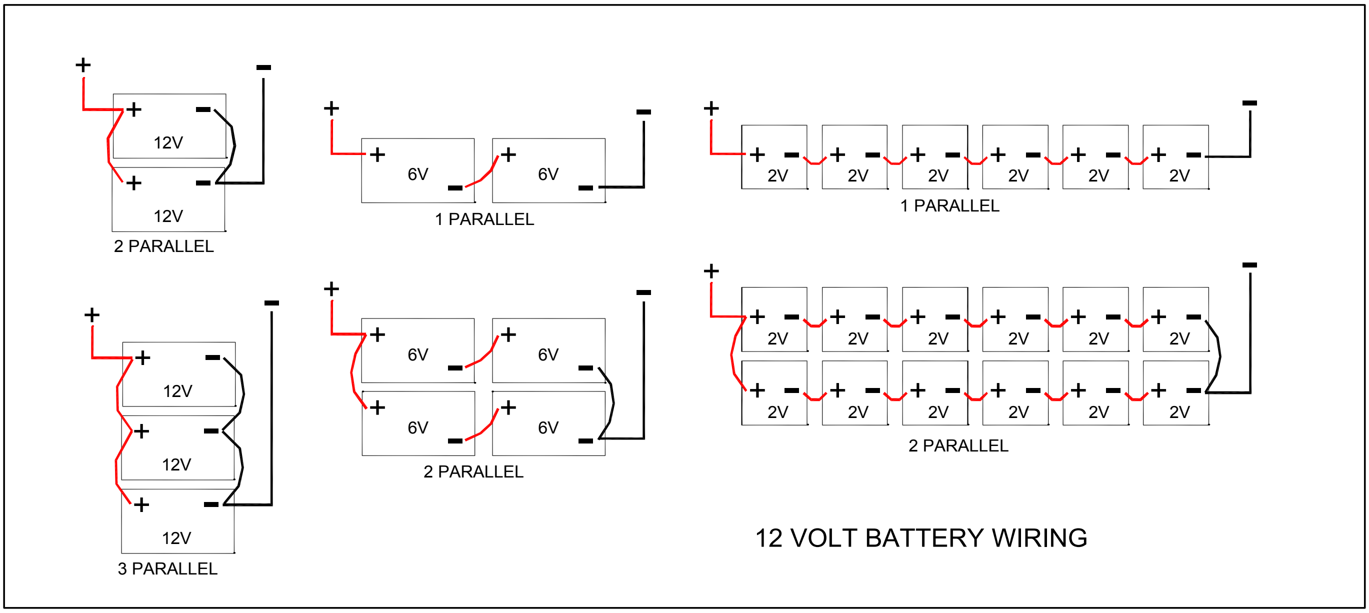
With proper care, lead-acid batteries will have a long service life and work very well in almost any power system. With poor treatment lead-acid battery life will be very short.

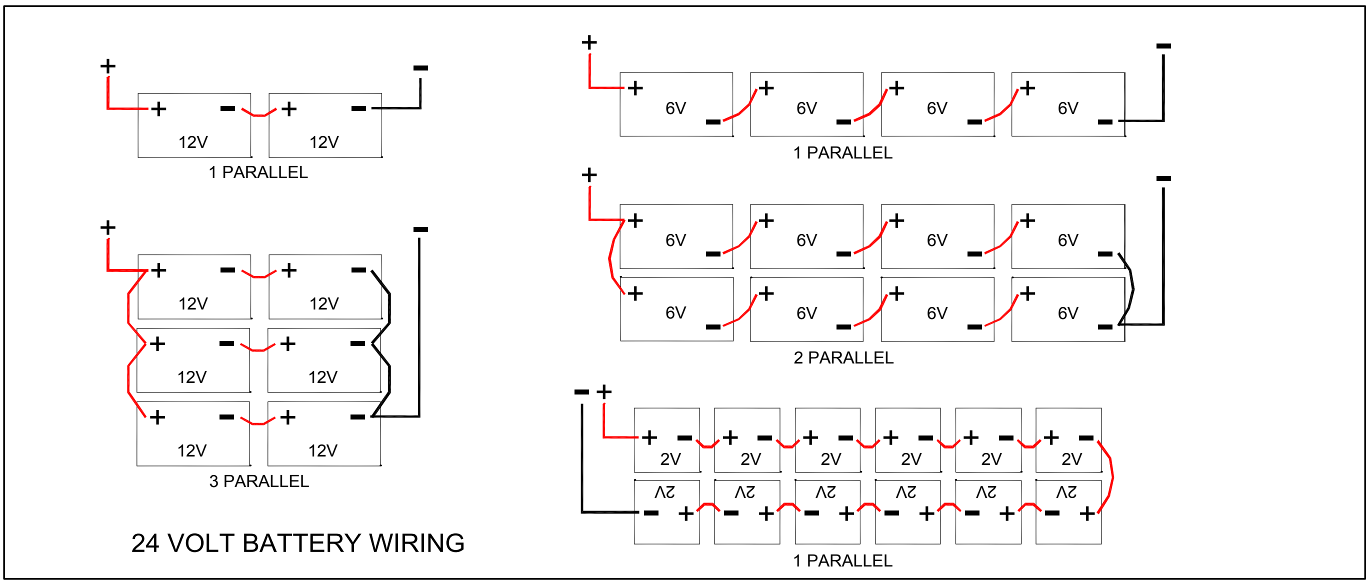
We strongly recommend the use of an amp-hour meter with all battery systems. See pages 78 and 79.

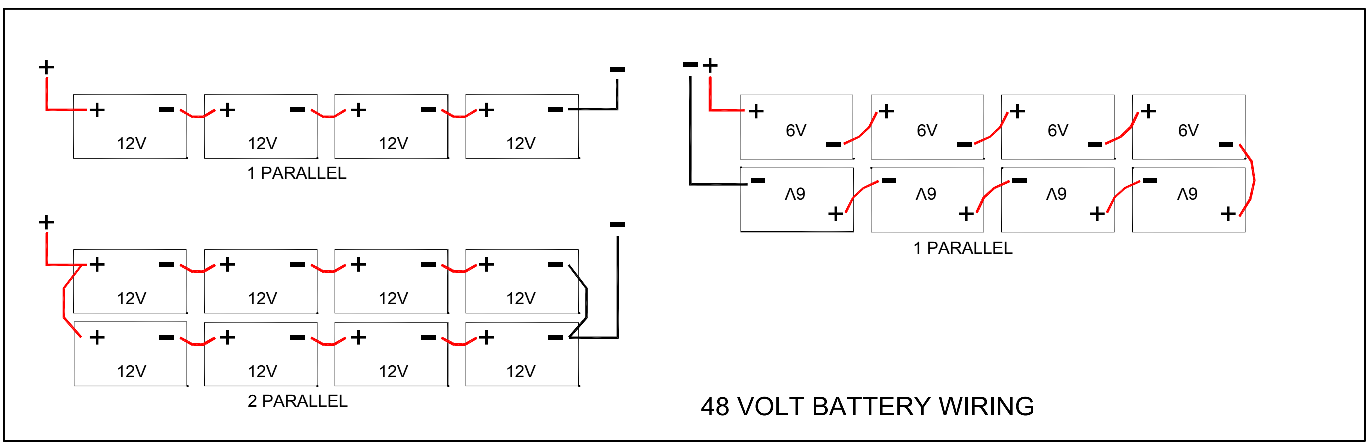
BATTERY WARRANTIES DO NOT COVER DAMAGE DUE TO POOR MAINTENANCE OR LOSS OF CAPACITY FROM SULFATION

BATTERY WIRING DIAGRAMS

The diagrams below show typical 12, 24 and 48 volt battery wiring configurations. Batteries can deliver extremely high current. Always install fuse protection on any positive wiring connected to batteries.







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Battery State-of-Charge

Battery state-of-charge (SOC) can be measured by an amp-hour meter, voltage or by specific gravity. Some care and knowledge is required to interpret state-of-charge from voltage or specific gravity readings. We recommend amp-hour meters for all systems with batteries.

Amp-Hour Meters

An□ -
ies charged. At a glance the user can see system voltage, current, and battery condition. (See the meter section for more information on amp-hour meters.)

Measuring Battery State-of-Charge

Battery voltage will vary for the same state-of-charge depending on whether the battery is being charged or discharged, and what the current flow is in relation to the size of the battery. The chart below will give you an idea of state-of-charge for various battery conditions in flooded cell lead-acid batteries. Voltage varies with temperature. While charging, a lower temperature will increase battery voltage. Full charge voltage on a 12 volt battery is 0.9 volts higher at 32°F than at 70°F. While discharging, a higher temperature will increase battery voltage. There is little temperature effect while a battery is standing.

(This information courtesy of Ralph Heisy, Bogart Engineering.)

Battery Condition @ 77°F	Nominal Battery Voltage		
	12V	24V	48V
Battery during equalization charge	Over 15	Over 30	Over 60
Battery near full charge while charging	14.4 to 15.0	28.8 to 30.0	57.6 to 60.0
Battery near full discharge while charging	12.3 to 13.2	24.6 to 26.4	49.2 to 52.8
Battery fully charged with light load	12.4 to 12.7	24.8 to 25.4	49.6 to 50.8
Battery fully charged with heavy load	11.5 to 12.5	23.0 to 25.0	46.0 to 50
No charge or discharge for 6 hours - 100% charged	12.7	25.4	50.8
No charge or discharge for 6 hours - 80% charged	12.5	25	50
No charge or discharge for 6 hours - 60% charged	12.2	24.4	48.8
No charge or discharge for 6 hours - 40% charged	11.9	23.8	47.6
No charge or discharge for 6 hours - 20% charged	11.6	23.2	46.4
No charge or discharge for 6 hours - Fully discharged	11.4	22.8	45.6
Battery near full discharge while discharging	10.2 to 11.2	20.4 to 22.4	40.8 to 44.8

Hydrometers

A hydrometer is very accurate at measuring battery state-of-charge if you measure the electrolyte near the plates. Unfortunately, you can only measure the electrolyte at the top of the battery. When a battery is being charged or discharged, a chemical reaction takes place at the border between the lead plates and the electrolyte. During charging, the electrolyte changes from water to sulfuric acid. The acid becomes stronger and the specific gravity rises as the battery charges. Near the end of the charging cycle gas bubbles rising through the acid stirs the fluid to mix it. It takes several hours for the electrolyte to mix so that you get an accurate reading at the top of the battery. Always try to take readings after a period of no charge or discharge.

Hydrometer Readings

The chart below shows battery state-of-charge at various specific gravities. These readings are correct at 75 degrees F.

State of Charge	Specific Gravity
100% Charged	1.265
75% Charged	1.239
50% Charged	1.2
25% Charged	1.17
Fully Discharged	1.11

Battery Sizing Worksheet

Use this worksheet to determine what size battery is required for your system. Battery size is measured in amp-hours. This is a measure of battery capacity. Battery voltage is determined by the number of "cells" in series. All lead-acid battery cells have a nominal output of 2 volts. Actual cell voltage varies from about 1.7 volts at full discharge to 2.4 volts at full charge. 12 volt lead-acid batteries are made of 6 separate cells in one case. 6 volt batteries are made of 3 cells in one case. Putting battery cells in parallel increases amp-hour capacity, but does not change voltage.

Battery Temperature	Multiplier
80ºF/26.7ºC	1
70ºF/21.2ºC	1.04
60ºF/15.6ºC	1.11
50ºF/10.0ºC	1.19
40ºF/4.4ºC	1.3
30ºF/-1.1ºC	1.4
20ºF/-6.7ºC	1.59

Step 1 Total average amp-hours per day required from the Systems Load Worksheet, line 9: ________

Step 2 Maximum number of continuous cloudy days expected in your area : ________

Step 3 Multiply line 1 by line 2: ________

Step 4 Divide line 3 by 0.8 to maintain a 20% reserve after deep discharge period. (Divinding line 3 by a more conservative 0.5 will maintain a 50% reserve and increase battery life): ________

If no special conditions below apply, skip to line 9:

Special Condition #1: Heavy Electrical Load

Step 5 Maximum amperage that will be drawn by the loads for 10 minutes or more : ________

Step 6 Multiply line 5 by line 5.0 ________

Special Condition #2: High Charge Current

Step 7 Maximum output amperage of PV array or other battery charger : ________

Step 8 Multiply line 7 by 5.0 hours: ________

Step 9 Amp hours from line 4, 6 or 8, whichever is largest : ________

Step 10 If you are using a lead acid battery, select the multiplier from the Battery Temperature Chart above which corresponds to the battery's wintertime average ambient temperature ________

Step 11 Multiply line 9 by line 10. This is your optimum battery size in amp-hours: ________

Step 12 Amp-hours of battery chosen. (Industrial Cell, T105=220, L16=350, etc.): ________

Step 13 Divide line 11 by line 12. This is the total number of batteries in parallel required ________

Step 14 Round off to the next highest whole number. This is the number of parallel strings required. ________

Step 15 To determine the number of batteries required in series, divide the system voltage (12, 24,48) by the voltage of the chosen battery (2V, 6V or 12V). ________

Step 16 Multiply line 14 by line 15. This is the total number of the chosen battery needed for the system ________