CHAPTER 6

Batteries

A photovoltaic system array does not produce electricity unless the sun is shining on it. For a PV system to provide electrical power when the sun's rays are not available, storage batteries are used. Batteries are also used in a PV system to provide the needed amount of surge power for heavy electrical loads that a PV system array cannot provide. In this chapter, we discuss the different battery types commonly used in PV systems. Battery specifications and battery performance are covered in detail. Also, no coverage of batteries is complete without a discussion of battery safety, including the proper way to handle batteries during a PV system installation.

Objectives

Upon completion of this chapter, the student should be able to

- Identify different storage battery types used in a PV system.
- Demonstrate an understanding of how a typical PV system battery works.
- Test a battery with a voltmeter or a hydrometer to determine its state of charge.
- Connect battery banks to get a desired voltage and amp-hours.
- Demonstrate an understanding of safety precautions when installing and maintaining PV system batteries.

Glossary of Terms

absorption charging A charging stage that occurs after bulk charging that uses a lower charge current for a longer period of time to bring the state of charge up another 10 to 15 percent.

battery An electrochemical device that stores DC electricity in chemical form for later use.

battery bank Batteries connected together in a series or parallel configuration to deliver a desired voltage and current.

bulk charging A charging stage that uses a high charging rate to bring a battery up to a state of charge of about 80 to 90 percent.

charging The process of a battery receiving current from a charging source and transforming the electrical energy into chemical energy.

cutoff voltage The minimum manufacturer-specified battery voltage that still results in some usable battery capacity.

cycle One charge-discharge sequence of a battery.

days of autonomy The number of days that a battery bank can supply the electrical load without being recharged.

depth of discharge (DOD) The percentage of used energy compared to the amount of energy available at full charge.

discharging The process of a battery transforming chemical energy into electrical energy and delivering current to a load.

discharge rate The ratio of the nominal battery capacity to the number of hours of battery discharge.

electrolyte The chemical medium in a battery where current flow takes place and is caused by the migration of charged particles called ions; sulfuric acid is the electrolyte in a lead-acid battery.

equalizing charging A type of battery charging that uses a limited amount of current to charge a battery higher than the bulk charging voltage; this process brings each battery in a bank to a full state of charge.

gassing The decomposition of water into hydrogen and oxygen gas; this happens during the charging cycle.

specific gravity The ratio of the density of a battery's liquid electrolyte to the density of water.

state of charge (SOC) The percentage of electrical energy remaining in the battery as compared to the amount of electrical energy in the battery when fully charged.

stratification A condition in liquid lead-acid batteries where the specific gravity of the electrolyte is greater at the bottom of the battery than at the top.

sulfation A condition where crystals of lead sulfate accumulate on the plates of a lead-acid battery, reducing battery performance and making the battery difficult to charge.

trickle charging A charging stage that uses a very small current to keep batteries fully charged over periods of time when they are not being used.

Battery Types

A **battery** is an electrochemical device that stores DC electricity in chemical form for later use. Batteries consist of two or more cells connected together in series to get the desired battery voltage. In a PV system the stored electricity from batteries is used at night and during cloudy weather when there is little or no available solar radiation. Batteries can also power electrical loads when a PV array is disconnected for repair or maintenance, and they can supply the surge current needed by electric motor loads to get started. Not all PV systems use batteries. For example, day use PV systems do not require batteries. Grid-tie PV systems do not require batteries, but they are sometimes used as an emergency backup. Batteries are typically installed in stand-alone PV systems. Batteries commonly used in PV systems are lead-acid and can either be a liquid vented style or a sealed style. They are readily available as 6-volt or 12-volt models. For this reason, the majority of the material presented in this chapter applies to 6-volt and 12-volt lead-acid batteries.

Liquid Vented Lead-Acid Batteries

Liquid vented lead-acid batteries (Figure 6-1), sometimes referred to as *flooded batteries*, are built with lead and lead alloy positive and negative plates placed in an **electrolyte** of sulfuric acid and water. The positive plate is lead dioxide and the negative plate is lead. If a circuit is attached from the negative plate to the positive

FIGURE 6-1

A 6-volt liquid-vented lead-acid PV battery.

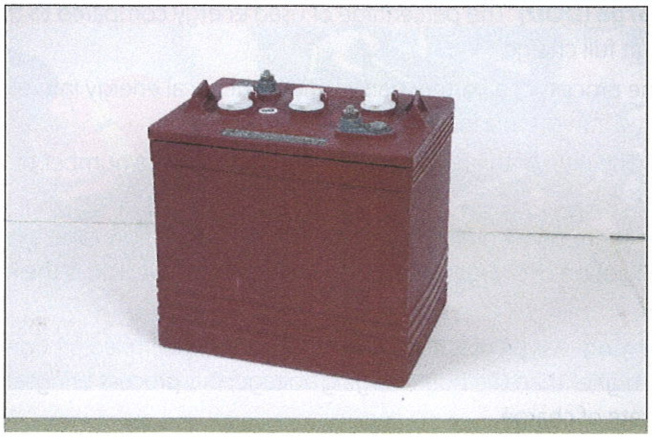
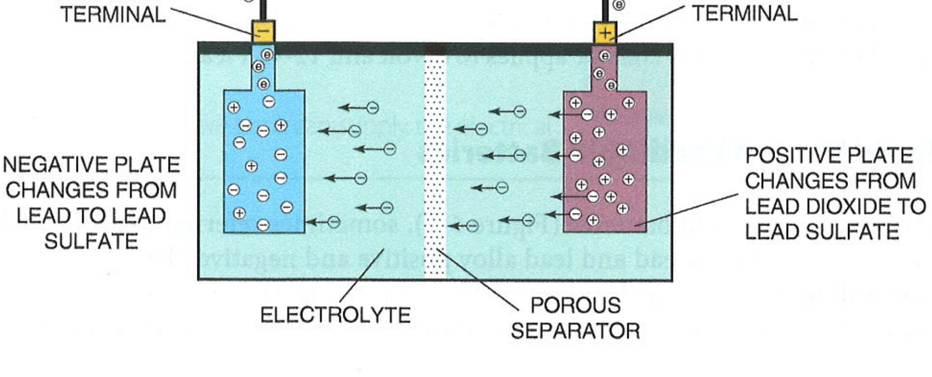


plate (Figure 6-2) of a fully charged lead-acid battery, current will flow through the load. As the current continues to flow, the battery loses more and more stored electrical energy. As the battery continues **discharging**, the positive lead dioxide plate loses its oxygen molecules. The oxygen molecules combine with hydrogen from the sulfuric acid electrolyte and makes water. The sulfate part of the sulfuric acid electrolyte combines with the lead dioxide positive plate and forms lead sulfate. The negative lead plate also combines with the sulfuric acid electrolyte and forms lead sulfate. During this chemical process, the sulfuric acid electrolyte becomes more water and less of an acid.

When a liquid-vented lead-acid battery is **charging**, electrical energy is applied to the battery and the chemical process reverses (Figure 6-3). It keeps reversing until the battery returns to its original fully charged state. As the battery nears full charge, hydrogen gas is produced and vented out. Water is lost when waste gases are vented, and the battery must be refilled periodically with distilled water. Some batteries have catalytic recombinator cell caps that return the vented gases as water.

FIGURE 6-2

A chemical reaction in a battery causes a flow of electrons from the negative terminal, through the load, and to the positive terminal.



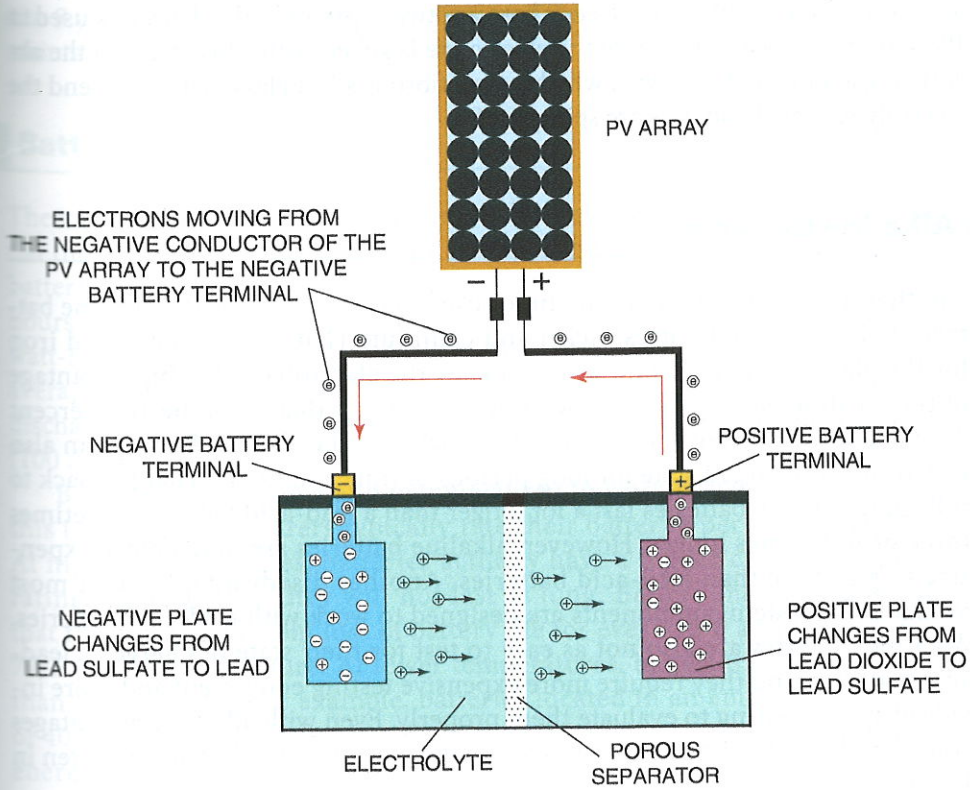


FIGURE 6-3

The chemical reaction reverses when a battery is being charged and keeps reversing until the battery returns to its original fully charged state.

> **CAUTION**
>
> **Hydrogen gas is very explosive! Make sure to properly vent the area where lead-acid batteries are stored.**

Sealed Lead-Acid Batteries

Sealed lead-acid batteries (Figure 6-4) have no caps, so there is no access to the electrolyte. They have a valve to allow excess pressure from overcharging to escape, and they are called valve-regulated lead-acid batteries (VRLAs). Sealed batteries

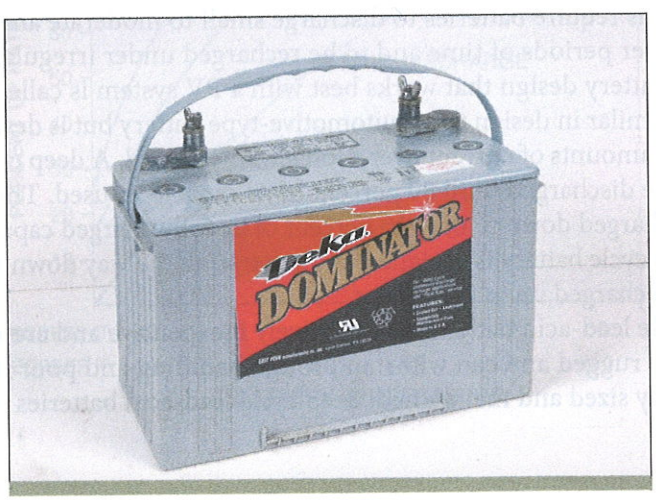


FIGURE 6-4

A sealed type lead-acid PV battery. Notice that this battery has a carrying strap that is used when moving the battery.

are considered maintenance free. There are two types of sealed batteries used in PV systems: the gel cell, where the electrolyte is gelled with silica gel, and the absorbed glass mat (AGM) type, which uses a fibrous silica glass mat to suspend the electrolyte. Sealed batteries are spill-proof.

Alkaline Batteries

Another battery type that is sometimes used in a PV system is the alkaline battery. This battery type uses nickel and cadmium (NiCad) or nickel and iron for the plates, and potassium hydroxide for the electrolyte. One big advantage of the alkaline battery over the lead-acid battery is that it can be 100 percent discharged with no adverse effects on the battery. The alkaline battery can also be left in a discharged state for long periods of time and then recharged back to full charge. These batteries last a lot longer than a lead-acid battery, sometimes three or four times longer. However, alkaline batteries are much more expensive to purchase than lead-acid batteries. Another disadvantage is that most available PV system components are designed to work with lead-acid batteries. Alkaline batteries are also not as easy to test for their state of charge as lead-acid batteries, and they require more expensive testing equipment and more involved system wiring to evaluate them properly. Even with all of the advantages considered, the alkaline battery has too many negatives to be used very often in PV systems.

PV Batteries versus Automotive Batteries

Automotive batteries are designed to put out large amounts of current for short times, such as when a car is started. Once a car is started, the electricity that is used for things like the radio and headlights may come from the battery, but as fast as the battery delivers electricity to the loads; it is recharged by the car's alternator. This means that a battery used in a vehicle is constantly maintained at full charge and is designed to perform well in this environment. An automotive-type battery is often referred to as a *shallow cycle battery* because of the relatively small amount of electricity it provides before being recharged to full capacity. Therefore, automotive-type batteries are not recommended for PV systems.

PV systems require batteries to discharge small to moderate amounts of current over longer periods of time and to be recharged under irregular conditions. The type of battery design that works best with a PV system is called a *deep cycle battery*. It is similar in design to an automotive-type battery but is designed to supply moderate amounts of current over a longer time period. A deep cycle battery is designed to be discharged until 80 percent of its capacity is used. This means that it will be discharged down to only 20 percent of its fully charged capacity. In other words, a deep cycle battery is designed to discharge all the way down to 20 percent and then be recharged up to full charge.

Deep cycle lead-acid batteries are relatively inexpensive and are readily available. They are rugged and can withstand rough handling and poor maintenance. When properly sized and maintained, deep cycle lead-acid batteries will last from

4 to 8 years. A longer battery life is possible if the batteries are of high quality and maintained properly on a regular basis.

Battery Capacity

The capacity of a battery is a measure of the electrical energy storage potential that each battery has. The most common measurement of the capacity of a battery is amp-hours (Ah). For example, if a battery can deliver 2 amps for 50 hours, it has a capacity of 100 Ah. Sometimes a battery capacity is measured in watt-hours (Wh). To calculate the watt-hour capacity of a battery, you need the average battery voltage. For example, if a 100 Ah battery has a 12-volt average discharge voltage, then the battery capacity is expressed as 1200 watt-hours (Wh) (100 Ah × 12 volts = 1200 Wh).

Batteries are designed and manufactured to work best at 77°F (25°C), and this is why manufacturers typically rate their battery's performance at 25°C. At higher temperatures, batteries actually have a higher capacity than their ratings indicate, but they will not last as long. Battery manufacturers state that there is a 50 percent loss of battery life for every 15°F above the standard 77°F (25°C) temperature. At lower temperatures, batteries have less capacity than their ratings. For example, batteries located in an ambient temperature of 40°F (4.4°C) lose from 10 to 15 percent of their capacity to store electrical energy. It should be noted that the rate of battery discharge also has an effect on the battery capacity. Slower discharge rates mean that the temperature change affects the battery capacity less. Faster discharge rates mean that the battery capacity is affected more by temperature changes. See Figure 6-5 for a look at the effect on battery capacity when temperature and discharge rates change.

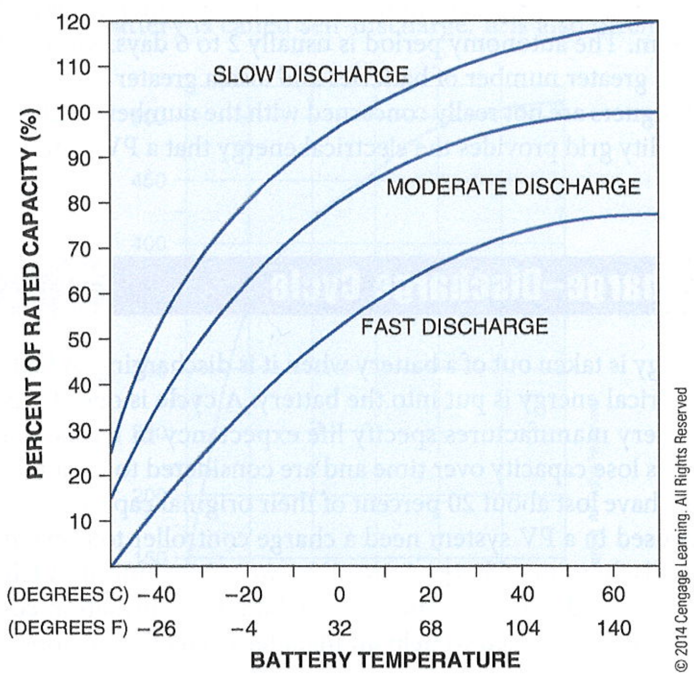


FIGURE 6-5 The effect of changing temperatures and discharge rates on battery capacity.

FIGURE 6-6

The state of charge and freezing points for liquid electrolyte lead-acid batteries.

Lead-Acid Battery Electrolyte Freezing Points	
Battery State of Charge	**Freezing Point**
100%	−71°F
75%	−35°F
50%	−10°F
25%	3°F
0%	17°F

When the ambient temperature around the batteries falls below 32°F (0°C), the battery performance becomes more of a problem in a PV system. Because the electrolyte becomes mostly water when a battery is deeply discharged, it can freeze (Figure 6-6), resulting in broken plates or a cracked battery case. The low temperature also means that the battery has very little, if any, storage capacity.

Days of Autonomy

The number of days that a battery bank can supply the electrical load without being recharged is called **days of autonomy**. This is an important number to keep in mind in the design of a stand-alone PV system so that during long periods of time when the PV system array does not have sun shining on it, or when it is taken offline for maintenance or repair, there is still available electrical energy for a building's occupants to use. This specification is a number that a system designer and the PV system owner use to help determine the number of batteries needed in a stand-alone PV system. The autonomy period is usually 2 to 6 days. More days of autonomy result in a greater number of batteries and also a greater system cost. Grid-tie PV system designers are not really concerned with the number of days of autonomy because the utility grid provides the electrical energy that a PV system cannot.

Battery Charge–Discharge Cycle

Electrical energy is taken out of a battery when it is discharging. A battery is charging when electrical energy is put into the battery. A **cycle** is one charge–discharge sequence. Battery manufactures specify life expectancy in terms of a number of cycles. Batteries lose capacity over time and are considered to be at the end of their life when they have lost about 20 percent of their original capacity.

Batteries used in a PV system need a charge controller to prevent overcharging and over-discharging. Charge controllers were introduced in Chapter 1 and are covered in more detail in Chapter 7. The battery information covered in the next two sections is designed to help an installer correctly set values in a charge controller.

Battery Discharging

At the beginning of the discharge cycle, the battery voltage between the terminals is the highest. As the battery is discharged, the terminal voltage slowly decreases. For example, a 12-volt battery has a terminal voltage of between 12.6 and 13 volts when fully charged. During the discharge part of a cycle, the terminal voltage drops to between 10.8 and 11 volts. The actual terminal voltage depends on the amount of current that is being drawn from the battery by the load. Each manufacturer specifies a **cutoff voltage.** For 12-volt liquid vented lead-acid batteries, the cutoff voltage is 11.3 volts, and for a sealed VRLA battery it is 11.6 volts. When the battery voltage drops below the cutoff voltage, it has no usable capacity left.

The ratio of the nominal battery capacity to the number of hours of battery discharge is the battery's **discharge rate.** A very common discharge rate is written as C/20. This means that a 100 Ah battery discharging 5 amps per hour would take 20 hours to completely discharge. Keep in mind that a battery's capacity is directly related to how fast it is being discharged (Figure 6-7). Slower discharge rates mean more electrical energy can be delivered from the battery. Faster discharge rates mean that less electrical energy can be delivered.

The **state of charge (SOC)** of a battery is the percentage of electrical energy remaining in the battery as compared to the amount of electrical energy in the battery when fully charged. When a battery is discharged, the SOC decreases; and when a battery is charged, the SOC increases. For example, a battery that has had 80 percent of its capacity used is at 20 percent state of charge.

The **depth of discharge (DOD)** of a battery is the percentage of used energy compared to the amount of energy available at full charge. For example, if a battery has had half of its capacity used, then the depth of discharge is 50 percent.

Because lead-acid batteries should not be totally discharged, manufactures specify an allowable depth of discharge. This is the maximum amount that the battery can be discharged. It is based on the cutoff voltage and discharge rate.

There is one last discharge item to consider. The gradual reduction of the state of charge of a battery is called self-discharge. It is also often referred to as

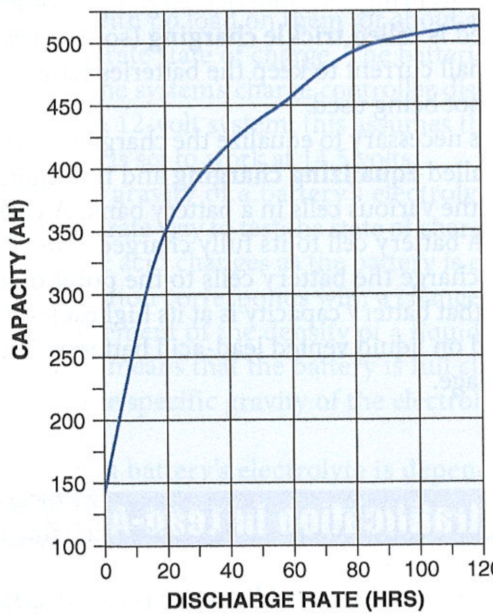


FIGURE 6-7

The effect of discharge rates on battery capacity. The battery used in this example is a C/20 battery with 350 amp-hour capacity.

shelf loss or standby loss. It happens very slowly when batteries are not used. That is, they have not gone through the charge–discharge cycle for an extended length of time. In most PV systems that use batteries, this amount of battery discharge is insignificant. However, if the PV system is small or installed on something like a weekend cottage that seldom gets used, a small trickle charge should be used to continuously keep the batteries fully charged.

Battery Charging

When a battery is charging, an electrical current is applied to the battery in a direction that is opposite to the direction of current during the discharge cycle. A battery charger (charge controller in a PV system) must provide the charging current at a voltage that is slightly higher than the battery voltage or else the charging cannot take place. For example, a 12 volt battery is typically charged with about a 14.5 volts charging voltage. When fully charged, a voltmeter used on the battery indicates around 12.6 volts.

The charging rate is specified in the same way that the discharge rate is. It is given as a ratio of the battery capacity to the number of hours of charge to get the battery fully charged. For example, to fully charge a 100 Ah battery with a C/20 rating, 5 amps (100 Ah/20 = 5 amps) is applied to the battery until it reaches its fully charged voltage.

When a battery is charged, the battery's voltage tends to rise quickly and then level out. The voltage will rise again and possibly cause **gassing**. Battery gassing produces both hydrogen and oxygen gas. The amount of voltage that starts the gassing process is called the gassing voltage. Eventually, the battery voltage levels off at the fully charged state.

There are three stages of charging. Batteries can be charged in only one stage, or they can be charged using a combination of stages. The first stage is called **bulk charging** and uses a high charging rate to bring a battery up to a state of charge of 80 to 90 percent. To get the state of charge closer to 100 percent, an additional stage, called **absorption charging**, can be used. A lower charge current is used for a longer period of time to bring the state of charge up another 10 to 15 percent. The last stage often used is called **trickle charging** (sometimes called float charging) and uses a very small current to keep the batteries fully charged over periods of time when they are not being used.

Once in a while it is necessary to equalize the charging level of all of the batteries in a bank. This is called **equalizing charging** and is designed to produce consistency between all of the various cells in a battery bank. A current limited charge is used that brings each battery cell to its fully charged state. It is a deliberate but controlled way to overcharge the battery cells to the point of gassing. Equalizing every so often ensures that battery capacity is at its highest level. Equalizing charging should only be used on liquid vented lead-acid batteries. If used on sealed batteries, it can cause damage.

Sulfation and Stratification in Lead-Acid Batteries

A problem that can occur with lead-acid batteries is called **sulfation**. This condition happens when batteries have not been fully charged for a long period of time. This usually happens in the winter, when the sun is low in the sky and doesn't provide much solar insolation during stormy and cloudy weather. In these conditions, the PV array cannot provide enough charging current to fully charge the batteries.

As discussed previously, a lead-acid battery has plates of lead and lead dioxide. When the battery is being discharged, the plates are coated with lead sulfate. When the battery stays in a low state of charge for an extended period of time, the lead sulfate on the plates tends to change into a crystalline form of lead sulfate. The crystalline lead sulfate resists charging and remains on the plates; this is called sulfation. Depending on how much of the plate surface is covered with crystalline lead sulfate, the battery will have a very low state of charge and a corresponding low voltage. If only a small area of a plate is covered with crystalline lead sulfate, the rest of the plates can be recharged. However, the battery capacity is now smaller because parts of the battery are not working properly. Sulfation causes unequal specific gravities in different batteries of a battery bank. To bring a battery back from sulfation you must charge the battery above the normal voltage for an extended period of time.

Another problem that can occur in liquid vented lead-acid batteries is called **stratification**. When these batteries are charging, electrolytic acid ions (charged particles) form on the plates but then gradually fall to the bottom of the battery. This results in a greater concentration of acid on the bottom of the battery than at the top and corresponds to a greater **specific gravity** at the bottom than at the top. Specific gravity is covered in more detail in the next section. The battery performance diminishes because different amounts of chemical reaction are taking place at the bottom than at the top. Stratification can be fixed by equalizing the batteries every so often. The gassing that takes place with equalization causes the electrolytic solution to mix up more evenly, so the acid concentration isn't greater in one area than in another.

Determining State of Charge

Batteries need to be at rest with no load on them for about an hour after they have been charged to get an accurate state of charge. The batteries in a PV system will be fully charged whenever the system's charge controller disconnects the PV array from the battery bank. For a 12-volt system, this assumes that the charge controller's high voltage disconnect is set to work at 14.5 volts.

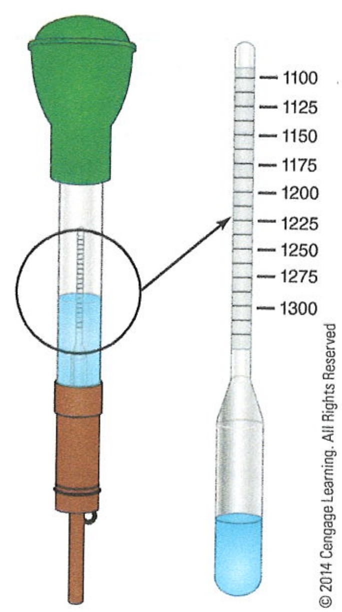


FIGURE 6-8

Measuring the specific gravity of a battery's electrolyte with a hydrometer is the most accurate way to test a battery's state of charge.

Measuring the specific gravity of a battery's electrolyte with a hydrometer (Figure 6-8) is the most accurate way to test the state of charge. This is true because the concentration of sulfuric acid changes as the battery is charged or discharged, and the change in concentration corresponds with a change in electrolyte density. Specific gravity is a measurement of the density of a liquid. A specific gravity of 1.260 in a lead-acid battery means that the battery is full charged (Table 6-1). As the battery is discharged, the specific gravity of the electrolyte falls to 1.120 for a state of charge of 0 percent.

The specific gravity of a battery's electrolyte is dependant on the temperature. Remember that the batteries used in PV systems have their ratings based on a temperature of 77°F (25°C). When the battery temperature is less than 77°F (25°C), the specific gravity reading is higher. There is a way to compensate for temperatures greater than or less than 77°F (25°C). First, take the hydrometer reading as usual. Second, determine the ambient temperature of the battery electrolyte. Third, use the information from Table 6-2 to subtract or add to get

TABLE 6-1

Battery State of Charge based on the specific gravity of a battery's electrolyte as determined by using a hydrometer.

LEAD-ACID BATTERY STATE OF CHARGE BASED ON THE ELECTROLYTE'S SPECIFIC GRAVITY	
STATE OF CHARGE	**SPECIFIC GRAVITY READING**
100%	1.260
75%	1.220
50%	1.185
25%	1.150
0%	1.120

the temperature-compensated specific gravity. For example, a hydrometer indicates 1250 (specific gravity of 1.250). The electrolyte temperature is determined to be 60°F (15.5°C). According to Table 6-2, you must subtract 0008 (0.008 specific gravity). This gives you a compensated reading of 1242 (1.242 specific gravity).

It isn't very hard to use a hydrometer, but you do have to be careful so that the acid does not get on your skin or in your eyes. Make sure to use a hydrometer that is designed for use on PV system deep cycle batteries. It has a glass float that is calibrated with numbers. Don't use the color codes that mean good, fair, or poor because they are used for automotive battery testing. Follow these steps to properly test a battery's state of charge with a hydrometer:

TABLE 6-2

Use the correction factor amount from this table to subtract or add to get the temperature compensated specific gravity.

TEMPERATURE CORRECTION FACTORS FOR LEAD-ACID BATTERY SPECIFIC GRAVITY		
ELECTROLYTE TEMPERATURE (°F)	**ELECTROLYTE TEMPERATURE (°C)**	**CORRECTION FACTOR**
130	54	+0020
120	49	+0016
110	43	+0012
100	38	+0008
90	32	+0004
80	27	0000
70	21	−0004
60	16	−0008
50	10	−0012
40	4	−0016
30	−1	−0020
20	−7	−0024
10	−12	−0028

1. Put on goggles. If available, you should also wear a rubber apron and rubber gloves.
2. Open one of the battery caps and place the hydrometer tip just below the surface of the electrolyte.
3. Squeeze the top bulb slowly to get rid of the air in the hydrometer.
4. Release the bulb slowly and draw the electrolyte up into the hydrometer until the bottom of the glass float isn't touching the bottom and the top of the glass float isn't touching the top.
5. Hold the hydrometer vertically and make sure the glass float is not touching the inside of the tube. If it is, gently tap the side to release it.
6. Read the number that aligns with the top surface of the liquid electrolyte.
7. Slowly squeeze the bulb to return the electrolyte back to the battery.
8. Slowly pull out the hydrometer, being careful not to drip any solution from the hydrometer tip. If you do, clean it up.
9. Use the temperature-compensation information from Table 6-2 to get a corrected reading, and use the information in Table 6-1 to determine the battery state of charge based on the specific gravity.
10. Reinstall the battery cap and clean up any spilled electrolyte.

There are times when an installer may not have a hydrometer available to test state of charge, or the batteries used in a PV system may be sealed so that access to the electrolyte is not possible. For these instances, you can determine the state of charge by using a voltmeter. Try to test the battery voltage at least 1 hour after charging. Follow these steps to properly test a battery's state of charge with a voltmeter:

1. Disconnect all loads from the batteries.
2. Assuming the use of a digital multimeter, set the selector switch to DC voltage.
3. Place the positive red meter lead on the positive terminal of the battery or battery bank.
4. Place the negative black meter lead on the negative terminal of the battery or battery bank.
5. Observe the indicated reading on the meter display.
6. Determine the state of charge by comparing the indicated voltage with the information in Table 6-3.

For example, if a multimeter indicates a battery voltage of 12.15 volts, the battery has a 50 percent state of charge.

TABLE 6-3

Battery State of Charge based on battery voltage.

LEAD-ACID BATTERY STATE OF CHARGE BASED ON THE BATTERY VOLTAGE

STATE OF CHARGE	BATTERY VOLTAGE
100%	12.60
75%	12.35
50%	12.15
25%	11.95
0%	11.85 or below

Battery Location

There are several things to consider when locating the batteries that are part of a PV system. Regardless of temperature concerns, batteries should be placed in a sturdy enclosure (Figure 6-9) or in a rack (Figure 6-10). Battery enclosures and racks have to be made from materials that cannot be adversely affected by any leaking electrolyte. An enclosure or rack also must be constructed so that if there is an electrolyte spill, it is contained. Enclosures that are liquid-tight or trays underneath batteries in a rack are ways to contain a spill.

If located in an unheated part of a building or outdoors, the battery enclosure must be insulated to a recommended R20 value. It is important for the batteries not to be exposed to temperatures that are too hot or too cold. If the location could be subjected to very low or very high temperatures, some kind of heating or cooling equipment should be installed to keep the temperature around the batteries steady. Keeping the temperature steady and moderate in the area where the batteries are stored results in better overall performance, longer life, and a reduction in required maintenance.

FIGURE 6-9

Batteries should be placed in a sturdy enclosure like this.

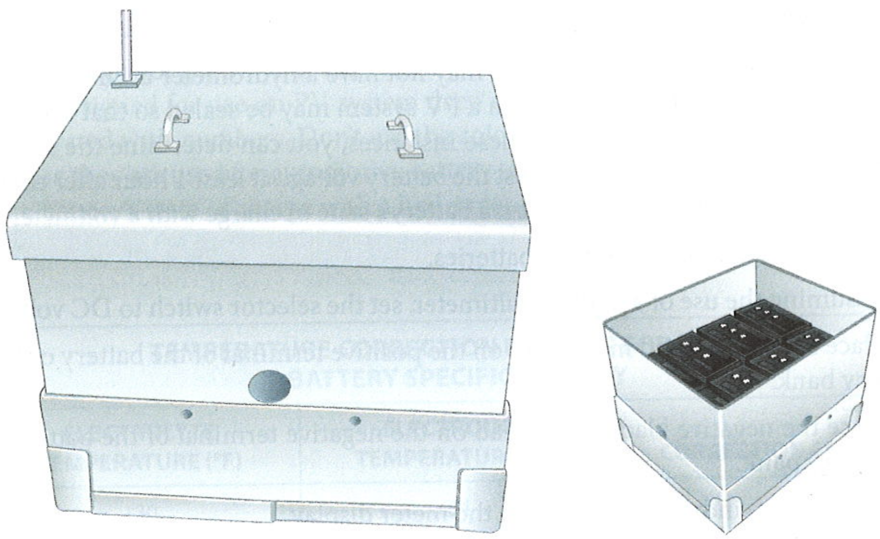
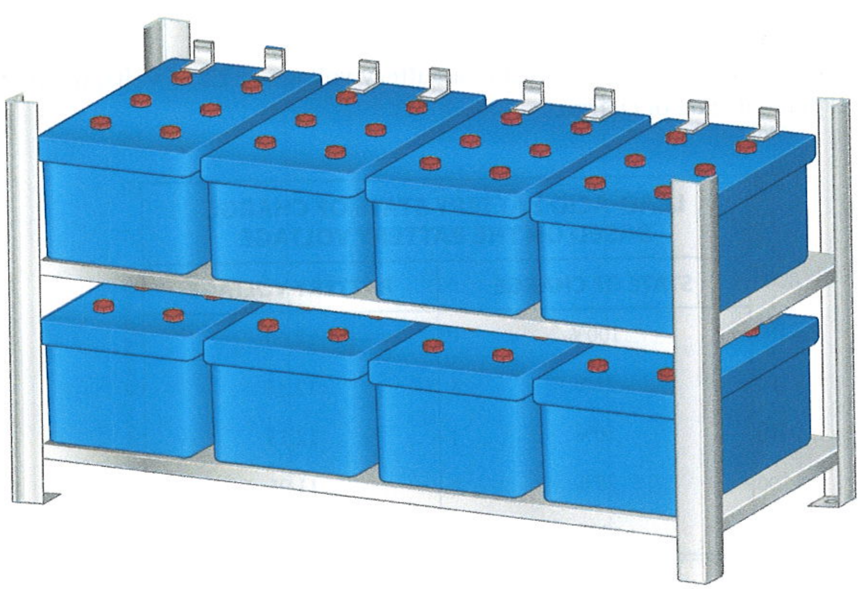


FIGURE 6-10

Batteries can also be stored in racks.



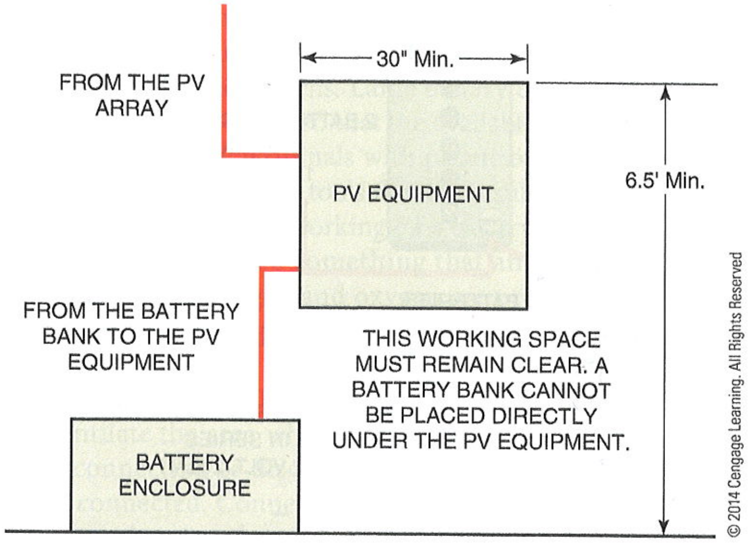


FIGURE 6-11

Locate the batteries out of the working space as defined in Section 110.26 of the National Electrical Code®. The width of the working space is 30 inches or the width of the equipment, whichever is larger. The depth of the working space must be a minimum of 36 inches from the front of the equipment. The working space must extend from the floor to a height of 6 ½ feet or the height of the equipment if it is greater.

The enclosure or area where the batteries are located also has to be well ventilated so that the hydrogen gas produced in lead-acid batteries can be vented into the atmosphere. Small battery systems that are charged at slow rates produce very little gas, and just venting the area or enclosure to the outside with something like a 4-inch (10 cm) flexible hose will work. If the batteries are all the VRLA sealed type, the authority having jurisdiction may allow them to be installed without any ventilation. Larger battery systems must have an active ventilation system that includes fans and blowers.

One last thing to consider when locating PV system batteries is to place them as near as is safely possible to the electrical equipment and loads to minimize wire sizes and length of wire runs. With this in mind, make sure to place the batteries out of the working space as described in *Section 110.26* of the *National Electrical Code*®. This section requires a minimum working space of 30 inches (76 cm) wide (or the width of the equipment if it is greater), a depth of 36 inches (91 cm) in front of the equipment, and a height of 6.5 feet (2 m). This means, for example, that a battery enclosure cannot be placed directly in front of PV system equipment like a charge controller and inverter, but rather must be placed to the side (Figure 6-11).

Battery Connections

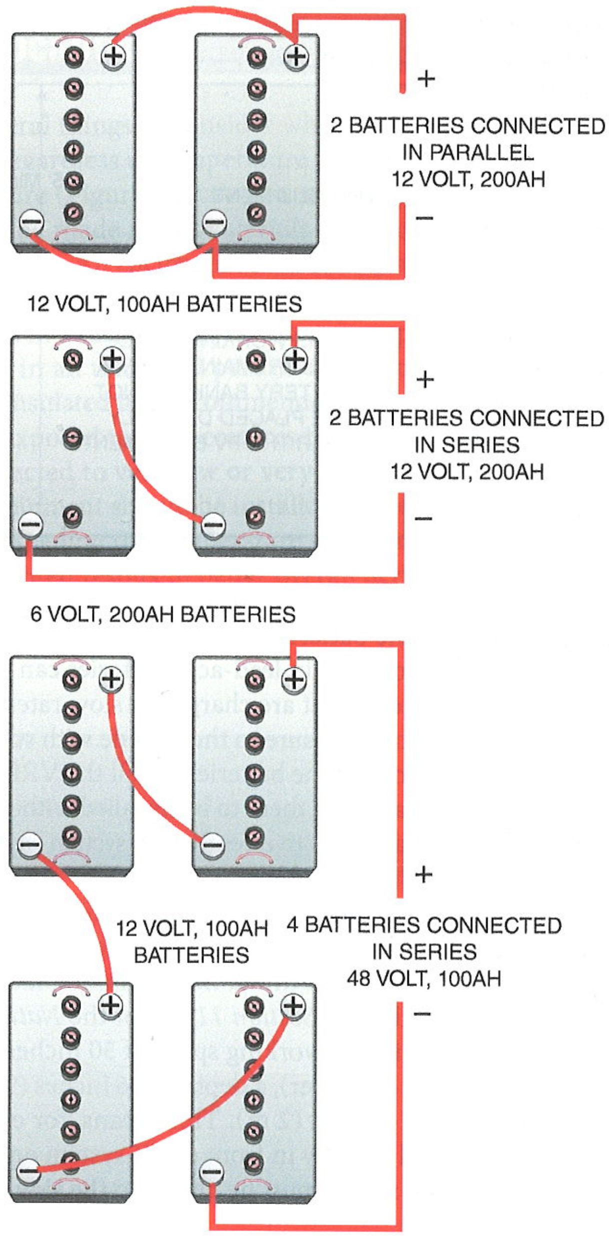
Batteries have to be configured to obtain the desired voltage and amp-hours required of the PV system. This is done by connecting them in series, parallel, or in series-parallel. Batteries connected in these configurations make up what is called a **battery bank**. To create equal path lengths for current flow through the batteries, try to wire into opposite sides of the battery bank and keep the cables equal length. See Figure 6-12 for some examples of different battery connections to get a desired voltage and amp-hour amount.

Battery Safety

Batteries used in a PV system are potentially the most dangerous components in the system. Installers can be exposed to dangerous chemicals if a spill should happen. Remember, the electrolyte in lead-acid batteries is sulfuric acid, which is very

FIGURE 6-12

Examples of different battery bank connections to get a desired voltage and amp-hour amount.



caustic and can burn skin and destroy clothing. Rubber gloves and aprons, along with goggles or a face shield, should be worn when installing and maintaining these batteries. If a spill does happen and an installer gets sulfuric acid on his or her clothes or skin, a solution of baking soda and water should be used immediately to rinse it off. The electrolyte in a NiCad battery is potassium hydroxide, and a solution of vinegar and water can be used to rinse that solution off skin or clothes. If an installer somehow gets some electrolyte in his or her eyes, flush the eyes with clear cool water for at least 15 minutes. See a physician to make sure all is well.

Sometimes batteries must have their electrolyte added after they are purchased. Be sure to slowly pour the concentrated acid into the water when mixing up the solution. Never pour the water into the acid. Remember to use glass or plastic funnels and containers when doing the mixing.

Batteries weigh a lot, and installers can be injured moving and lifting them into place. Always follow the manufacturer's instructions on how to safely lift a battery. If necessary, have proper lifting equipment available when installing a battery bank.

Battery banks can produce voltages and currents that are high enough to seriously injure, or even kill, an installer. Short circuit currents can be thousands of amps and can cause electrical burns. Large battery banks should be split up into smaller segments when servicing so that the available short circuit current is less. Be sure to cover the battery terminals with plastic or rubber covers to lessen the chance of a short circuit. Use only tools that are insulated and designed for use on "live" electrical equipment when working on a battery bank.

Explosion hazards are also something that an installer must be aware of. Explosive mixtures of hydrogen and oxygen are produced during the charging process. These gases may be present around the batteries for a long time after the charging process is done. Any sort of spark or flame could ignite the mixture and cause an explosion. The best protection against an explosion hazard is to properly ventilate the area where the batteries are located. If possible, when an installer is connecting or disconnecting batteries, it should be done with no electrical load connected. Connecting or disconnecting batteries under load can cause sparking and arcing that could ignite the explosive gases should they be present.

The safety rules shown below should be followed when handling, installing, maintaining, or replacing batteries in a PV system:

- Draw a battery connection diagram before wiring. This will help make sure that the battery bank is connected properly and that safety problems resulting from a wrong connection are all but eliminated.
- Remove all jewelry. Items like gold chains hanging around an installer's neck can make a direct connection across positive and negative battery terminals and result in severe arcing.
- Use proper tools. Insulted tools rated for the voltage encountered must be used when working on battery banks.
- Ventilate the battery area adequately. Proper ventilation lessens the chance of an explosion of the batteries' vented gases.
- Keep batteries out of living and working spaces. Never install batteries in the areas of a building where people live or work.
- Wear proper personal protective equipment (PPE). This includes goggles or a face shield, rubber apron, rubber gloves, and proper footwear.
- Have baking soda available. Baking soda is mixed with water to provide a neutralizing rinse in case the electrolyte is spilled on an installer's skin or clothes.
- Have fresh water available. Clean water can be used to mix with baking soda for rinsing off spilled electrolyte. It can also be used to flush out an installer's eyes in case an electrolyte gets in them.
- No smoking near any battery. Smoking can provide the ignition source that could start a fire or cause an explosion.
- Lift batteries from the bottom or use straps. Many batteries used in PV systems come with carrying handles or carrying straps installed.
- Use nonconductive hard hats and tools around batteries. Metal hard hats or noninsulated tools could fall onto the top of a battery bank and cause severe arcing.
- Always follow the battery manufacturer's instructions on how to install their batteries.