Batteries 101

Virtually all power generation systems require some form of energy storage. For grid-tied systems, the utility accepts surplus power and gives it back when needed. A battery bank is required for systems that need to function without the grid, either all of the time or during an outage. In these systems, the solar array or other charging source charges the batteries whenever they are producing power, and the batteries supply power whenever it is needed.

Battery Technologies

The most common battery technology used is **Lead-acid**, in which lead plates are used with a sulfuric acid electrolyte. The electrolyte can be fluid or absorbed in fiberglass mats (AGM), or gelled. AGM and gel batteries are together known as VRLA (Valve Regulated Lead Acid) and are sealed, do not require water addition, and do not emit gases when operated within specifications. Lead-acid batteries are relatively inexpensive and readily available compared to other battery types. New advanced lead-acid batteries have carbon additives in the negative plate to prevent sulfation at partial states of charge (PSoC), while remaining less expensive than high-technology batteries. **Lithium-ion** batteries are lighter weight and compact for their power and energy capacity. One advantage of Li-Ion batteries is their long life even when cycled heavily, and without needing to be brought to a full state of charge each cycle. This makes them particularly suitable for short to long-duration use in self-consumption systems where net-metering is unavailable or utility rate structures otherwise discourage energy exports during peak solar production hours.

Standby or Cycling Batteries

Batteries come in a wide variety of sizes and types, but the most important designation is whether they are made for daily cycle service or standby service. Automobile starting batteries should not be used for renewable energy systems.

Standby power batteries are designed to supply power to loads for occasional use, and are preferred for grid-tied solar systems with battery backup. They are optimized to supply moderate to large amounts of power only during utility power outages, and float at full charge most of the time. They are designed to use a minimal amount of energy to stay fully charged. They are not made for frequent deep discharges and have a limited cycle life but often very long calendar life when kept in float conditions. AGM batteries are most common for standby power applications as they are less expensive, have low self-discharge and require little to no manual maintenance. Deep cycle flooded batteries are not desirable for standby applications. They do not have longer life than AGM batteries when kept in float charge for long periods of time. They also have a high standby loss (often as much load as a refrigerator or more), need isolation, ventilation, and much more maintenance.

Deep cycle batteries are designed to be repeatedly discharged by as much as 80% of their capacity and are therefore a better choice for off-grid PV systems. Even when designed to withstand deep cycling, most batteries will have a longer life if the cycles are kept shallower.

Deep cycle batteries can be either flooded or sealed lead-acid variants or, increasingly, newer chemistries like lithium-ion or aqueous hybrid ion.

Caring for Batteries

Maintenance requirements vary by battery chemistry and configuration. Additionally, some maintenance tasks, such as adding water or equalization, require on-site manual operations and/or oversight, while charge regulation, voltage checks and related measurements can be automated via sophisticated charge controllers or battery management systems, which are a de facto requirement for lithium-ion batteries.

Sealed lead-acid batteries, gel cells and AGM (Absorbed Glass Mat), are often referred to as maintenance-free because they don't require watering or an equalization charge. This makes them well-suited for remote or unattended power systems. However, sealed batteries require accurate regulation to prevent overcharge and over-discharge.

Lead-acid batteries should always be recharged as soon as possible. The positive plates change from lead oxide, when charged, to lead sulfate, when discharged. The longer they remain in the lead sulfate state, the more of the plate remains lead sulfate when the battery is recharged. The portion of the plates that become “sulfated” can no longer store energy. Batteries that are deeply discharged and then only partially charged on a regular basis often fail in less than one year (except those with nano-carbon). Always use temperature compensation when charging batteries to prevent over or under-charging. NOTE: Battery warranties do NOT cover damage due to poor maintenance or loss of capacity from sulfation.

Check the electrolyte level in wet-cell, or "flooded" batteries, at least once every three months and top-off each cell with distilled water. Do not add water to discharged batteries! Electrolyte is absorbed when batteries are discharged, so if you add water at this time and then recharge the battery, electrolyte will overflow and create a safety hazard. Keep the tops of your batteries clean and check that cables are tight. Do not tighten or remove cables while charging or soon after charging! Any spark around batteries can cause a hydrogen explosion inside the case and potentially ignite a fire or an even larger explosion if the batteries are not properly vented.

An "equalization" charge should be performed on flooded batteries whenever cells show a variation of 0.05 or more in specific gravity from each other. This is a long steady overcharge, bringing the battery to a gassing or bubbling state. Do not equalize VRLA batteries!

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

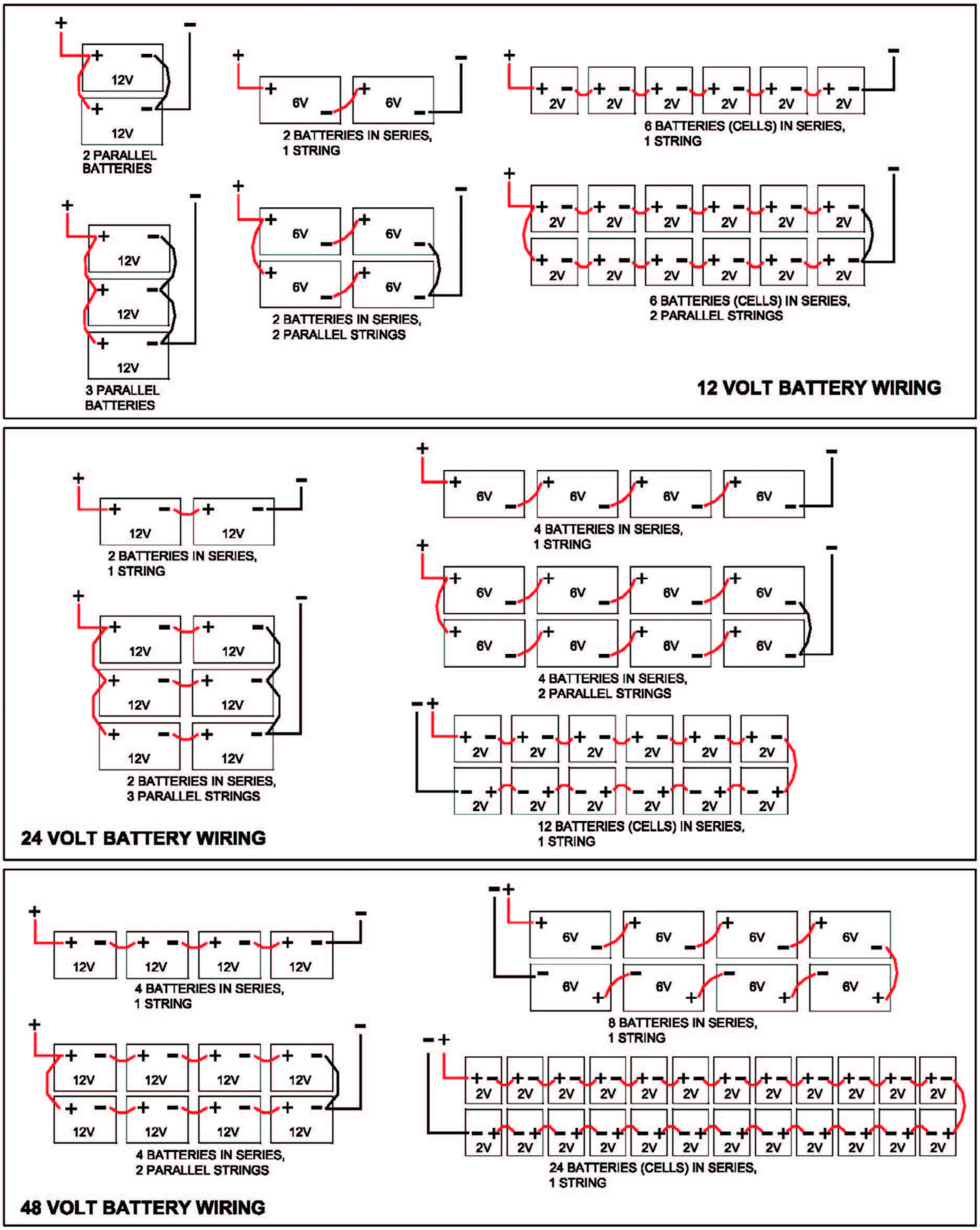
Always use extreme caution when handling batteries and electrolyte (sulfuric acid). Wear appropriate personal protective equipment, including electrical- and chemical-resistant gloves with sleeves, goggles, and acid-resistant clothing. “Battery acid” will instantly burn skin and eyes and destroy cotton and wool clothing. Similar precautions apply to other battery types - always read and adhere to manufacturer safety recommendations when handling batteries. For any type of battery, be sure to remove any metal jewelry and avoid shorting the battery terminals.

Battery Wiring Diagrams

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

With lead-acid batteries it's best to use one series string of batteries to get the desired voltage and capacity. If that is not possible, using up to three strings in parallel is acceptable. Note in the diagrams below, that when using parallel battery strings it's essential that the bank's output cables be connected to opposite corners of the battery bank. For instance, if using two parallel strings, connect the positive bank output to the positive output terminal of the first string, and the negative bank output to the negative output terminal of the second string (or vice-versa on the polarity). If using three strings, one output cable would attach to the first string, and the second output cable would attach to the third string. This helps insure equal current flow through all strings of the battery bank.

Using four or more parallel strings is not recommended without taking extensive care that all the strings receive the same amount of charging current and load. Large central buses should be used, with equal-length cables (hence equal resistance) between the buses and each parallel battery string. This also is a good method to use with two or three parallel strings.



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. An amp-hour meter is like a fuel gauge for batteries and provides all the information needed to keep batteries charged. At a glance, the user can see system voltage, current, and battery condition (see Meters and Monitoring).

Battery voltage will vary for the same state-of-charge depending on whether the battery is being charged or discharged, and what the current is in relation to the size of the battery. The table below shows typical battery voltages at each state-of-charge for various battery conditions in flooded lead-acid batteries. Voltage varies with temperature. While charging, a lower temperature will increase battery voltage. Full-charge voltage on a 12 VDC battery is 0.9 VDC 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 idle, though higher temperatures will increase the self-discharge rate. Source: Ralph Heisey of Bogart Engineering.

Lead Acid (including AGM and Gel) Battery Voltage at Various States of Charge			
Battery Condition at 77 ℉	**Nominal Battery Voltage**		
	12 VDC	**24 VDC**	**48 VDC**
Battery during equalization charge	> 15 VDC	> 30 VDC	> 60 VDC
Battery near full charge while charging	14.4 - 15 VDC	28.8 - 30 VDC	57.6 - 60 VDC
Battery near full discharge while charging	12.3 - 13.2 VDC	24.6 - 26.4 VDC	49.2 - 52.8 VDC
Battery fully charged with light load	12.4 - 12.7 VDC	24.8 - 25.4 VDC	49.6 - 50.8 VDC
Battery fully charged with heavy load	11.5 - 12.5 VDC	23 - 25 VDC	46 - 50 VDC
No charge or discharge for six hours - 100% charged	12.7 VDC	25.4 VDC	50.8 VDC
No charge or discharge for six hours - 80% charged	12.5 VDC	25 VDC	50 VDC
No charge or discharge for six hours - 60% charged	12.2 VDC	24.4 VDC	48.8 VDC
No charge or discharge for six hours - 40% charged	11.9 VDC	23.8 VDC	47.6 VDC
No charge or discharge for six hours - 20% charged	11.6 VDC	23.2 VDC	46.4 VDC
No charge or discharge for six hours - fully discharged	11.4 VDC	22.8 VDC	45.6 VDC

Battery near full discharge while discharging	10.2 - 11.2 VDC	20.4 - 22.4 VDC	40.8 - 44.8 VDC

A **hydrometer** is very accurate at measuring battery state-of-charge in flooded lead-acid batteries if you measure the electrolyte near the plates. Unfortunately, you can only measure the electrolyte at the top of the battery, which is not always near the plates. When a battery is being charged or discharged, a chemical reaction takes place at the border between the lead plates and the electrolyte.The electrolyte changes from water to sulfuric acid while charging. The acid becomes stronger, increasing the specific gravity, as the battery charges. Near the end of the charging cycle, gas bubbles rising through the acid stir the fluid. 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 the battery has been idle or slowly discharging for some time.

This table shows the battery state-of-charge corresponding to various specific gravities for a battery bank in an ambient temperature of 75 °F. Some batteries will have a different specific gravity density by design, check with the manufacturer.

Hydrometer Readings at Ambient Temperature of 75 ℉	
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