Battery System

A battery system leverages chemical reactions to store electricity for later use, be it electricity from a generator or public. In technical terms the electricity itself cannot actually be stored, but the relative energy equivalent is stored as potential energy through chemical reaction, and can be transformed into electricity later. Chemical batteries work by charging a solution that retains the charge long enough to be discharged again and distributed later.

System Architecture

Batteries are finite storage mediums and operate in relatively simple ways.

Batteries can only receive and supply DC currents, while most large electrical appliances and power sources use AC currents. To accommodate this, batteries require external devices to convert currents based on usage and need.

- To receive an AC current the battery will need a transformer or specialised battery charger.
- To deliver an AC current, the battery will need an external inverter.

These 2 devices are often combined into an inverter-charger which can be used as an intermediary between the battery and the closed circuit.

As each battery has a limited capacity, battery power supplies require special equipment to monitor and control the flow of electricity entering a battery, called a charge controller. A charge controller will continuously monitor the charge state of a battery – recognising how "full" it is – and should automatically terminate charging once a battery is full. Batteries are highly energetic and can be extremely dangerous if over charged! An overcharged battery can spark, start fires, and even explode, possibly throwing hazardous chemicals while it does. No battery power backup should be attempted without a proper charge controller in place.

Just like a generator installation, a battery power backup should also have all available protections in place, including breakers, fuses, and a grounding cable.

Thus, a battery system usually includes:

- One or more batteries.
- Inverter-charger.
- Charge controller.
- Cabling and protective devices such as fuses and grounding.

Batteries

A battery is a storage device capable of storing chemical energy and converting it into electrical energy through electrochemical reaction. There are many different types of chemistry that are used, such as nickel-cadmium batteries used to power small portable devices or Lithium-ion (Li-on) batteries used for larger portable devices. The most proven type of chemistry and the longest used however is the lead acid battery.

Types

Batteries are made with several materials and shapes suitable for different purposes. This guide will focus on the most common batteries used as a back-up for power generation sources. The two main types can be summarised as:

1. Flooded Batteries.
2. Valve Regulated Lead Acid Batteries.

Flooded Batteries:

Flooded cell batteries are the most common conventional battery used in internal combustion vehicles. Flooded cell batteries are referred to in several ways:

- Flooded Battery.
- Wet Cell Battery.
- Spillable Lead Acid Battery.
- Resealable Lead Acid Battery.

These batteries contain a combination of a liquid electrolyte that is free to move in the cell compartment. Users have access to the individual cells and can add distilled water (or acid) as the battery dries out. The main characteristic of this kind of battery is their low cost, which makes them available almost everywhere in the world and widely used in low income or developing economies. Handling flooded batteries are quite easy, and they can be charged with a simple unregulated charger. However, these batteries require periodic inspection and maintenance, and extreme climates can have a greater effect on battery lives due to the electrolyte solution inside the battery having the ability to evaporate or freeze.

These batteries are commonly made with two terminals and 6 caps allowing access to each 2V compartment or cell, giving 12V in total. For this type of battery, the typical absorption voltage range is 14.4 to 14.9 volts and a typical float voltage range 13.1 to 13.4 volts.

Car or truck batteries are not suitable to be the permanent system for storage Vehicle batteries are designed to provide high current during short periods, specifically to start a combustion engine. There are lead-acid batteries that are specifically designed recently for storage applications.

VRLA (Valve Regulated Lead Acid) Batteries:

Valve Regulated Lead Acid (VRLA) battery is a term that can refer to a number of different makes and designs, but all share the same property - they are sealed. VRLA batteries are sometimes referred to as sealed or non-spillable lead acid batteries. The sealed nature of the batteries make transport easier and less dangerous, and may even be transported via aircraft under certain circumstances. Being sealed however reduces their lifespan as they cannot be refilled – on average their life span is 5-years at 20°C.

VRLA batteries are usually more expensive and require a fully regulated charger, which makes them less common throughout the world. These batteries may still use lead acid as a chemical solution, but they may use threaded pins instead of chambers and terminals.

The namesake of the battery comes from a valve regulating mechanism that allows a safe escape of hydrogen and oxygen gasses during charging. There are also more advanced designs, including:

Absorbed Glass Mat (AGM) Batteries	The AGM construction allows the electrolyte to be suspended in close proximity with the plate's active material. This enhances both the discharge and recharge efficiency. Since there is no liquid inside, these batteries scan perform better than flooded batteries in applications where maintenance is difficult to perform, however they are sensitive to over or under charging affecting their life and performance. AGM batteries perform most reliably when their use is limited to the discharge of no more than 50% of battery capacity. AGM batteries are usually the type of batteries selected in off-grid power systems.
Gel Cell Batteries	Gel cell batteries have a water-acid in gel form. The electrolyte in a gel cell battery has a silica additive that causes it to set up or stiffen. The recharge voltages on this type of cell are lower than the other styles of lead acid batteries, and gel cells are probably the most sensitive cell in terms of adverse reactions to over-voltage charging. Gel batteries are best used in very-deep cycle applications and may last a bit longer in hot weather. Unfortunately a total deep discharge will irreversibly destroy the battery. If the incorrect battery charger is used on a gel cell battery, poor performance and premature failure is certain. Note: It is very common for individuals to use the term gel cell when referring to sealed, maintenance-free batteries, much like one would use a brand name when referring to an entire product category. Be very careful when specifying a charger - more often than not, when someone is referring to a gel cell they really mean sealed, maintenance-free VRLA or AGM-style battery. Gel cell batteries are not as common as AGM batteries, and would be hard to source in humanitarian contexts.

Battery Type	Absorption Voltage Range	Float Voltage Range
Flooded Batteries	14.4 to 14.9 volts	13.1 to 13.4 volts.
VRLA Batteries	14.2 to 14.5 volts	13.2 to 13.5 volts.
AGM Batteries	14.4 to 15.0 volts	13.2 to 13.8 volts.
GEL Batteries	14.0 to 14.2 volts	13.1 to 13.3 volts.

Capacity

Capacity is defined as the total amount of energy a battery can store and reproduce in the form of electricity. Battery capacity is usually described in multiples and orders of magnitude of Watt-hours (Wh) – 1 Wh to one 1 kWh (1,000 Watt-hours). A Watt-hour is defined as the electrical energy required to supply a Watt of electricity for one continuous hour. For example, a standard 60W incandescent bulb would require 60Wh of stored energy to function for one hour. It is easy to see why properly estimating consumption needs are important for designing battery back-up systems, especially for security or mission critical related items.

Probably the most important specification of a battery is its capacity rated in Amp-hours (Ah). Determining Wh is done when Ah are combined with battery voltage - often 12 volts.

$$\text{Energy (Wh)} = \text{voltage (V)} \times \text{capacity (Ah)}$$

A battery capacity depends on:

- **Discharge Duration**: Usually manufacturer indicated capacity at 20hrs, noted as C20. For a C20 batter, the same battery will be able to deliver more energy in 20 hours than in 10.
- **Temperature**: Capacity can increase or decrease with external temperature. Rating is benchmarked at 20°C.

Also keep in mind that cycling a battery through its full capacity will likely damage it if done repeatedly. To increase battery lifespan, there should always be some energy left in it before recharging. For this reason, usually only 50% of the capacity is used. As a result, the energy a battery can actually deliver is better measured by looking at half its full capacity.

$$\text{Energy} = 0.5 \times \text{voltage} \times \text{capacity}$$

Example:

A 100Ah battery contains 1,200Wh:

100 x 12 = 1,200Wh

To increase its lifespan only 600Wh can be used. How long would a 40W light bulb last in continuous use?:

600Wh / 40W =15 hours

A 40W light bulb could run for **15 hours** before the battery needed to be recharged.

As a rule of thumb, the larger the battery and the higher the capacity, the more efficiency increases while the price per watt-hour decreases. It is recommended to use the battery type with the highest capacity available, and then work off multiples of that battery type to reach the overall energy storage needs. Continually adding smaller, lower capacity batteries will lead to higher costs and more problems later on.

Float Life

Float life is the expected service life of a battery if undergoes continuous charge, and is never discharged. When a battery is installed in an electrical system that constantly receive a charge, it is called "float charging." If power is cut and float charged batteries are switched to, the "float life" indicates how long these batteries can last. Float life decreases with temperature and manufacturer float life is usually rated at 20°C. As a general rule, float life will reduce by approximately half for every average temperature increase of 10°C.

A battery with a rated float life of 10 years at 20°C. How long will it last if the average temperature is 30°C?

Example: 10 / 2 = 5 Years

It will last **5 years** if the average temperature of the battery room is 30°C and only **2.5 years** if the average temperature of the battery room reaches 40°C.

Cycle Life

In addition to float life, "cycle life" is the number of cycles that the battery can withstand during its service life. A battery cycle is defined as a battery being fully charged and then fully discharge, making one full “cycle.” It is common to have this information in technical specifications, and it is recommended to buy batteries with a cycle life of more than 400 cycles.

Cycle life depends on the depth of discharge. A 50% depth of discharge is a good compromise between over-investment and quicker degradation.

Other Specifications

The other characteristics of a battery are:

- **Self-Discharge Rate:** Self-discharge rate is defined as how quickly a battery will dissipate electricity if stored full but unused. Useful only if the batteries are intended to be stored for long duration. A lead-acid battery self-discharge rate is generally below 5% a month.
- **Freezing Point:** A battery will be destroyed if its electrolyte solution freezes. The freezing temperature depends on its construction, composition, and rate of charge, and a discharged battery freezes more easily. A battery freezing point is almost always below that of water, however.

Number of Batteries Needed

The type of battery required for an installation will depend on the power needs, the budget, in the country of operations, and the conditions under which they system has to perform.

Once the battery model has been identified, the number of batteries required must be calculated. This can be done with the following formula, always rounding the number up.

Number of batteries = (Energy consumption) (max cycle depth × Battery voltage × Battery capacit

A system analysis indicates a need for 12,880Wh. The available batteries are 220Ah / 12V, and require a 50% maximum depth of discharge. How many batteries are required?

Example:

12880 / (50% × 12 × 220) = 9.76

10 batteries are required.

Note that all the batteries used in a battery system must be exactly the same:

- **Same Capacity:** if 500Ah are needed it is not possible to use 2 x 200Ah + 1 x 100Ah. The system would require 5 x 100Ah or (preferably) 3 x 200Ah.
- **Brand and Model:** As much as possible, batteries should the same brand and model.
- **Age:** As far as possible, all batteries should have the same "history". It is strongly recommended to not mix old and new batteries, even if they are the same model.

Inverter-Charger

While is important to select batteries that have the correct storage capacity and design, inverter-charger devices can increase the efficiency of the system. Equally, an inverter-charger can damage a system if it is installed incorrectly, or of it is malfunctioning or poorly designed. The purpose of an inverter-charger is to transform current from AC to DC to charge batteries, and from DC to AC to discharge batteries. Inverter-chargers can do much more however – they can function as the "brain" of the electrical installation, coordinating the energy flows between the main source (generator or grid), batteries, and the end user. A proper inverter-charger can provide a far better quality of service than any other back-up systems, including:

- Power available from the inverter can be as high as 4 times the maximum power of the main power supply.
- Increased generator lifespan.
- Regulated voltage and frequency.
- Uninterrupted power supply.

Inverter-chargers should be purchased along with:

- Battery controllers.
- Temperature sensors.

Battery Cable Connections

The cables that join batteries together play an important part in the performance of the battery system. Choosing the correct size (diameter) and length of cable is important for overall system efficiency. Cables that are too small or unnecessarily long will result in power loss and increased resistance. When connecting batteries, the cables between each battery should be of equal length to ensure the same amount of cable resistance, allowing all batteries in the system working equally together.

Particular attention should also be paid to where the main system cables that are connected to the battery bank. All too often the system cables supplying the loads are connected to the first or "easiest" battery to get to, resulting in poor performance and service life reduction. These main system cables that run to the DC distribution (loads) should be connected across the whole battery bank. This ensures the whole battery bank is charged and discharged equally, providing optimal performance. The main system cables and the cables joining the batteries together should be of sufficient size (diameter) to handle the total system current. If there is a large battery charger or inverter it is important to be sure that the cables are capable of carrying the potentially large currents that are generated or consumed by the connected equipment, as well as all the other loads.

Installing a Battery System

Battery Room

A battery room has the same purpose as a generator room:

- Isolate the battery system to decrease the risk of accident - such as acid leakage or harmful gas emissions - and prevent non-authorised access.
- Ensure good operating conditions: a battery room must protect electronics against water and dust, and be well ventilated.

Batteries used for power back up and distribution need a specific place to be located, and must be well planned. It is convenient to have the battery room close to the main power supply or the distribution board, however the batteries must not be installed in the same room as the generator. High or fluctuating temperatures considerably affect the service life and batteries performance, and it is recommended to have a separate well ventilated battery room with a temperature as close as possible to 20ºC. A dry and ventilated a cellar or underground room is a perfect location, provided the underground storage location will not flood or collapse.

Under no circumstances should battery storage locations be located in living or working spaces. A fully charged battery is highly energetic, and can spark, give off fumes, combust, or even explode. A faulty charger or an overcharged battery may display signs of distress, including swelling and smoking. However, an overcharged battery may also display no signs and provide no warning. A ruptured battery can propel shrapnel and throw very toxic chemicals, while the fumes may be extremely harmful or even lethal if breathed. If a battery shows any signs of warping, distress or overheating, the entire system should be shut off, and the battery should be disconnected when safe to do so. Do not attempt to reuse damaged batteries – they should be disposed of safely, and in accordance with local laws and regulations.

Installation Sizing

To size a battery system, the following will need to be determined:

- The maximum power the inverter has to be able to deliver to the installation.
- The amount of energy that must be stored in the battery to cover your needs.
- In some case, the power the charger can deliver to the batteries.

Please reference the section on energy management on how to calculate the power and energy the system has to deliver.

To manually calculate the maximum power of the installation:

1. List all electric appliances fed by the installation.
2. Find the maximum power of each electrical appliance. For appliances including an electrical motor the maximum power is approximately three times the nominal power. For example, a 300W water pump will need around 1kW to start.

3. Add all power together.

To manually calculate the energy consumption of the installation:

1. List all electric appliances fed by the installation and their nominal average power.
2. For each appliance determine how long should be in use. The assumed energy needed for each appliance can be calculated by: average power x duration.
3. Add all energy requirements together.

Take into consideration the hours that the battery system is intended to deliver electricity and plan accordingly. A battery configuration won't be the same if the system will deliver power only during night or be used as a full day twenty-four-hour backup. If it is possible, plan to run a generator during peak energy consumption hours, decreasing the number of batteries required and reducing the full cost of the system.

The power of the battery charger will determine how long recharging will take. A high-power charger that can charge batteries rapidly is useful if the main power supply is very expensive – a big generator with high consumption - or if the electricity from the main power supply is only available during short duration - public grid available only few hours per day.

To be able to charge the batteries in a fixed duration, the formula to use is:

Power=Energy consumption / charge duration

Example:

An installation has an estimated energy consumption of 12,880Wh, and needs to reach a full charge in 6 hours. What Wattage must the charger be?:

12,880 / 6 = 2,150W

The charge power must be at least**2,150W**.

Charger power is often rated in current (Amps) rather than in power (W). To calculate charge current from the charge power simply divide the charge power by the charger voltage (usually 12, 24 or 48V).

- If 12V charger is used, the charge current must be: 2,150 / 12 = 180A.
- If 48V charger is used, the charge current must be: 2,150 / 48 = 45A.

Additional considerations:

- The minimum duration to charge battery is 4 hours. Faster charging may damage batteries, and some batteries may have limitations longer than 4 hours.
- Even with a powerful battery charger, the charge may be longer due to the limited power available from the main power supply - with 5kW generator, buying a 10kW charger is pointless.
- For chargers that have advanced settings, the charge algorithm may extend charge duration to save battery life. Some chargers automatically decreases the charge power when the battery is close to 100%.

Connecting Batteries

There are several ways to wire multiple batteries to achieve the correct battery voltage or capacity for a particular DC installation. Wiring multiple batteries together as one big bank, rather than having individual banks makes them more efficient and ensures maximum service life.

Series Connection

Wiring batteries together in series will increase the voltage while keeping the amp hour capacity the same. In this configuration, batteries are coupled in series to gain higher voltage, for instance 24 or even 48 Volt. The positive pole of each battery is connected to the negative pole of the following one, with the negative pole of the first battery and the positive pole of the last battery connected to the system.

For example; 2 x 6V 150Ah batteries wired in series will give 12V, but only 150Ah capacity. 2 x 12V 150Ah batteries wired in series will give 24V, but still only 150Ah.

Parallel Connection

Wiring batteries together in parallel has the effect of doubling capacity while keeping the voltage the same. Parallel coupling involves connecting the positive poles and negative poles of multiple batteries to each other. The positive of the first battery and the negative of the last battery are then connected to the system.

For example; 2 x 12V 150Ah batteries wired in parallel will give only 12V, but increases capacity to 300Ah.

Series/Parallel Connection

A series/parallel connection combines the above methods and is used for 2V, 6V or 12V batteries to achieve both a higher system voltage and capacity. A parallel connection is required if increased capacity is needed. The battery should then be cross-wired to the system using the positive pole of the first and the negative pole of the last battery.

For example; 4 x 6V 150Ah batteries wired in series/parallel will give 12V at 300Ah. 4 x 12V 150Ah batteries can be wired in series /parallel to give you 24V with 300Ah capacity.
