# Build Your Own Direct Charging Plant

Battery Charging Made Easy

## By Robert Sharman:

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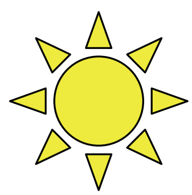

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Published in Australia by Tasman Publishing Pty Ltd
PO Box 266, Deloraine, TAS 7304
Written and compiled by Robert Sharman
Printed by: Tasman Publishing Pty Ltd v.01

ISBN: 978-0-9581100-5-1



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# Contents

# Introduction

A direct charging plant is an engine driven battery charger. Where a conventional battery charger is a device that plugs into a power point and runs on “mains” type electricity from the grid or from a generator, a direct charging plant produces a voltage and current suited to the battery bank it is connected to.

If you own a battery bank that is part of a power system for your motor home, caravan, camp site, remote cabin or house, conventional wisdom dictates that in order to charge this battery bank you will need a battery charger. Usually the battery charger is a backup, a device to add power if your demand is high, your renewable energy input falls short or for some reason there is a breakdown in power supply. Often the battery charger is an afterthought, a device that requires a generator providing mains type power to plug the battery charger into. All too often this afterthought turns out to be unsuited, unreliable or both.

This book is for people who seek battery charging in a more efficient form than what a conventional battery charger and generator combination can offer. A direct charging plant will provide high performance battery charging in a low cost, easy to make and compact package that will result in more economical fuel usage and better battery charging performance.

**Let’s have a quick look at the components involved:**

- First you need an engine
- Connected to the engine is a driveline
- The driveline connects the engine to a generating device
- The generating device connects to the battery bank
- Battery charging is controlled by a regulator

For a mobile application you want something small, compact, light and portable. For a household power system something fixed permanently in place is a better option.

You choice of components will be decided by your intended use, the expected power output, the attached battery bank size and your budget. Before we move on and look at the components and how they are connected together lets just have a quick look at battery charging using a conventional mains powered battery charger versus a direct charging plant.

**Mains powered charger:**

- Requires generator
- Often lacks sufficient voltage or adjustability to fully charge batteries
- Expensive
- Inefficient – requires differing input voltage to output voltage
- Easily damaged – not recommended for use in parallel with an inverter
- Bulky
- Low output or high expense
- Unreliable. After 20 odd years in the renewable energy business I can report that there are very few long lasting high output battery chargers available. The very few ultra reliable chargers on the market are very expensive and still have a limit on them regarding battery load while charging.

**Direct Charging Plant**

- Self contained, requires no generator
- Produces sufficient voltage to fully charge any battery type
- Fully adjustable (depending on regulation)
- Relatively cheap to build
- Efficient – same voltage as battery bank
- Robust, use with any inverter and any load
- High current outputs easily achieved
- Owner built and easy to repair
- Ultra reliable. One of the first alternator based direct chargers I ever built is still functioning perfectly today after more than 15 years of operation

You're probably starting to get the picture; direct charging plants are owner constructed, high efficiency battery charging plants that can be built for less expense than the purchase price of a high output mains type charger. They are more robust and reliable as well!

# Chapter 1

## Terminology used in this book

Back several hundred years ago, long before direct charging plants, batteries, solar panels, renewable power schemes or grid fed electricity were even imagined; a Scottish bloke was busy tinkering on a device that would change the world forever. This device was the steam engine and the Scotsman's name was James Watt. James was born in 1736 and passed away some 83 years later. Such was James's legacy on the industrial age that a unit of measurement that we are going to study and that will be used extensively throughout this book is named after him. This unit is the watt.

A watt is a measurement of energy and it is most useful to us in our electricity producing endeavours because it will tell us precisely what we need energy-wise and what we produce energy-wise, and it will detail the capabilities of all of our components.

What we need is a leveller and that is what the watt is. You see no matter what type of generation device you are building or buying, all you are really interested in is the work it is capable of doing for you! This will be calculated in watts.

### What is a watt?

As previously stated a watt is a measurement of work or energy and it doesn't just relate to electricity. Back when James was a lad, power was described in terms of what a horse could do – horsepower. This was a little ambivalent as you can imagine; questions could be asked like ... how old is the horse? What size is it? What did it have for breakfast? You get the picture. When Mr. Watt came onto the scene, a unit of horsepower became standardised. It became James's word and it is James Watt who named this motive force and what exactly it should be, regardless of what the horse had had for breakfast. It is commonly agreed that 1 horsepower = 746 watts.

The watt and its definition of work is a lot broader than just the output of an electrical device. In metric adopting countries, the power any given car has is measured in watts, or the equivalent which is kilowatts. A kilowatt (kW) is simply

1,000 watts. Most folks who like their cars will know the kW output of the engine and although we are not really into cars in this book, this example tells us that the watt is a pretty versatile measurement. Let's move along here and look at watts related to electricity.

If you have ever lived in a house connected to the grid, you will understand that the grid owner or electricity provider will send you a bill for the amount of power you have used, or you will pay for your power via a coin in a slot or whatever. You will know that electricity costs money and is a commodity. You have been sold electricity by the kW, or more correctly the kilowatt-hour (kWh). A kW is 1,000 watts. A kWh is the consumption of 1,000 watts of electricity for a period of one hour. For example, this could be a 1,000 watt radiator keeping your toes warm on a cold night for an hour before bed, or a 500 watt heater going for two hours, or a 100 watt light bulb burning for 10 hours.

If you own an engine that you wish to turn into a direct charging plant the engine will have a power output stated in horsepower. It will often be easier to convert this figure into watts as a measure of the work the engine can perform. We have already mentioned that 1 horsepower = 746 watts.

Say you have a 5 horsepower engine. This can easily be converted to watts by the sum: 5 (hp) x 746 (watts) = 3730 watts (or 3.73 kW)

If you have a battery bank the capacity will be in amp-hours. Multiply the amp-hour capacity by the battery voltage and you will have watts or more correctly watt- hours, which is how much work you can get the battery bank to do before it goes flat.

The point of all this can be summed up by the following: If you wish to build a direct charging plant you will need to understand watts. Your engine will have a power rating. This will be in watts or horsepower. If it is in horsepower then we will convert this figure to watts.

Your generator will have an electrical output. This will be in watts. Your battery will have a storage capacity and in some instances we will also convert this to watts or more correctly watt-hours of electrical storage. The watt gives us a common language that describes both power requirements, power output and power storage very well indeed.

Let's move on and look at what electricity actually is and how the watt fits in with volts, amps and other measurements you will hear about in your renewable energy endeavours.

## Basic Electricity

Back around the era of James Watt, another man named Benjamin Franklin in another country (America) decided it would be a good idea to fly a kite on a metal string in a thunderstorm. The kite string had a key attached near the end and was connected to a short length of rope as Ben had already deduced that the energy from a thunderstorm was best conducted through metal and could probably be stopped with something non-metallic. When Ben reached out and touched the metal key, he was rather surprised to receive a hefty electrical shock. Fortunately it didn't kill him; as we now know, electricity produced in thunderstorms can be lethal. Ben went on to become not only the first recorded victim of deliberate non-fatal electrocution but a founding father and statesman in America. Benjamin Franklin (1706 – 1790) gave us, amongst other things, a heap of electrical knowledge that is still in use today. What Ben did was figure out that electricity could be put to work to do useful stuff.

The 18$^{th}$ century was truly the dawn of the electrical era. Georg Simon Ohm (1789 – 1864), Alessandro Volta (1745 – 1827) and a host of other lesser known experimenters and scientists were having a heap of fun while playing around with electricity in wonderment and awe. But this book is not about history; it is more about renewable energy so let's leave these folk behind and instead learn a bit about the electrical terms that bear their names; the watt, the ohm and the volt.

### So what is electricity?

So what actually is electricity? Well blowed if I know! You obviously don't need to be a rocket scientist to use the stuff. All I know is a few basics about what it does and how it flows from one place to another. This is all you need to know as well to be right up there with all the so-called experts of the world who make satellites and motor homes and other stuff that runs on solar power. Defining electricity exactly is still a cause of contention. There is not a lot of point in trying to define the undefinable at this stage!

In its basic form electricity can be described as a bunch of things called electrons. Electrons are one of the building blocks of the universe. What is interesting is that when electrons aren't busy building the universe they can be made to flow through wires and perform work. The potential of this electricity is measured in volts, after the aforementioned Alessandro Volta.

This electricity can take two forms: either direct current (DC) or alternating current (AC). Although it is possible for electricity to flow through a multitude of wires, for the purpose of this lesson we will consider it to flow through only two for DC and two or three for AC. These are positive and negative for DC, and active and neutral for AC or three separate phases through three wires for three phase AC. For DC wiring, these wires should be coloured red for positive and black for negative. In AC wiring, the colours are red or brown for active and black or blue for neutral. In three phase AC the wires may all be the same colour. In order to flow, electricity needs a supply wire and a return wire. For DC, the supply wire is the positive and the return wire is the negative. For AC, the supply wire is the active and the return wire is the neutral. Connecting these wires together results in a short circuit, the result being a blown fuse or a tripped circuit breaker or a high electrical flow and resultant damage. Connecting these wires to an appropriately sized appliance will result in work being performed (operation of the appliance).

The potential - or voltage - is a rating given to the electrical supply. The relevance of this is that an appliance of any description that runs on electricity will have a voltage requirement.

DC volts can be described as a continual electron flow in one direction and this is usually depicted as a flow from positive to negative.

AC volts can be described as an oscillation of electron flow where the electrons flow alternately back and forth at the supply cycle which, for domestic power, is usually 50 hertz (50 times per second). One of the advantages of AC power is that it is easier to transmit over long distances due to the oscillation. Three phase AC power produced via a direct charging plant will have a cycle directly related to the speed (revolutions) of the device generating the power.

## Common examples of voltage

**12 volts:** Car electrical systems, small appliances made to be run from batteries etc, small stand alone DC solar systems, devices designed to run from a car power outlet or a car cigarette lighter socket.

**24 volts:** Some truck power systems, stand alone solar systems requiring more power than a 12 volt system can supply etc.

**48 volts:** Stand alone solar systems requiring more power than a 24 volt system can supply etc.

**60, 110, 120 volts:** Other sized DC stand alone systems, the voltage being chosen to match the size of the power requirements.

**Three phase alternating current (AC)** Three phase electricity will be referred to in this book because most generators, alternators, permanent magnet motors etc. which we will be tinkering with produce three phase electricity. Producing three phase electricity is more efficient than producing single phase power.

### Still keeping it simple, just slightly more technical

We have already stated that electricity is just a bunch of electrons that come out of wires. The question now is how much of this stuff comes out.

If voltage is the potential, how much power comes out is current. Current flow is measured in Amperes or Amps.

Very interesting but what we really want to know is how much work we can do with our electricity. This is measured in watts (we already met James Watt earlier). Now James did all the hard work thinking this stuff out and now that he has worked it out for us, its simplicity is extraordinary.

### Three simple things to learn

- Electricity is just a bunch of electrons coming out of two wires. Its potential is measured in volts (V).
- The amount of electricity coming out of the wires is current (the flow of electrons) measured in amps (A), or current ($I$) which is the same as amps.
- The amount of work we can do with the electricity is measured in watts. Put simply, this refers to the appliances we can run. A watt is a measurement of available energy, either required or produced.

### Georg Ohm

Georg Ohm was also mentioned earlier. He figured out that if voltage is potential, current is flow and watts are work, then; *there must be a simple relationship between these three things*.

A summary of what we know so far: Electricity is a bunch of electrons coming out of wires. The potential is measured in volts (V). The amount that is flowing is measured in amps (A) which is sometimes expressed as current (*I*). The work we can do with our electricity is measured in watts.

*Georg figured out a simple relationship between volts, amps and watts.*

Before we get slightly more technical and look at the teachings of Georg Ohm, let's look at a simple electrical appliance everyone is familiar with.

## Thomas Edison

An electrical genius in his day was Thomas Edison (1847 – 1931). Most folks seem to have heard of him. After several thousand attempts, Tom's best known gift to the future was the electric light bulb. Life would be pretty ordinary without it.

The simple light bulb Tom gave us has an output measured in watts. A 60 watt light bulb needs 60 watts of electrical energy to give out its full light output. The 60 watts of work required is the same 60 watts required regardless of whether the light is 12 volts, 24 volts, 240 volts 110 volts or whatever.

This is where Georg Ohm comes in. The difference between the above lights at different voltages is the amount of current that flows to them. Let's get out a trusty calculator and have a look at Mr. Ohm's law of voltage and current.

Getting slightly more technical (but only slightly), Ohm's law states that watts divided by volts = current required (amps).

The current required to power a 60 watt 12 volt light is 60 ÷ 12 = 5 (amps)

The current required to power a 60 watt 24 volt light is 60 ÷ 24 = 2.5 (amps)

The current required to power a 60 watt 240 volt light is 60 ÷ 240 = 0.25 (amps)

This also works the other way around. Amps x volts gives you the amount of watts required to power an appliance. My electric toaster uses 5 amps. Given that it is a 240-volt device: 5 x 240 = 1,200 watts.

Now a small but important point can be noted here: 60 watts at 240 volts requires only a small current flow of 0.25 amps. 60 watts at 12 volts on the other hand requires a larger current of 5 amps. Amps = current flow. The larger the amperage, the larger the current flow and the thicker the cable required to carry it.

Let's look at it in another way: How much work can 5 amps of current do? As work is measured in watts we need to convert the 5 amps of current into watts. Amps x volts = watts. Clearly 5 amps of current will do different amounts of work depending on the voltage.

5 amps coming out of a 12 volt battery will do 5 x 12 = 60 watts of work or around enough for a bathroom light. On the other hand, 5 amps coming out of an Aussie household power point measuring 240 volts will do 1,200 (5 x 240) watts worth of work which is enough to heat up a toaster at breakfast time or power 20 x 60 watt light globes.

And a final bit to get our head around here; if the abovementioned 60 watt light bulb is left on for one hour it will consume 60 watt hours, whereas if the toaster is run continuously for an hour, besides burning the toast it will consume 1,200 watt hours or 1.2 kWh.

## Summary of basic electricity

- Electricity is just a bunch of electrons coming out of wires
- The potential of the system is volts.
- The amount of electricity flowing is amps.
- The work we can do (stuff we can run) is measured in watts. A watt is a measure of power (work) required, or power (work) generated, or power (work) consumed.

Georg Ohm gave us some simple electrical laws that are precise, and his electrical law should, at least in part, be committed to memory.

### Ohm's Law states

Volts x amps = watts (which is the amount of work we can do with our electricity). Watts ÷ volts = amps (which is the amount of current that will be flowing through the wires).

The reason we want to commit this to memory is that the amount of work we can get done with our electricity is what we are interested in and the amount of current that flows through the wire will determine the size of the wire required during the construction phase of our renewable energy project.

Before we move on from the world of watts, volts, current and other things related to the electricity we plan to produce, let's look at a few other terms we will come across and what they mean.

## Efficiency

If you take a 5 horsepower engine and calculate that it produces 3730 watts or 3.37 kW you may be excused for thinking that this engine could produce 3730 watts of electricity. This is where efficiency comes in. This engine will produce 3730 watts of work under perfect conditions running at full speed. In reality a bit of altitude, temperature and other factors will reduce this amount of work somewhat.

You then need to take this work and convert it to drive a generator. The driveline will not be perfectly efficient. The driveline then turns a generator of some sort to make electricity. The conversion of rotational energy into electricity is not perfect.

All this comes down to efficiency. Your engine will only have available about 75% of its rated power (this depends a bit on who built it and rated it and whether it is diesel or petrol). Your engine will be around 75% efficient.

You will loose another 10 odd percent in the driveline and another 40 odd percent in the generation of electricity.

The production of electricity from an engine will at best be around 30 – 40 percent of the engines rated power output. The above mentioned engine rated at 3730 watts could at the very best be expected to produce around 1500 odd watts of electricity.

### Resistance

Resistance is inefficiency. As electricity flows along a wire it encounters resistance to flow. Resistance can be calculated and will result in a voltage drop. Resistance is also related to wire size (diameter of the conductor).

## Battery Terminology

A single portion of a battery is a cell. In this book when we refer to a cell we are referring to a 2 volt device. When we refer to a battery we are referring to a bunch of cells connected together.

## Series and parallel connections

Depending on the configuration of cells into a battery there will be series and parallel connections. Also common is parallel strings of a bunch of cells connected in series. Series and parallel connection of battery cells will be covered in the battery chapter.

*Let's move on and look at batteries and battery charging!*

# Chapter 2

## Batteries and Battery Charging

A battery is a chemical storage device for electricity. Discharging the battery modifies the chemical state, recharging restores the original chemical state.

The term “battery” was coined by an American, Benjamin Franklin, who was describing the electrical storage capabilities of charged glass sheets but it was a French inventor, a guy by the name of Gaston Planté who first demonstrated a lead acid cell to the French Academy of Sciences in 1860. The lead acid cell remains to this day the storage method of choice for home power users. Other battery types are making inroads as less expensive manufacturing techniques are discovered but the lead acid cell remains the mainstay of storage batteries.

A lead acid cell is a chemical storage device that uses a reversible chemical reaction to store electricity. The voltage of a lead acid cell is 2 volts (nominal). Regardless of the size of a lead acid cell the voltage will always be 2 volts (nominal). Nominal means that the voltage differs during charge and discharge. The actual voltage is closer to 2.2 volts fully charged, in an unused state. Commonly people think of lead acid batteries having a voltage of 12, this being the voltage of a car starting battery. A car starting battery is actually 6 lead acid cells joined in series in a single plastic box. Each cell is in a separate compartment.

For the purpose of this book, a cell is the device that stores electricity and a battery is a collection of cells. These cells can be in a single box like a car battery or separate cells like solar storage batteries or series combinations of cells or boxes of cells (batteries). A lead acid battery cell comprises of differing plates of lead alloys (battery plates) separated by acid (battery electrolyte). The number of plates and or the distance between the plates does not change the battery voltage but it does change the battery characteristics. Another variable in battery construction is the strength or density of the acid in the electrolyte.

### Terminology in this book

When a lead acid cell is referred to it will be a 2 volt device. The relevance of this is that some battery manufacturer’s data refers to cell voltages, because the manufacturer has no idea how many cells you are using or what configuration they are wired into.

When we refer to a lead acid battery in this book we are referring to a group of lead acid cells connected together.

## Battery types

Lead acid batteries can be broken down into several different types:

- Starting batteries
- Deep cycle batteries
- Standby batteries
- Industrial batteries

These batteries can be further broken down into three broad groups; unsealed, sealed and gel type.

## Starting batteries

Starting batteries are as the name suggests designed to start engines. A car battery is a good example. The requirement of a starting battery is to produce a high amount of current for a short period of time. This is what is required to start most engines. A secondary requirement is the ability to recover quickly, to be ready for starting again if the need arises.

To allow high starting currents a typical car battery has thin plates of lead closely spaced together. The combination of thin closely spaced plates will produce high current delivery capabilities and high rate of charge acceptance. The downside of closely spaced, thin plates is the risk of plates warping, with the resultant possibility of the plates touching together and damaging the battery.

Plate warping can occur when a starting battery is discharged deeply (allowed to go “flat”). Starting batteries do not make good deep cycle batteries because the risk of the plates in the cells warping is increased with discharge. These batteries are designed for high, short term discharge followed immediately with a recharge.

Starting batteries are occasionally used in deep cycle applications but the differences in construction between starting and deep cycle batteries should be understood and the depth of discharge must be limited to a greater extend than with a deep cycle battery.

The amount of work a starting battery can do is stated in Cold Cranking Amps (CCA). CCA is commonly described as the amount of current a starting battery can supply to a starter motor at -18°C (0° F) for 30 seconds. The amount of current required by a starter motor is determined by the starter motor size. This data is supplied by the starter motor manufacturer or the manufacturer of the engine that the starter motor is attached to. A starting battery should always be sized correctly to starting requirements.

Starting batteries have a higher density of electrolyte than deep cycle batteries. The higher density of electrolyte makes for better current flow but is detrimental to battery life.

## Deep Cycle Batteries

Deep cycle batteries are designed for applications where long periods of discharge are anticipated between recharging and where batteries are discharged and recharged at the same time, such as solar or renewable energy used in charging batteries in motor home or household applications.

Deep cycle batteries differ from starting batteries in that deep cycle batteries have a lesser number of thicker plates arranged further apart than those found in starting batteries. Thicker plates spaced further apart provides protection against the plates warping and subsequent plate to plate contact at the expense of high short term current supply.

Deep cycle batteries can also be utilised as starting batteries but the amount of CCA available should be calculated correctly if there is no manufacturer supplied CCA data. CCA is the amount of amperage that can be delivered at 0°F for a period of 30 seconds without the battery voltage dropping below 7.2 volts.

Deep cycle battery capacity is stated in amp-hours. An amp-hour is a measure of battery capacity that relates to the amount of amps that the battery can provide over a period of one or more hours (more on calculating amp-hours later).

Deep cycle batteries have a less dense electrolyte than starting batteries. If you are testing the density of the electrolyte (specific gravity) of a deep cycle battery with a car type hydrometer you can expect a fully charged deep cycle battery to show about 50% charged on a starting battery hydrometer.

## Standby Batteries

Standby batteries are very similar to deep cycle batteries but their design differs in that a standby battery is generally kept in a fully charged condition with a permanently connected battery charger until the standby battery is required. When a standby battery is required the discharge can be quite high. Standby batteries are generally used in applications like telecommunications facilities or critical medical equipment, to provide power in case of a (mains) power failure. A standby battery can be expected to supply power until either the power is restored or an alternate power supply (like a generator) can be brought online. Standby batteries can be very good deep cycle batteries. Like deep cycle batteries, standby batteries have their capacity stated in amp-hours. If you were choosing a battery for an application like say a home or motor home, you would not choose a standby battery. That said, the most common second hand battery on the market is an ex standby battery.

## Industrial Batteries

Industrial batteries are deep cycle batteries made for specific applications like forklift machines, golf carts, street sweepers etc. Industrial batteries make excellent deep cycle batteries but can require higher maintenance due to minimum sizing and minimal electrolyte capacity. Industrial batteries are generally more compact for their capacity than deep cycle batteries. Industrial batteries also have their capacity stated in amp-hours. For a new battery bank purchase sometimes industrial batteries can offer a more cost effective solution than deep cycle batteries. The trade off is a higher maintenance requirement and more effort to make the battery installation comply with Australian Standards.

## The difference between unsealed, sealed and gel type batteries

An unsealed battery has a removable vented cap and direct access to the electrolyte. Electrolyte will need to be checked and topped up if required with distilled or deionised water.

A sealed battery is a flooded battery with sealed caps and an inbuilt water combiner that will prevent most of the water loss that is associated with an unsealed battery. It is usually not possible to add water to a sealed battery.

A gel battery is a battery where the electrolyte has been turned into a jelly like substance that will not flow or spill. This allows some gel batteries to be laid on their sides.

An unsealed battery is the most robust battery on the market. Unsealed batteries are immune to a bit of overcharging and the charge voltage tolerances are not critical. Electrolyte can be removed and tested and water can be added if required.

Sealed batteries require more precise voltage regulation than unsealed batteries because the risk of water loss must be taken into account. Often this water cannot be replaced and too much loss of this water from the electrolyte will result in reduced battery life.

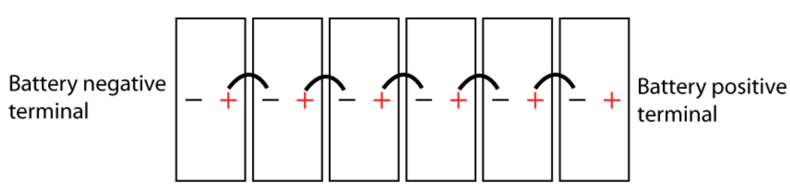
Gel batteries are even more critical when it comes to charging voltage and charging regulation because overcharging or an over voltage can move the gel away from contact with the plates resulting in gas pockets that cannot be repaired and reduced battery capacity or complete battery failure. The gel in gel batteries also seems to dry out as the battery ages making gel batteries lifetime less than that of unsealed batteries.

All batteries produce explosive gasses when being recharged. All batteries require suitable ventilation and there is NO difference in ventilation requirements between differing battery types.

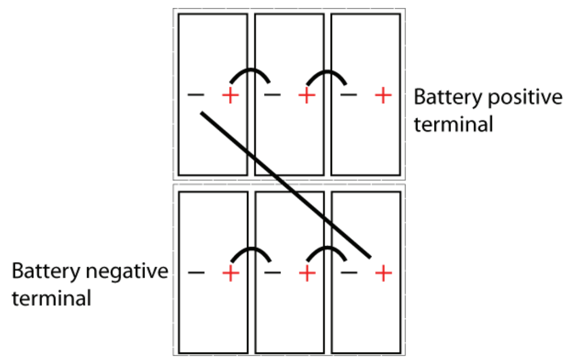
## Understanding parallel and series connections

Series connections are the most common cell connections. There is not much use for a single lead acid cell, the voltage is simply to low. Joining a bunch of cells together in parallel makes a battery bank which has a higher voltage and is a much more useful device. As already mentioned a car battery is simply 6 lead acid cells joined together in series.

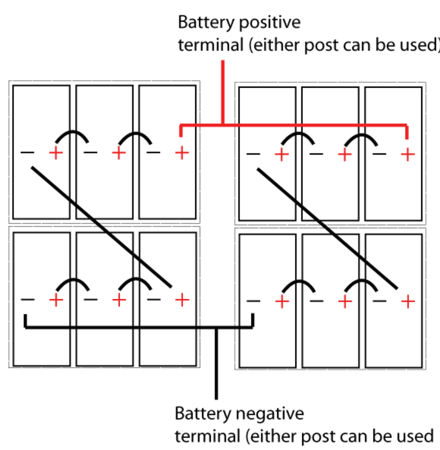
Series connections increase voltage but battery capacity remains the same as the cell capacity. Series connections are depicted below: Let's assume that the cell capacity is 220 amp/hours.



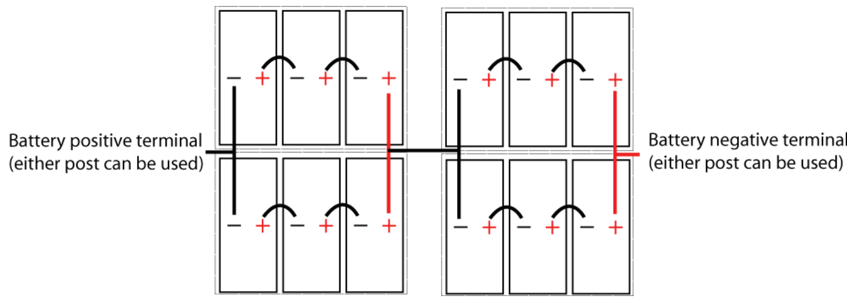
Above: Inside a typical 12 volt battery, all cells joined in series. Capacity of single cell = 220 amp-hours. Capacity of battery = 220 amp-hours @ 12 volts.




Above: Typically 220 amp-hour golf cart batteries are 6 volts. Here two are joined together in series to make a 12 volt battery. Capacity of each golf cart battery = 220 amp-hours @ 6 volts. Capacity of completed battery bank = 220 amp-hours @ 12 volts.




Above: 4 x 220 amp-hour golf cart batteries in series parallel. The completed battery voltage = 12 volts, 440 amp-hours. Note: If the parallel connections are taken away we are left with 2 x 220 amp-hour 12 volt batteries




Above: 4 x 220 amp-hour golf cart batteries connected in parallel then in series to make a 12 volt 440 amp-hour 12 volt battery. Note: If the centre connector is taken away we are left with 2 x 6 volt 440 amp-hour batteries

You should understand the differences in connection of both series parallel and parallel series arrangements.

Connecting batteries in series to achieve the desired battery voltage then connecting to another series string is preferable to connecting in parallel first.

The best way to arrange batteries is to have only a single string of identical cells wired in series. Series strings of single cells will charge evenly. The next best and a common way to arrange batteries in to make series strings then connect the strings in parallel. The parallel strings may not all charge evenly and the recommended maximum number of series strings is three. The strings can easily be separated occasionally and a boost charge performed to even up the charge in all cells.

The final diagram shows where batteries are first connected in parallel then the parallel batteries are connected in series. This is the least preferable method of connection because separating into groups results in a different voltage than the groups joined together.

## Battery "rules"

- Series only connection of cells is the most desirable connection when making a battery
- Series then parallel is a common practice but should be limited where possible to a maximum of three strings

- Connecting cells in parallel then connecting the parallel groups in series is not recommended but will work if required
- A battery bank should comprise of identically sized and aged cells
- Rules are made to be broken. You should always use what you have and I have seen different sized cells connected together and different sized battery banks connected in series and or parallel. It will work but some efficiency is lost. If you connect a 200 amp cell to a 150 amp cell in series you are limiting the capacity of both cells to 150 amps.
- If you connect a 120 amp-hour 12 volt battery in parallel to a 150 amp-hour 12 volt battery you are limiting the final capacity to 240 amp-hours (twice the capacity of the smallest battery).
- When you connect together separate series strings of cells in parallel it can be a good idea to occasionally separate the strings and charge them individually. This will even up all the cell voltages. This is not usually possible if individual cells are joined in parallel.
- Before working on battery terminals it is of utmost importance to understand the risks and minimise them. Battery dangers are covered at the end of this chapter.

## Understanding battery capacity

We have already learned that deep cycle battery capacity is stated in amp-hours. An amp-hour is a measurement of how many amps of current can be taken out of a battery over a specified time. What needs to be understood is that the capacity of a battery changes depending on how much power is taken from it over a period of time. A battery will produce more total energy if it is discharged slowly than it would be able to supply if the demand in current was high over a short period of time. For this reason a battery manufacturer will state several different amp-hour capacities in conjunction with several different time frames.

Let’s look at a typical deep cycle battery from manufacturer X. This battery is sold as an 1100 amp-hour deep cycle battery suited to a solar system.

**A battery manufacturer states a battery capacity as follows:**

| | | |
|---|---|---|
| 1190 amp-hours | @ | C120 |
| 1100 amp-hours | @ | C100 |
| 790 amp-hours | @ | C20 |
| 690 amp-hours | @ | C10 |
| 620 amp-hours | @ | C5 |

What this data translates to is the amount of work the battery can perform over a given period of time.

Looking at line 1 we can see that if we discharge this battery over 5 days or 120 hours (C120) we can expect to get a total discharge of 1190 amps. Translated this is a continuous electrical flow of 1190 ÷ 120 = 9.9 amps

If we go to the last line we can see that if we discharge the battery heavily with a large discharge current we can expect a total capacity of 620 amp-hours over a 5 hour period (C5). Translated this is a continuous electrical flow of 620 ÷ 5 = 124 amps

Two ends of the scale produce totally differing discharge periods resulting in two completely different capacities. Clearly the battery produces more *total* energy when discharge slowly.

The amount of work this flow of amps can produce will depend on the voltage of the battery bank that is being used. To calculate the amount of work we need to convert amp-hours to watts or watt-hours.

Referring back to the previous chapter this conversion is done using Ohm's law. Amp hours divided by battery voltage = watt hours or watts of work the battery can perform.

## Discharging a battery

When a battery is connected to a load and expected to perform work it begins to discharge. In the case of a starting battery the discharge is usually of a short duration with a high current flow. In the case of a deep cycle battery the discharge is usually a lesser current over a longer period of time.

**There is a basic rule to discharging deep cycle batteries called the 10% rule**

The 10% rule states that the maximum continuous discharge from a deep cycle battery should be no more than 10% of the batteries C10 capacity. A 220 amp-hour golf cart battery for example should not be discharged continuously at more than 22 amps.

As a lead acid battery discharges the battery plates become more prone to damage and begin to wear out. To prevent damage and premature wear a deep cycle battery should be limited as to the amount of power removed. Typically no more than 30% discharged should be considered maximum for normal use. In the case of the above 220 amp-hour golf cart battery this limits the discharge to 66 amps taken out over a minimum length period of 3 hours.

Manufacturers of deep cycle batteries provide data for their product. This data should include cycle life. Typically the cycle life of a quality deep cycle battery looks like this:

1500 cycles to 80% discharged
2500 cycles to 50% discharged
3300 cycles to 30% discharged
>5000 cycles to 10% discharged

The manufacturer goes on to state that repeated discharges below 30% should only be planned with consultation from the factory. This consultation would involve an assessment of the charging equipment and a determination of discharge and recharge times. If more than 30% of a deep cycle battery capacity is removed then it would be prudent to recharge the battery back to full as soon and as efficiently as possible. This is where a direct charging plant will be a huge asset!

### Cell voltage during discharge

The nominal voltage of a battery cell is 2 volts. The actual cell voltage will vary slightly but fully charged it should be around 2.2 volts. When a load is connected to a battery bank the cell voltage will begin to fall. If the load is of a brief duration the cell voltage will fall when the load is applied and rise again after the load is disconnected.

As the battery becomes discharged the cell voltage will continue to fall and when the load is removed the recovery will be back to a lower level than the 2.2 volts of a fully charged cell.

Below is a table showing approximate cell voltages after different levels of discharge:

| Cell Voltage | State of Charge |
|---|---|
| 2.2 | Full |
| 2.1 | 75% |
| 2.0 | 50% |
| 1.9 | 25% |

The table of voltages is approximate and precise voltage will vary slightly depending on the age of the cell and the length of time it has rested after the discharge. The cell should be stable with no discharge or recharge for at least 30 minutes prior to taking the voltage reading to obtain any real accuracy in determining battery state of charge by cell voltage. In the case of a battery where cell voltage cannot be measured simply multiply the cell voltage by the number of cells to obtain a battery voltage. For a 12 volt battery the fully charged voltage should be around 6 (cells) x 2.2 (cell voltage) = 13.2 volts

A deep cycle battery bank should have a permanently connected and accurate volt meter attached. If your battery bank has an accurate volt meter attached and you monitor it you will begin to understand the voltage versus state of charge under a wide variety of load and charge conditions.

Eventually, if you keep discharging a battery the cell voltage will fall to such a low level under discharge that appliances will cease to function. An inverter for example will have a low voltage cut out that will turn off the inverter at around the 50% discharged state.

If you connect a load to a fully charged battery the initial voltage drop will be slight (depending on the load). A 10% (C10) load on a fully charged battery would result in a voltage drop of only around 0.1 volts. On the other hand if the same load was applied to a battery with only 50% of charge remaining then the initial voltage drop would be much higher, say around 0.3 – 0.5 volts depending on battery age and condition. The low voltage cut out on an inverter would be on very