electricity

If you get too much of it then it will kill the life out of you and lay yourself flat on the floor, dead. Just a little warning there, but nothing to be worried about as long as you're paying attention: it's the high voltage that gets you.

There are various terms used to describe electricity, and you need to get your head around them to be able to understand the finer points of a battery-based, renewable-energy system. To elucidate: I have in the past spoken to, and have been asked to give advice to, owners of small wind turbines. The first thing that becomes apparent is that they have no idea how much power they are creating and using. Combine this with only a vague knowledge about batteries and their amp hour storage capacity, and you have a recipe for system failure. So, without further ado, I will introduce the terms. We are going to think of electricity in terms of water flowing through a pipe and filling a water tank.

voltage

This is measured in volts. It is effectively the 'pressure' of electricity: the higher the voltage the greater the pressure and the greater the potential flow of electricity. So if you think of it in terms of water: the greater the pressure, the more water will flow through a given size of pipe.

current

This is measured in Amperes (amps). It is the 'volume' of electricity and, thinking of it in terms of water; it is the amount of water that flows through the pipe for any given pressure.

Ampere hours (Ah) is a measure of current and time. If you were to power a 40 watt light that took its power from a 24 volt battery bank, then the current would be: 40 ÷ 24 = 1.7amps. If you used this light for an hour it would use 1.7 amp hours of electricity. Battery capacity is measured in amp hours, for more detail see the capacity section of the batteries chapter (page 000).

watts

This is a measurement of the energy available: it is the combination of volts and amps. If we think in terms of water again: water at a low pressure going through a large pipe fills a tank in a certain time. The tank could be filled in the same time with water at high pressure through a smaller pipe. So low volts and high amps give the same power as high volts and low amps.

The energy you use from the National Grid is measured in kilowatt hours (kWh), which is a measurement of watts and time. You see it as a unit of electricity on your electricity bill. A kilowatt is a thousand watts, so a circuit that uses a thousand watts in one hour will use a kilowatt hour per hour when it is switched on. A ROCs meter, see page 27, fitted to the output of an inverter is a standard electricity meter that measures the kilowatt hours of energy produced by a home-generation system.

resistance

This is measured in ohms, and is represented by an Omega symbol (Ω), that looks like an upturned horseshoe.

Riding a bike up a hill illustrates a resistance. The rider needs to put more energy into the pedals to move the bike up the slope. Once he starts going downhill the brakes are needed or else he will become intimate with a hedge, building or the road surface. The action of the brakes on the rim produces heat, which is the energy in the motion being dissipated.

Electricity is similar in that a load, (we've talked about electrical load before on page 40) like, for instance, a light bulb, will resist the flow of electricity in a circuit and only allow enough through to produce light – energy is used to create light just like energy is used to bicycle uphill. If there is a short in the circuit that allows electricity to flow from positive to negative without going through the bulb, then a huge amount of current will flow and things will get very hot and burn out. This is because with a short circuit there is no resistance to the flow of electricity.

So why do you need to know this sort of stuff? Well, it needs to be appreciated when using power that the parts of the system need to be matched. It is also very useful when assessing the outputs and consumptions of the installed system, especially if you are like me and want to get the most out of what you have paid for. If you don't understand electrical terms then there is no way for you to work out if you are using more power than you are generating, and what an individual piece of equipment will consume.

I have provided a couple of examples below for you to work through to see how the various terms relate to each other.

An easy way of thinking about all this is by taking a 12 volt bulb with a resistance that only allows 1 amp through it and so by using the formula below we can work out that it will use 12 watts of power, or 12 watt hours per hour.

Basically volts x amps = watts

or watts ÷ volts = amps

So if you have a 12 volt bulb, like those used on a car, running off a 12 volt battery, and it draws 1 amp, as shown on an amp meter, then the bulb is using 12 watts of power from the battery.

12V x 1A = 12W

This is the sort of thinking that is required when deciding which house circuits to leave on the mains and which to connect to your home-generation system to prevent draining the batteries and leaving them in a constantly flat condition.

So let's look at another example for you to think about:

A 3 kilowatt inverter when producing its 'rated output', which is the manufacturer's stated maximum continuous output, will draw 60 amps from a 48 volt battery, which means it is a 48 volt inverter. So the sum is 60A x 48V = 2880W.
Or a 24 volt inverter will draw 120 amps from a 24 volt battery and the sum will be 120A x 24v = 2880W.

Here are some more examples of how the current varies with voltage for a given wattage showing how the current increases as the volts reduce. So, for a 1 kilowatt load, like a small heater, drawing 1000 watts the variations are as follows:

1 kW = 1000W = 4A at 240V or 9A at 110V or 20.8A at 48V or 41.6A at 24V or 83A at 12V.

As you can see the 12 volt inverter is switching more current than the 48 volt model and so there is a greater strain on the inverter and, as described later in this chapter (page 114), the cables have to be larger to cope with the higher current.

series and parallel

These are terms used to describe the way things are wired up.

Series wiring is where the electricity goes through one thing and then through the next and the next, etc. So, if you had a 48 volt system and a box of 12 volt bulbs, you could use four of the 12 volt bulbs 'in series' and they would work on the 48 volt system. I have done this when I ran out of 50 volt bulbs, which are what I usually use on the system. In a large battery bank 2 volt batteries are wired in series to make up the battery voltage to suit the system voltage, i.e. 12, 24, 48 etc.

Parallel wiring is where the electricity has several paths to choose from, rather like the amp meter and shunt described in the *components* chapter (page 28). If perchance you had some 48 volt/20 watt bulbs then, to get sufficient light, you would wire two or three bulbs in parallel, so that all the bulbs came on at the same time and each would give 20 watts.

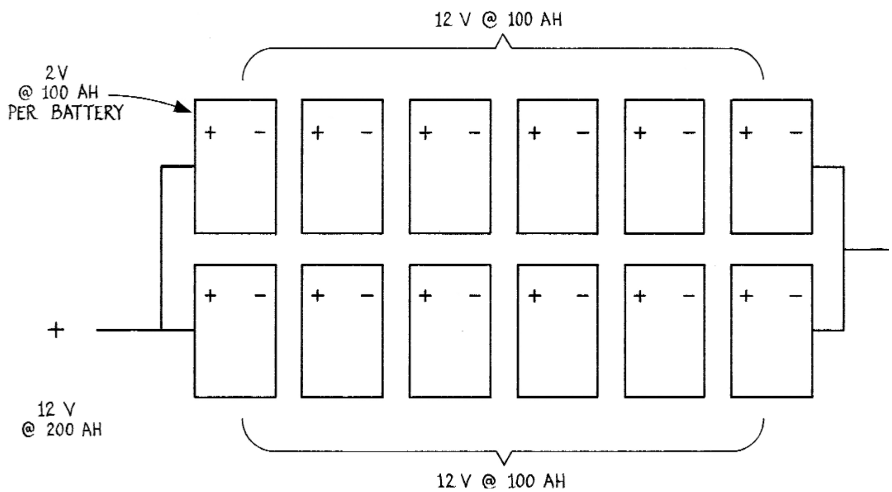

fig 46: 2 pairs of batteries in series / parallel

To increase the storage capacity of a battery bank you can add another series of batteries in parallel with the first, see fig 46. The batteries are wired in series to get the correct voltage, and then another set of batteries are added in parallel to increase the amp hour capacity.

volt drop

The higher the current the larger the cables need to be: in the example given above for 1 kilowatt load being drawn from a 12 volt inverter, the cables need to be large-sized welding cable.

Which reminds me that I should explain something about cable size and resistance: if you draw too many amps through a cable the action of resistance will create heat. This heating represents a loss of power and can be a fire hazard. Circuits have fuses to prevent this heating effect, which is usually caused by either a fault or misuse. See the *system components* chapter (page 28) for more detail about fuses.

Ok, so it's the combined action of too many amps and a cable that is too small that causes the heating in cables and also causes volt drop. What is actually causing it is the resistance of the cable to the current flowing through it. Cables are made of metals that are good at conducting electricity, but each metal has different resistance to the electrical flow. Steel has seven times the resistance of copper and so for the same current the steel cable has to be seven times the size of the copper cable.

The action of resistance in cables results in power loss and what we call 'volt drop'. Here is a concrete example: I built the Ecolodge in one of my meadows and its lights are run on 48 volt direct current power from the battery bank. The lodge is about 100 metres from the battery bank and so when all the lights are on, using a high current, the voltage measured in the lodge is 45 volts. This shows there is a volt drop of 3 volts, which doesn't sound much but it affects the amount of light produced.

The bulbs draw 1.2 amps each and so:

48 volt from the battery bank would yield

$$48V \times 1.2A = 57.6W$$

But with 45 volts:

$$45V \times 1.2A = 54W.$$

So we can see that the volt drop has reduced the amount of light produced – not by much you say, but it all adds up.

That's why the National Grid is run at such high voltages (up to 32,000 volts): to reduce the current and the heat losses whilst being able to use cables of a practicable size. If you try to run a car headlight off a 12 volt battery with about 500 metres of thin bell-wire-type cable, the bulb would hardly glimmer due to the resistance in such a long length of small-diameter cable.

cable size

When planning a new home-generation system it is necessary to make sure that the cable size is large enough for the estimated load required from the system and so prevent volt drop or resistance heating. It is possible to work out the correct size for any system and in this section I am going to go through the process from basic principles so that you can work out the right size of cable for any given voltage and current.

So, electrical cable is classified by the cross-sectional area of the conductor, i.e. without the insulation external coating. Cables of $75mm^2$ or $50mm^2$ are common for battery cables from rectifiers and to the inverter. An 8mm diameter cable has a cross-sectional area of 50mm2; you have to go back to school and use πr^2 (3.142 x the radius squared) to change the diameter of a circle into area.

Now then, we can work out what size of cable is needed for a specific current (amps) and distance. This is based on the specific resistance of the conducting metal in the cable. This information was retrieved from *Teach yourself Electricity* by C W Wilman, published in 1942. The resistance of copper is 0.0000017 ohms per cubic centimetre. We are able to work out the resistance of any given cable from the length, cross-sectional area, and the current flowing through it. Having worked out the resistance we can then calculate the volt drop and hence the power loss. There are three calculations here and for interest sake I am going to go through them with examples and try to make it as straightforward as possible.

To calculate the resistance of a length of cable: take the specific resistance of copper and multiply it by the length of the cable (in centimetres). Then divide the answer by the cross-sectional area of the cable (in square centimetres).

A square centimetre is 10mm x 10mm, which gives an area of 100 square millimetres, and so an 8mm cross-sectional area cable is written as 0.08cm2 when we are working in centimetres (8 ÷100 = 0.08).

cable size calculation

Right, so here's the first bit of maths:
Let's take as an example 24 metres of 6mm cable with a maximum current of 30 amps at 24 volts.
Cable length in centimetres:

24 m x 100 = 2400 cm

Cross-sectional area of 6mm area cable in centimetres:

6 ÷ 100 = 0.06 cm

Resistance (R) of the cable:

(0.0000017x2400) ÷ 0.06

R = 0.00408 ÷ 0.06
R = 0.068 ohms

The next bit of the calculation gives the volt drop

Volt drop = amps x ohms (resistance of cable)

Volt drop = 30 x 0.068
Volt drop = 2.04 volts

From this we can now calculate the loss in power. If the current remains the same but the volts have dropped then there is a reduction in the available power, because if we go back to the start of this section we get our fundamental equation:

volts x amps = watts

Power produced with full voltage:

24V x 30A = 720W

Power produced after volt drop

24V – 2.04V = 21.96V
21.96V x 30A = 658.8W

Loss of power:

720 – 658.8 = 61.2W

To show this as a percentage we take the actual loss in watts and divide it by the initial power before loss, and multiply the result by 100.

61.8W ÷ 720w = 0.0858

0.0858 x 100 = 8.58%

Which is quite a large loss of power and so the cables need to be larger. It is up to you to decide what an acceptable power loss is and, more importantly, where in the system the loss occurs. If it is in the power cables around the battery and inverter where large currents frequently flow then losses should be kept to a minimum because if the power is lost at this point then it is lost even before it is fed into the rest of the system. To get your head around this try substituting 8mm^2 cable into the calculations and see how the loss is much reduced. It works out at 6.4% for 8mm^2 cable, which is better.

As a guide it is usual to use 50mm^2 or 75mm^2 cable for batteries and inverter cables, and 25mm2 to 50mm2 cables from turbines and solar arrays depending on the output of the units and the voltage.

This is where the low-voltage side of the system (the battery side of the inverter) choice makes a big difference. If we re-run the 6mm calculation above for a 48 volt rather than a 24 volt system then the volt drop is 1.02 volts and the percentage loss only 2.08. I remind you that at 48 volts the current required to produce 720 watts is 15 amps. So as you can see the ideal is to use large cable on the low-voltage side, and if cable runs are of considerable distance then go for a larger system voltage (see page 121).

types of electricity

There are two main types of electricity: namely alternating current (AC) and direct current (DC).

Let’s deal with the easy one first; direct current consists of one cable having a positive charge and the other cable having a negative charge. Direct current (DC) comes from batteries, dynamos, or battery chargers. Batteries produce direct current and have a positive terminal and a negative terminal. Dynamos were fitted to all cars before the advent of the alternator, and old-type wind turbines were DC machines (like the famously reliable Jacobs machine, or the Lucas Freelight). It meant that they were ideal for charging batteries but used carbon brushes to collect the current from the spinning armature. These brushes needed regular maintenance otherwise they stuck, prevented contact and left the turbine spinning freely without a load – usually in a gale. These dynamos are also labour intensive to manufacture and hence expensive to produce. Battery chargers change mains AC power into DC suitable for charging batteries. There is more about this sort of stuff in the electrical components part of the *system components* chapter (page 23).

Alternating current is exactly what it says, the electricity in each cable alternates between positive and negative in a series of waves. It is produced like this because of the way the generators are constructed, and the wave pattern is called a ‘sine wave’. See fig 47 for a diagrammatical explanation and imagine that below the line the voltage is negative and above it is positive.

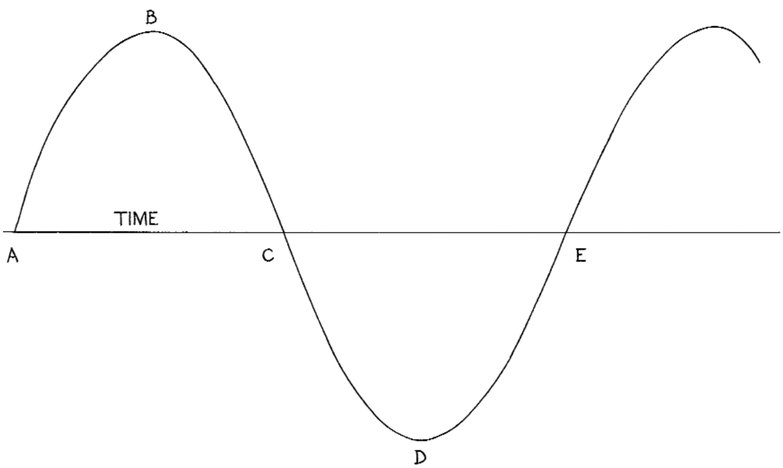

fig 47: alternating current sine wave

generators

I don’t want to go into huge amount of detail about generators, but just for interest’s sake let’s go back to 1831 when Michael Faraday was messing about with magnets and coils. Faraday artificially produced electricity with a magnet and a coil of wire shaped a bit like a doughnut. Electricity is produced in the coil of wire when the magnet passes the coil, and the change of magnetic forces causes electrons to flow. There is more about electrons in the *solar panels* chapter (page 59) but suffice it to say that electricity is the flow of electrons through a conducting material.

In generators there are coils of wire and magnets, but let's talk specifically about modern brushless alternators, which are the heart of the modern wind turbine. An alternator is a generator that produces AC as opposed to DC electricity. The magnets are permanent magnets and not electro-magnets as in the past. This means that the magnets can be mounted on a shaft and have no electrical connection to them, hence the term 'brushless alternator'. The coils of wire where the electricity is created can then be mounted around these spinning magnets, which are driven by the turbine blades, and the coils can remain stationary.

The next thing is that electricity is created when there is a change in the magnetic polarity (north to south to north, etc.), and so the magnets are fixed in place on the shaft with opposite magnetic poles next to each other. As the changing magnetic poles pass any given coil in the alternator the current changes from positive to negative and back again, as the magnetic polarity goes from north to south to north etc. Right so that's enough of that, but I hope it gives some insight into why we get alternating current from brushless generators.

Wind turbine generators are built to various formats, some have the magnets on a shaft in the middle and others have the magnets on the outside and the coils in the middle. My Proven turbine has the coils mounted in a doughnut shape with magnets mounted on round steel plates fitted either side of the doughnut coils, whereas the FuturEnergy turbine included in my research study has the coils in the middle on the shaft and the magnets fitted in the case on the outside. In all modern generators it's the magnets that spin and the coils that remain

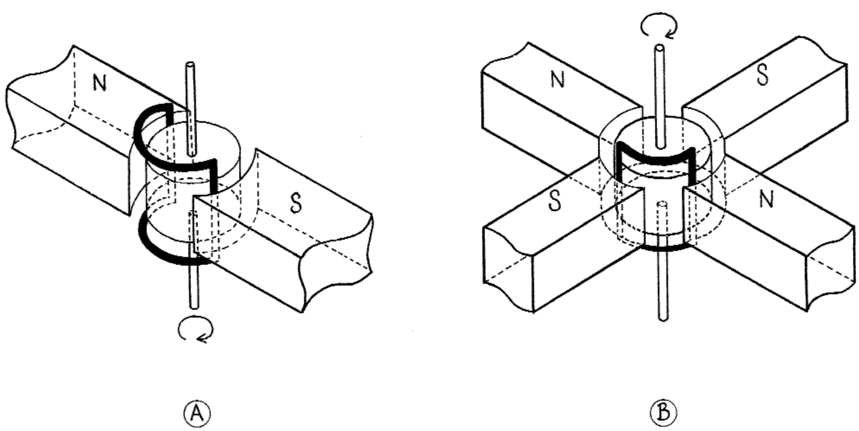

fig 48: 2 pole (A) and 4 pole (B) generator coils and magnets

stationary, so that the permanent electrical connection can be maintained. To show how the magnets interact I've included a drawing here from an old book on electricity called *Modern Electrical Practice*, published around 1930 and illustrating an older type where the coils spin on the generator shaft. This shows how the magnets and coils work together in that the north magnet acts on one part of the coil as the south acts on the other part at the same time.

three-phase generators

Most wind turbine generators are three-phase, which means that for a given set of rotating magnets there are three sets of generating coils and so three times as much electricity can be produced. Each set of coils produces the peaks and troughs of the AC electricity sine wave pattern at slightly different points. Imagine if you will that the three sets of coils are labelled a, b, and c. The magnets move past coil set a, then b, then c, and then back to a, and so on and produce a series of overlapping wave forms.

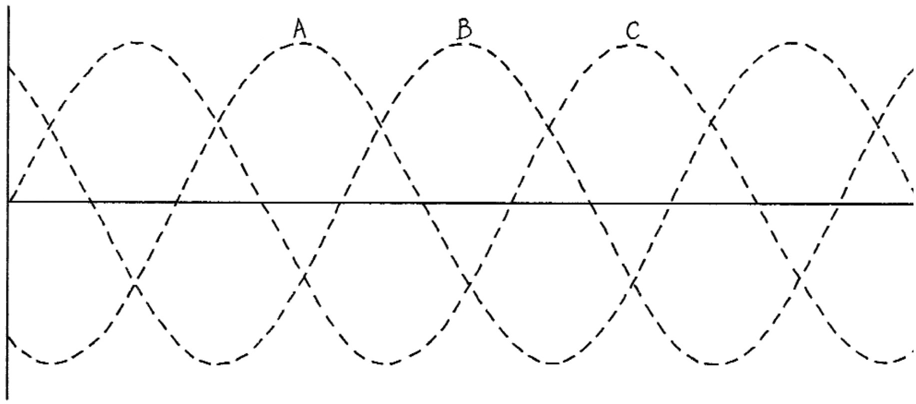

fig 49: three-phase wave form

Many three-phase motors show all the ends of the three sets of coils in the motor-connecting box, however with generators there are just 3 wires instead of 6. The configuration is shown in fig 50 and electricity can be measured between any two wires because the other ends of the coils are connected together inside the generator. This means that the three phases of power are produced between A and B, B and C and A and C.

Car alternators are rectified three-phase, 12 volt alternators, and it is interesting to note, although, you understand, purely as a side issue, that if one of the diodes in the rectifier is faulty then you lose the output of two phases, not just one.

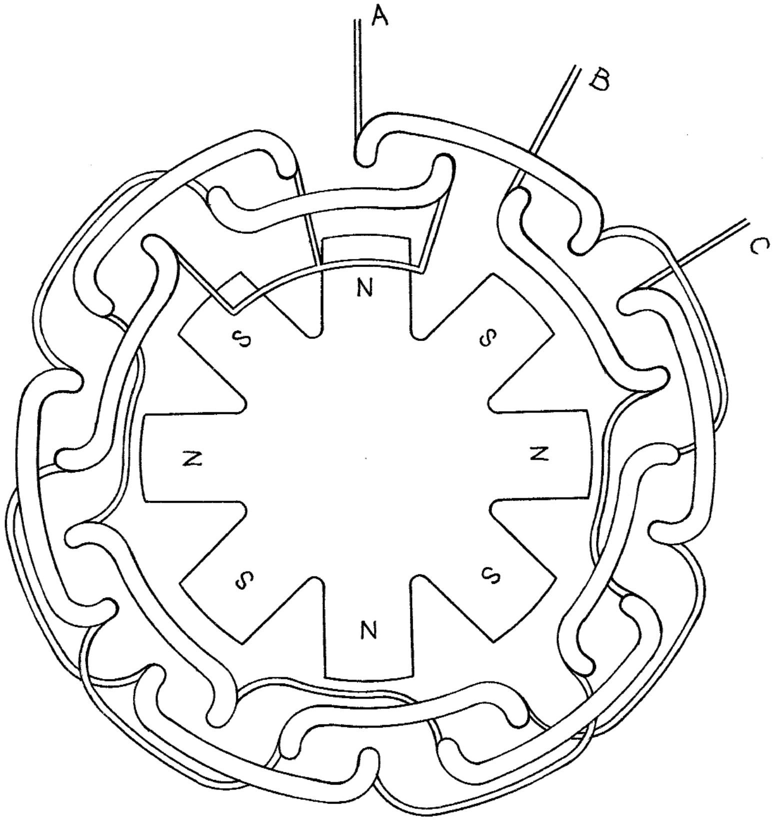

fig 50: three phase coils and magnets