Windpower Workshop

Hugh Piggott

Foreword by Tim Kirby

British Wind Energy Association

Windpower Workshop

Building Your Own Wind Turbine

Hugh Piggott

Centre for
Alternative
Technology
Publications

The Author

Hugh Piggott runs his own successful windpower business from his home on the beautiful, appropriately windswept, peninsula of Scoraig, off the coast of Scotland. There he advises individuals and companies at home and abroad on small to medium scale windpower turbines and systems. He has been making windmills for twenty years from scrap parts and teaching others how to do so, for example on the Centre for Alternative Technology's twice-yearly windpower course. His books are amongst the Centre's best sellers. He has a wife and two children. He has also written *It's A Breeze! A Guide to Choosing Windpower, Scrapyard Windpower* and *Choosing Windpower* for C.A.T. Publications.

Contents

Foreword

Windpower bites. It's one of those multi-faceted subjects which appeals to all sorts of people from all sorts of angles - free power, no environmental costs, not to mention a world of opportunity for the 'gadget' folk. But what's it all about, and what can practically be done?

Although wind is one of civilisation's oldest forms of mechanical power, it suffered something of a relapse from the start of this century as the benefits of mass cheap energy supply came through. But as the true (and horrendous) costs of mass fossil fuel use come to light, wind is making a big comeback, particularly with large grid connected turbines in Europe. A growing number of countries are doing their best to encourage wind energy generation as part of a range of vital measures towards sustainability.

Although it may seem contrary to 'green' thinking, in many ways the 'grid' is a useful environmental tool – it allows one area's surpluses to meet another area's needs. This avoids much of the costly (economically and environmentally speaking) requirement for energy storage – common in most small 'off the grid' systems. If we all wanted to use autonomous wind energy with battery storage, we would run out of lead before we got very far!

But there certainly are places where the grid does not reach, and plenty of people wanting to live in them. Scoraig, Hugh Piggott's base in Scotland, is just such a place. With a healthy community heading for a hundred souls (an achievement after total abandonment by the old crofting community in the 1950s), all off the grid, and many with their own small windmills, it has been the perfect place for earning the experience and reputation as the best there is in 'DIY' windpower.

Wind can be an excellent choice for isolated power supply, and such is the nature of the folk who live in such places that many will prefer to 'DIY' wherever possible. This book does an admirable job in filling a gaping hole in the available literature on practical small scale wind engineering. It comes from a disciplined and highly trained devotee who has explored all the angles and learned most of the lessons (many of them the hard way). Wind is no more simple than it is free (again economically and environmentally speaking), and a guide is most recommended. There are plenty of pitfalls, most of them easily avoided.

The reward is that wind is the closest thing to being able to 'magic' clean energy from thin air, and Hugh Piggott is a true guru of the art. Read on and enjoy.

Tim Kirby
Chairman
British Wind Energy Association

Chapter One
A Wild Resource

This book is written for those who want to build their own windmill, and also for those who love to dream. It was inspired by the windpower course at the Centre for Alternative Technology, an event where folk from all backgrounds come together to share the excitement of learning about windpower. Much has been omitted for lack of space, but you can find it elsewhere. For basic knowledge of electricity, forces, and turning moments, look through a school physics book. For details of how to site a windmill and live with windpower, see the companion volumes called *It's a Breeze* and *Off the Grid* (also available from CAT Publications).

The wind: a wild resource

Wind energy is wild stuff, and very tricky to handle. Capturing wind energy is like riding an antelope, when we could be using a Volkswagen. Most newcomers to wind energy underestimate the difficulties. Do not expect to get much useful power from a small windmill in a suburban garden, nor to knock together a reliable windpower system in an afternoon!

Look hard at the size of wind machine needed to produce the energy needed. Is this a realistic project for you? Do you have the workshop facilities? Do you have access to a suitable site, where there is space to allow the machine to operate safely and unobstructed?

If your motivation is to clean up the environment, then small scale windpower is not necessarily the best approach. Insulating your house may well save more energy. If you are an urban supporter of renewable energy, you can ask your local electricity board about their green tarriff, or devote yourself to winning the environmental debate on wind farm acceptance.

But if you have the time, the workshop, the site, and the passion, then you will build a windmill, and enjoy the hard-earned fruits. I hope this book helps. Be careful.

No free lunch

The wind is free, until the government manages to put a tax on it, and many people assume that wind energy will therefore be a bargain. If that were so, then we would see windmills everywhere, but of course 'there is no such thing as a free lunch'.

Wind is a very diffuse source of energy. To produce useful amounts of power, windmills need to be large; to work efficiently and reliably they need to be well engineered. So they are expensive. If you build your own, you can save most of the cost, but spend a great deal of your valuable time.

Battery depreciation

Power from small, stand-alone wind-electric systems using batteries is not likely to be cost-competitive with power bought from the national grid in the near future. Even the cost of the batteries can rule it out. Batteries may last about seven years before they are worn out. It has been calculated that just the cost of replacing the batteries can be roughly the same as the cost of buying the same amount of power as the system produces in this period, from the mains supply.

This comparison highlights the fact that battery-windpower is not likely to be viable in the city. (There are other reasons, such as low windspeeds, turbulence, and the fury of neighbours.) In remote places, the cost of installing and maintaining power lines may be greater than that of the windpower system, so windpower becomes a more economic and reliable source than the mains.

Pay less and get more from the scrapyard

I am a frequent visitor to my nearest non-ferrous metals dealer, where I collect cable, batteries, steel for welding, sheet aluminium, etc. Using scrap materials will not necessarily reduce the quality of the job. You can afford to buy something much heavier from the scrapyard than you could afford to buy new. For example, it was once possible to obtain 'scrap' batteries from telephone exchanges. I have used them for ten of their twenty year lifetime. If I had bought new batteries, I would only have been able to afford a small poor quality one. (However, use some discrimination. Most batteries are scrapped because they are useless, so check them carefully with a voltmeter before buying.)

Everything in the scrapyard is there for a reason, but very often the reason is modernisation. There may be nothing wrong with the 'scrap' you buy.

The environmental cost

Every source of power has an environmental price. Windpower is clean and renewable, but it does have some downsides. At least the pollution it causes is here and now, so 'what you see is what you get'!

Noise

There are two main kinds of noise which can arise: blade noise and mechanical noise. Blade noise is rarely a problem, as it sounds similar to wind in trees, or flowing streams, and is often masked out by these very sounds.

Mechanical noises can arise where there is vibration or hum from the generator or gearbox. These tonal noises can drive people crazy, especially if they are kept awake. Others (the owners) will enjoy the music of the windmill feeding power into the battery and sleep all the better!

Visual intrusion

Visual intrusion is even more subjective than noise. One person's sleek dream machine might be another's eyesore. A windmill will normally be attractive to the owner, especially if self-built. Neighbours may be willing to accept it, but tact and

Table 1.1 Instant Power Outputs in Watts

Windspeed:	2.2m/s 5 mph	4.5m/s 10 mph	10 m/s 22 mph	20m/s 44 mph
Blade diameter 1m	1	6	70	560
Blade diameter 2m	3	25	280	2,300
Blade diameter 3m	7	60	630	5,000
Blade diameter 4m	12	100	1,120	9,000

This table gives you an idea of how much power your windmill may produce. It assumes a modest power coefficient of 0.15. For example, a two metre diameter windmill in a ten metre per second wind might produce 280 watts. Do not be fooled by the apparent precision of the figure. In reality you may get between 200 and 400 watts, depending on what 'power coefficient' you can attain.

diplomacy are very important in gaining this acceptance.

How much power can you expect?

Power (in watts) is the rate of capture of energy, at any given instant. Table 1.1 shows how much power you can expect a windmill of a given size to produce in a given windspeed. The table assumes that your windmill catches 15% of the raw power in the wind. The percentage caught is known as the 'power coefficient' (or Cp) and we shall see later why it is such a small a part of the total.

The raw power in the wind depends on the density of air (about 1.2 kilograms per cubic metre), the speed of the wind and the size of the rotor. Windspeed is critical (as you can see from the table). Stronger winds carry a greater mass of air through the rotor per second and the kinetic energy per kilogram of air depends on the square of its speed, so the power in the wind will increase dramatically with windspeed.

The area swept out by the windmill's propeller, fan, sails, wings, turbine, blades depends on the square of the diameter. We call the windmill rotor blade assembly the rotor for short. Do not confuse this with the rotor of the generator.

At the back of this book there are windpower equations which you can use to calculate the power output of a windmill. Better still, use a spreadsheet to teach your computer to do the sums for you!

As you can see, the power in the wind varies enormously. There are only a few watts available in a light wind. It is not easy to design a machine which can convert this amount of power effectively, and yet survive the huge power surges which arise during gales.

The wind is always changing, and the power fluctuations can be extreme. We need to harvest it when it is there, and either store it for periods of calm, or use some other power source as a back-up. In the days of corn-grinding windmills, the millers kept a store of grain, and ground it as and when they could. Nowadays, small wind-electric systems use batteries, which absorb surplus power during windy weather, and keep the supply going during calm periods.

A quick guide to predicting energy capture

Energy captured in a given time is the average power multiplied by the hours. This depends at least as much on the site as on the machine itself.

Site conditions	Average windspeed
Trees and buildings	3 m/s (6 mph)
Open fields, with few hedges	4.5 m/s (10 mph)
Hilltops or coasts (open sites)	6 m/s (13 mph)

Average power output from a windmill is not the same as its instantaneous power output when windspeed is average. Again, there is an equation for this at the back of the book.

From Table 1.2 we can see that a two metre diameter windmill will give an average power output of about 51 watts where the average windspeed is 4.5 metres per second (10 mph). These are just ballpark figures: average output could in reality be anything from 30 to 80 watts.

What can you power from a windmill?

The average power from a windmill must be matched up to the average power needs of the user(s). The typical person (in Europe) has an average domestic electricity consumption (at home) equivalent to using 100 watts all the time. Sometimes they might use

Table 1.2 Average Power Outputs in Watts

Average windspeed:	3 m/s 7 mph	4.5m/s 10 mph	6 m/s 13 mph
Blade diameter 1m	4	13	30
Blade diameter 2m	15	51	121
Blade diameter 3m	34	115	272
Blade diameter 4m	60	204	483

many kilowatts, but at other times they hardly use anything.

So for a family of five an average power of 500 watts would be needed. But it is possible for a family of five to get by using under 100 watts if they use energy-efficiency lighting with care and avoid the use of electric heaters in low windspeed periods.

Efficiency: where does the energy go?

In Tables 1.1 and 1.2 we assumed that the windmill would catch 15% of the power in the wind. In reality, the power coefficient will depend on how much is lost at each stage of the energy conversion process. Some is even lost before it can begin.

Betz's theorem

Albert Betz (1926) is credited with figuring this out, so his name is always used to refer to this theory.

In order to extract power from the wind, it must be slowed down. To remove all the wind's power would involve bringing the air to a halt. However, this would cause a pile-up of stationary air at the windmill, preventing further wind from reaching it. The air must be allowed to escape with some speed, and hence with some kinetic energy (which is lost).

According to Betz, the best power coefficient we can hope for is 59.3%, but in practice this figure will be whittled down further by other losses described next.

Drag

The rotor blades convert the energy of the wind into shaft power. Later we discuss the advantages of using a few, slender blades which rotate fast, compared with many wide blades, rotating slowly. Fast moving blades will experience aerodynamic 'drag'. Drag holds the blades back, wasting some of the power they could be catching from the wind, so we need to make the blades as 'streamlined' as possible. Even the best designed 'airfoil section' blades will lose about 10% of the power they handle this way. Home built blades may lose a lot more.

Mechanical friction

There will also be friction losses in the bearings, brushes and any sort of mechanical drive, such as a gearbox or pulley system. These will only increase slightly with increasing speed. Therefore when the windmill is working hard, in a strong wind, the friction losses may be only a tiny percentage of the total power. But in light winds friction losses can make an enormous difference, especially in very small windmills, which have relatively low rotor torque.

Whether this is significant will depend on what is expected from your windmill. If it is your sole electricity supply, it will be crucial to have high efficiency in light winds and you should use direct drive from the rotor blades to the generator, with no gearing arrangements. Those who use the wind for supplementary heating only, for which light winds are of little use, may cut costs by using a geared motor, or a belt driven alternator, which will work well in a stiff breeze.

Copper losses

The next stage is to make electricity. This takes place in the coils (or windings) of the generator. Electric current suffers from its own kind of friction, which heats the wires.

This 'friction' is in proportion to the 'resistance' of the copper wires carrying the current (see windpower equations). You can reduce the resistance (and so the 'copper loss') by using thicker wires. This makes the generator heavier and more expensive, but it may be worth it.

The resistance of a copper wire increases with rising temperature. Copper losses heat the coils, which increases temperature, thereby increasing resistance and causing more copper loss. This vicious circle can lead to burn out in the worst case, and will certainly lower the efficiency of the machine, so it will be important to look at the cooling of the generator, in the overall design.

Copper losses increase with the square of current. When the generator is working at 'part load', in other words in light winds, losses in the main windings are very small. Some generators also have 'field coils' (see chapter five) carrying an almost constant current. These losses are rather like the mechanical losses discussed above. In light winds, they may consume all the power the blades can produce, leaving you with nothing.

Finally, do not forget about copper loss in the cable from the windmill. Where the cable is very long, it also needs to be very thick. If the cost of thick cable becomes ridiculous, then it is worth changing the system voltage. At higher voltages, less current will be needed to transmit the same amount of power. High voltage means much lower copper loss in cables, which is why it is used, in spite of the safety problems it may cause. A 12 volt system will lose 400 times as much power as a 240 volt system, when using the same cable.

Iron losses

Most generators also suffer from iron losses, which are described in detail in chapter four.

Rectifier losses

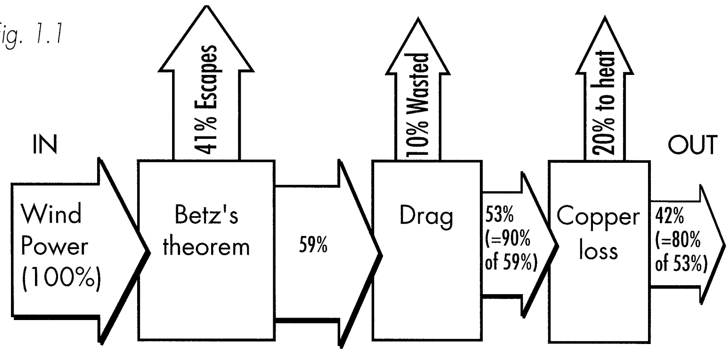
Very often, small windmills are built with permanent magnet alternators, which produce alternating current (a.c.). The power is then fed into a battery, for use as direct current (d.c.). A converter is required, which changes the a.c. into d.c. This is the 'rectifier'.

Modern rectifiers are simple, cheap, reliable semiconductor devices, based on silicon diodes. They work very well, but like everything in this world, they need their percentage. (One begins to wonder if there will be any power left at the end of all this!) In this case the rule is simple: each diode uses about 0.7 volts. In the course of passing through the rectifier, the current passes through two diodes in series, and about 1.4 volts are lost. In other words, to get 12 volts d.c. out, we need to put 13.4 volts in. This represents another energy loss, representing about 10% of the energy passing through the rectifier.

Again, changing to a higher voltage will reduce this loss. For example, in a 24 volt system the voltage lost in the rectifier will be

How the Losses Add Up

Fig. 1.1



the same as in a 12 volt system (1.4 volts), but it is now less than 5% of the total.

How the losses add up (or rather multiply)

Each stage in the system passes on a percentage of the power it receives. We apply these percentages to each other in a row (Fig. 1.1) to get the overall power coefficient. It is fortunate that we are starting off with free energy! Of course, there are losses in any process. For example, every internal combustion engine always converts most of the energy in its fuel to heat, seldom recovered for any useful purpose.

Design basics

Matching the rotor to the generator

For a given size of rotor, it is tempting to use a very large generator, to make use of the high power in high winds. But, for a given size of generator it is tempting to use a very large rotor, so as to obtain full power in low winds.

A big generator with a small rotor will very seldom be operating at rated power, so it will be disappointing, especially if the generator's part-load efficiency is poor. A small generator with a large rotor will achieve full power in low winds, giving a more constant power supply. The drawbacks are that the larger rotor will:

- need a stronger tower (chapter 8);

- run at lower rpm (next section);
- require more control in high winds (chapter 6).

The usual compromise is to choose a generator which reaches full output in a windspeed around ten metres per second (10 m/s). See the first and the fourth columns of Table 1.1, or the first two columns of Table 1.3. (page 19).

It is also vital to match the rotational speed (rpm) of these two components, for which we need to understand their power/speed characteristics.

Tip speed ratio

The speed of the tip of one blade depends on the revolutions per minute (or rpm), and the rotor diameter. For example, the tip of a two metre diameter rotor, running at 500 rpm, travels at about 52 metres per second. This is over 100 mph! Operating tip speeds of up to 134 m/s (300 mph) are not unknown, but for the sake of a quiet life you should try to keep it below 80 m/s.

Tip speed ratio is the magic number which most concisely describes the rotor of a windmill. It is how many times faster than the windspeed the blade tip is designed to run. A windmill rotor does not simply have a best rotational speed (e.g. 600 rpm). Its optimum rpm will depend on the windspeed, the diameter and the tip speed ratio. (See windpower equations.)

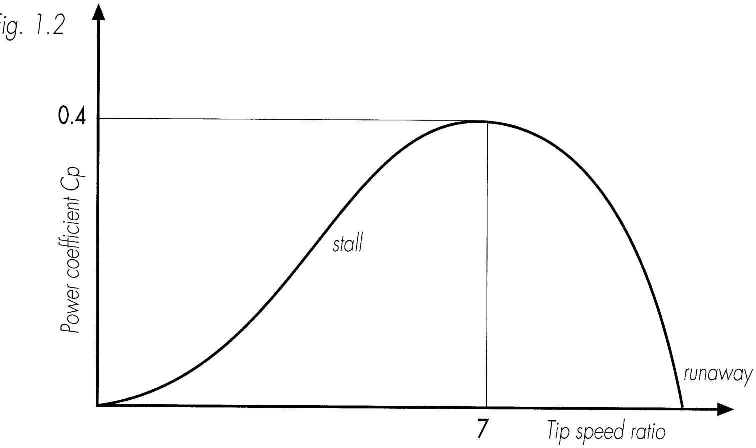
The windmill rotor will do best at a particular tip speed ratio, but it will inevitably have to work over a range of speeds. The power coefficient 'Cp' will vary depending on tip speed ratio, for any particular rotor design. It will be best at the 'design' or 'rated' tip speed ratio, but acceptable over a range of speeds.

Figure 1.2 overleaf shows the power coefficient of a typical rotor designed to operate at a tip speed ratio of 7. A small shift in rpm or windspeed will not make much difference. If the rpm is too low, compared to the wind, then it will stall, and performance will drop. If there is no load on the rotor (perhaps because a wire has broken in the electrical circuit), the rotor will overspeed until it reaches a certain point, where it becomes so inefficient that it has no power to go faster. Most windmills are quite noisy and alarming at runaway tip speed.

In chapter three we shall look more closely at how to design a

Power Coefficient and Tip Speed Ratio

Fig. 1.2



windmill rotor to run at a particular tip speed ratio.

Generator characteristics

The rotor will accelerate until the load (generator) absorbs all the power it can produce. If the generator and the rotor are well matched, this will occur at the design tip speed ratio, and the maximum power will be extracted from the wind.

Generators also have their preferred speeds of operation. As we shall see later, the voltage produced by a generator varies with the speed of rotation. It will need to be run fast. If it is connected to a battery, then no power will come out of the generator until its output voltage exceeds the battery voltage.

The shaft speed (rpm) above which the generator delivers power is known as the cut-in speed. The speed required for full power output is known as the rated speed. These speeds need to correspond to the speeds at which the rotor 'likes' to run, in the corresponding windspeeds.

Finding the best rpm

Table 1.3 gives guidelines for matching speeds to generators. Choose the power you need in the first column. This is the rated output of the generator (and thus the windmill). The second column suggests a suitable rotor diameter, based on the assump-

Table 1.3 Rpm for Various Turbines + TSRs

Power (watts)	Diameter (metres)	TSR=4	TSR=6	TSR=8	TSR=10
10	0.4	2032	3047	4063	5079
50	0.8	909	1363	1817	2271
100	1.2	642	964	1285	1606
250	1.9	406	609	813	1016
500	2.7	287	431	575	718
1000	3.8	203	305	406	508
2000	5.3	144	215	287	359
5000	8.4	91	136	182	227

tions that your Cp is 15% and the rated windspeed is 10m/s. The remaining columns give figures for the generator speed required in rpm, for each of a series of possible rotor tip speed ratios.

Suppose you want 250 watts, using a tip speed ratio of six. Choose the fourth row. From the second column, read the suggested rotor diameter: 1.9 metres. What rpm must the generator operate at? Looking across we find that the fourth column has 609 rpm.

This brings you up against the hardest problem in small windmill design. It is impossible to find a generator with such a low rated speed. Generators work much better at high rpm. They are usually designed to give full output at between 1500 and 3000 rpm. Here are various ways around this problem, each with its own pros and cons which will unfold as you read this book:

- Gear up the speed between the rotor and the generator;
- Use a higher tip speed ratio;
- Work at a higher rated windspeed;
- Modify the generator to work at lower speed;
- Build a special, low speed generator.

You must also consider the cut-in speed. Ideally, the generator cut-in rpm should be about one third of its rated rpm. Keeping the rotor at its design tip speed ratio, this allows cut-in at about 3.3 m/s (assuming 10m/s rated windspeed). If the cut-in rpm is higher than half the rated rpm, then problems may be found in reaching this rpm in low windspeeds.

Summary

Windpower is fun but not free. There is a price to pay not only in pounds but also in your time and through an impact on other people's environment. You can use the tables in this chapter to select the size of machine needed. The tables take account of the losses for you by making some assumptions about the power coefficient. Speed-matching the rotor to the generator creates some dilemmas. Fast rotors are noisy, slow generators are heavy and gearing between the two wastes power.

Human life and happiness is of course more important than windpower, so the next chapter is about safety. After that we look at how to design and build windmills, from the rotors, through the electrics, to the tails and towers.

Chapter Two
Safety

For many people, experimenting with small windmills is stepping into the unknown, a real life adventure. If you were sailing a yacht, or wiring a 13 amp socket, there would be someone nearby to tell you the safe way. Far fewer people know about windmills. That puts a bigger responsibility on you to be safe.

Consult with experienced people where possible, but do not necessarily expect them to give the final word. A domestic installation electrician will probably be unfamiliar with variable-voltage 3-phase supplies, for example. Someone needs to know the risks, and that person is you.

Electrical safety

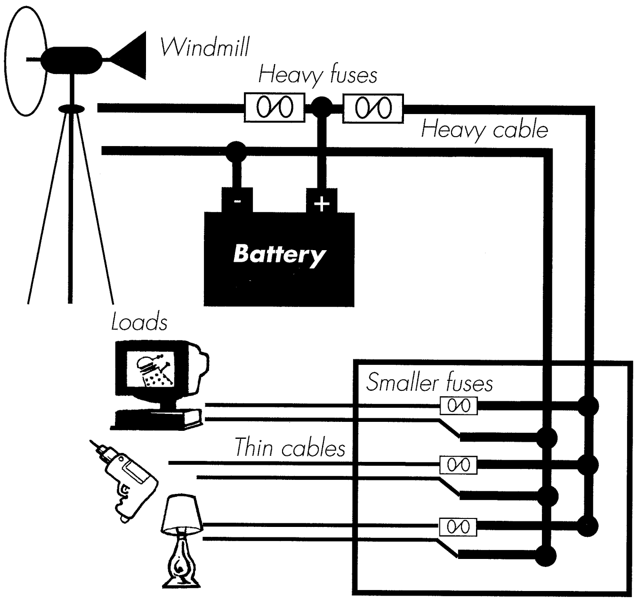
Electricity supplies present two main hazards: fire and shock. Both are covered thoroughly by the IEE wiring regulations, and many books are published to interpret these regulations. American readers should check the NEC code, which now includes sections specifically about renewable energy.

Protection against fire

In the last chapter we mentioned copper loss, whereby electric current flowing through a wire generates heat. When a wire is carrying too much current, it can become hot enough to melt the PVC insulation coating and set fire to the building.

Correct Use of Overcurrent Devices

Fig. 2.1



Short circuits, fuses and MCBs

Excessive current may be due to overload, where too much power is being used from the circuit, or due to a 'short circuit'. A 'short' is the name given to a fault in which there is contact between the two wires from the supply (positive and negative, or live and neutral). A mains supply, or a battery, can deliver very high currents of thousands of amps when short circuited.

Whatever the cause, excessive currents need to be stopped before they start fires. Every circuit coming from a mains supply (or a battery) needs to be fitted with an 'overcurrent device', a fuse or a circuit breaker, which will break the circuit automatically if too much current flows (Fig. 2.1). Fuses are cheap to fit but cost money to replace. Miniature Circuit Breakers (MCBs) are increasingly popular, despite the extra cost. MCBs look just like switches, can be used to disconnect a circuit manually, and if they trip they are easy to reset. They are generally more sensitive than fuses, and therefore safer.

The heat produced depends on the size of the wire. If they use different sizes of wire, each circuit needs to be considered separately. The overcurrent device must be capable of carrying the current normally to be expected in the circuit and it must be designed to disconnect if the cable is overloaded or short circuited.

Bad connections and scorched walls

Cables are not the only fire hazards in an electrical system. A corroded connection will develop a high resistance to the flow of current before it fails completely. Normal current passing through this resistance heats it up, perhaps to the point where it can scorch the surroundings. Therefore:

- always mount connections on fireproof materials, not wood.
- prevent moisture from corroding the connections by keeping them clean and dry.

Heaters

Last but not least, there is a fire risk from incorrectly installed heaters. An electric heater needs good ventilation, and may need to be surrounded by fire-resistant materials for safety.

'Dump load' heaters are particularly hazardous. These exist for the purpose of disposing of surplus energy. They are normally controlled by an automatic control circuit, which operates without human supervision. If the dump load is rarely needed, it may come on unexpectedly after a long interval. It may by then have been covered up by old coats, or some other inflammable material.

Protection against shock

An electric shock is a current through the body. It happens because a person touches two different conductive objects, between which there is a voltage. There are several different ways to protect against the risk of shock.

Using extra-low-voltage

The simplest way to prevent shock is to use very low voltages such as 12 or 24 volts. Even if a person touches both terminals of the battery, there will be no sensation of shock (try it if you don't believe me). Voltages below 50V are termed 'extra low voltage' (ELV). If you keep them segregated from higher voltage circuits, these are relatively safe.

A word of warning about 'battery voltage'. The voltage rating of a windpower system is nominal, not exact. If the battery is disconnected, and the windmill is running fast, there will be much higher voltages coming from the windmill. Also, there are windmills which use transformers and high voltage transmission from the generator to the control box, in order to minimise cable loss. Never assume that the voltage from the windmill is too low to give you a shock.

Enclose it, fuse it and earth it

If you must use mains voltage, then it is essential to take precautions. The safest way to treat a mains voltage supply is to follow standard mains voltage wiring practice. This will make your system easier for others to understand. But remember that in practice your windpower supply may not behave just like the mains.

All live conductors must be inside a box, away from idle fingers.

By all means recycle cable from the scrap heap. But always check that the insulation (sheathing) on the cable is perfectly undamaged before you use it for mains voltage work.

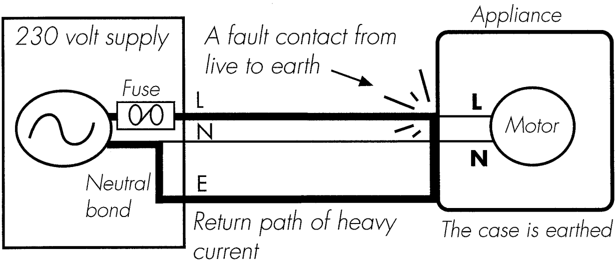
The 'eebad' system

Mains supplies here in the UK are made safe by a system called 'earthed equipotential bonding, and automatic disconnection of supply'. 'Equipotential bonding' means connecting together every metal surface you are likely to touch. The bonding cable will 'short circuit' any dangerous voltage which may arise due to a fault. Bonding of electrical appliances is achieved by the 'earth' wire in the cable. Use your common sense to decide which other objects to bond together; where there is electricity in use, all exposed metal surfaces must be bonded. A dangerous voltage is unlikely between your knife and fork, unless you are eating inside your fusebox. But water and gas pipes need to be bonded to the earthing system.

Metal objects are not the only conductors you will make contact with. Planet earth is a conductor, so a voltage between the water tap and earth could give you a shock. Hence it says 'earthed equipotential bonding' in the recipe for safety. You should bond all

An Earth Fault Blowing a Fuse

Fig. 2.2



'earth' wiring to one or more copper clad rods driven into the soil.

'Automatic disconnection of supply' is also required, so that when a fault occurs, it is quickly over. A 'fault' would be an untoward contact between a 'live part' (which should be insulated) and an exposed part (which is earthed). Such a contact will result in a dangerous situation and the supply must shut down.

In mains wiring, the automatic disconnection is often achieved using overcurrent devices. In this country, the neutral side of the supply is bonded to earth at the supply. Any contact between a live part and an earthed part is therefore a short circuit of the supply, causing massive overcurrents, which will operate the fuses or circuit breakers (Fig. 2.2).

Residual Current Devices (RCDs)

If the supply is a windmill or an inverter, then there may not be enough current forthcoming to blow or trip the device, even when the supply is shorted out directly. An overcurrent device is not a suitable 'automatic disconnect' for such a supply. A 'residual current device' (RCD) is needed. This is very sensitive, responding to a tiny leakage of current to 'earth' by tripping off the supply.

When you connect an RCD in your system, first check where the neutral is bonded to earth. There must never be more than one bond between neutral and earth, and it is usually made at the supply. Where a number of alternative supplies are used, neutral should be bonded at the distribution board. The bond between neutral and earth must be on the supply side of the RCD, or the RCD will not 'see' the fault current at all (Fig. 2.3 overleaf).

Correct RCD Positioning

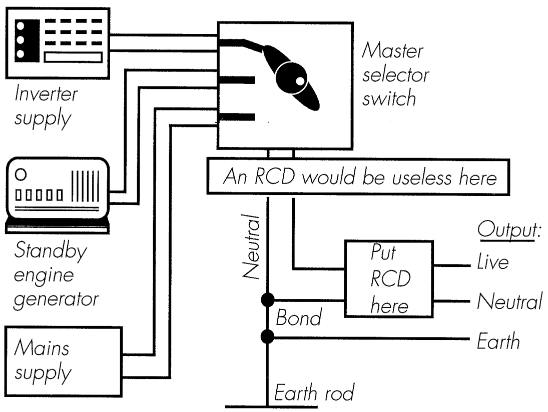


Fig. 2.3 The RCD must be downstream of the neutral bond.

Protective devices summarised

To prevent fires, fit an MCB at the supply end of the live (or positive) side of every cable in the system. The current-carrying capacity of the cable must be at least as large as the MCB's rating, which must be greater than the intended load current to be used.

To avoid shock hazard, check that the neutral is bonded to earth at the supply, and fit an RCD.

Battery hazards

I hate batteries. They are the worst feature of stand-alone windpower systems. I wish we did not need batteries, but they are essential where wind energy is to be the primary source for your electricity. They combine several dangerous features.

Firstly, they are heavy enough to damage your spine when you shift them around.

Secondly, they are full of corrosive sulphuric acid, which attacks your clothing and your skin. It is especially hazardous to the eyes. Clean up spills with an alkaline solution (e.g. washing soda, some of which you should always have handy). In the event of skin (or eye) contact, wash with plenty of water. (Wash your overalls promptly too, unless you want the acid to eat holes in them.)

Thirdly, they will kick up a terrific spark and could give you a nasty burn if you short circuit them, with a spanner for example. Remove all jewellery when working with batteries. Always fit a fuse or circuit breaker to protect the wiring. Do not let the overcurrent device touch the battery or it will corrode.

Lastly, they give off explosive gases, which can be ignited by a spark, so keep batteries in a ventilated enclosure. A small vent at the highest point, leading to the outside, is all you need — the hydrogen gas rises rapidly. Never create sparks around the vents on top of a battery case. Sparks are a common cause of explosions within the battery. The trapped gases explode, and blow off the top, scattering acid around.

Dispose of batteries responsibly. Lead is toxic, acid is toxic, and both need to be recycled, not dumped. Scrap merchants will sometimes pay to take them off your hands. Your local authority will be able to help you dispose of them safely too.

Other responsibilities

Working with revolving machines

Windmill blades spin at high speeds. The blades need to be out of reach of passers-by and children.

When you complete your first set of rotor blades, do not be tempted to test them out by holding them up to the wind in some makeshift way, in your excitement. Once the rotor starts, you will not be able to stop it. Gyroscopic forces will probably twist it out of your grip, and someone is likely to get hurt.

Exposed belt drives, shafts and suchlike are dangerous. When experimenting with generators and drive arrangements at ground level (for instance on a lathe) you must treat them with great respect. Wear no loose clothing, and keep your hair out of the machinery!

Here is a story told to me by Mick Sagrillo, a windmill guru of some standing in the USA:

"I was up in Alaska on the Yukon river, 35 miles by boat from the nearest telephone. I was working with someone on his Jacobs, bench testing it on the ground with a battery. It was about 10 pm, and, of course, we had worked way longer than we should have. At the time, I wore a ponytail half way down my back, but tucked up under a cap.

"Somehow, the slow spinning generator shaft got a hold of my hair,