

WIND FARMING BASICS

This document is a detailed briefing paper discussing the basic issues and terms associated with wind farming in Australia. This paper was prepared as background information for the preparation of a fact sheet for dissemination to the general public. As a result this document, any related documents (listed below) and the fact sheet itself attempts to be as non-technical as possible and sometimes goes to great pains to explain what may appear to be quite obvious to someone intimately involved in either wind energy or a specific issue.

However, as is often the case, such attempts may unintentionally oversimplify the issue or present information in a distorted way. We may also have made errors or omissions in the preparation of this document. Please do not hesitate to forward any suggested changes or additions to this document to Grant Flynn at Sustainable Energy Australia (Grant@SustainableEnergyAustralia.com.au).

Where possible footnotes have been provided within the text to allow the reader to consult the source article directly.

This document should be read in conjunction with the following sub-documents;

- Glossary of Australian Wind Energy Terms

This document has also been distilled into a very brief fact sheet of just 2 pages which can also be downloaded from the AusWEA: Australian Wind Energy Association web site at www.auswea.com.au.

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SUMMARY

WHAT IS A WIND TURBINE GENERATOR?

A wind turbine generator consists superficially of four major components. They are the foundation, tower, nacelle and the rotor which consist of the three blades and a central hub. The picture (right) shows one of the wind turbine generators at Codrington with the main components labelled.

The small dark green “box” next to the tower contains an electrical transformer. Sometimes this transformer is housed within the wind turbine generator itself (either in the base of the tower or in the nacelle).

While there is a variety of foundation techniques - used according to the ground and soil types encountered at each site - the foundation of a wind turbine generator is typically a thick slab of reinforced concrete.

For a typical utility scale wind turbine generator being installed in Australia today the foundation will be in the order of twelve to thirteen metres across and three metres deep. They are often shaped like a two layer wedding cake; with each layer one and a half metres thick.

While the bottom layer extends the full distance across the top layer is only just wider than the tower itself (about five metres) and has tie-down bolts embedded in it as well as conduits for power and signal cables. The foundation is then back-filled so that it ends up being under the ground. This allows the host farmers to graze up to the base of the tower.

Foundations of this type can be thought of as a the base of a wine glass, in that it is wide and flat and essentially is designed to stop the wine glass (the tower and generator) from tipping over.

At Codrington the foundations consist of about 250 cubic metres of concrete and about 12 tonnes of reinforcing steel. Great care is taken by engineers to ensure the concrete is very strong and the surface is very flat (less than one millimetre drop across the foundation). We don't want any leaning towers!

The tower supports the nacelle above the ground. The towers are built to be extremely stable and rigid so as withstand the vibrations created by the wind and movements of the rotor. For large modern wind turbines there are two main types of tower – enclosed, tubular, steel towers and the open, steel lattice tower. Both are tapered slightly towards the top.

Here in Australia only the tubular tower is used. While tubular towers are more expensive, they are aesthetically more pleasing, provide better protection for equipment and personnel and do not provide any perching platforms for birds or access points for vermin.



The towers are constructed in a number of sections - 2 to 4 depending on the overall height. The tower sections are put in place using a very large crane to lift each section in place which is then bolted into place before the next section is lifted into place. Generally the bottom sections (which are wider because of the taper of the tower) are shorter to keep the weight of each section to manageable levels.

A ladder, with a fall-arrest system, runs up the inside of the tower and provides weather-protected access. Each tower segment is equipped with platforms and emergency lighting. The electrical enclosures, containing the equipment used for operation of the wind turbine, are mounted in the foot of the tower making it possible to operate all the key functions of the system without having to climb up the tower beforehand.

The tower is protected against corrosion by rust inhibitors and an epoxy coating in accordance with ISO 12944. The paint is generally an off-white colour and has a dull mat finish to minimise reflections. All the steel sheets and welding seams are tested for defects by means of ultrasound or X-ray before being installed to ensure it will last the full life of the machine.



Regardless of the tower type the nacelle needs to be above the ground so that the blades can rotate without hitting the ground. The wind also becomes stronger and less turbulent the higher you are above ground level. This is a major determinant for the height of the tower. In low wind speed areas the machine can be placed on a taller tower to try to reach the stronger winds however this will also mean the tower and its foundation will be more expensive to build and it becomes an economic decision as to whether the extra energy yield is worth the expense of the taller tower.

Aesthetically it is best if the blades come about half way down the tower so a machine with a rotor diameter of 64 metres is most likely to be installed on a tower approximately 64 above the ground. If the blades come too far down the tower then the machine may appear to be “squat” and if the tower is too tall the rotor can appear to be detached from the ground.



The nacelle, at the top of the tower, contains the drive-train, gearbox, generator and controlling equipment.

The equipment inside the nacelle generally determines its size and shape. For a large megawatt size machine the nacelle is typically about the size of a medium sized truck (about 8 metres long, 3 metres wide and 3 metres high).

Personnel can access the nacelle by climbing the ladder in the tower and entering via a hatch in its floor. Larger machines have small cranes inside the nacelle to allow tools and equipment to be lifted to the nacelle rather than having to carry them up a ladder.

The roof of the nacelle often opens up so that personnel can move around the nacelle more freely.



Because the nacelle is too heavy to be moved by a fan-tail like a traditional wind pump, it rests on a large bearing mounted on the top of the tower. This allows the machine to follow the wind no matter which direction it blows from. The controller tracks the number of times the nacelle rotates in any particular direction to ensure that the electrical cables do not become twisted. If needs be, the turbine will shut down and yaw around so as to untwist the cables.



The rotor consists of three blades which are held together by a central hub. The blades catch the wind and rotate the hub and attached drive shaft. All wind turbine generator's rotate clockwise when looking from upwind. Sometimes people incorrectly call the rotor a fan or propeller. This is quite misleading because a wind turbine generator's rotor is driven by the wind. It does not - and can not - drive the wind. Only on rare occasions, during maintenance, can the rotor be turned very, very slowly by using the generator as a motor.

The length of the rotor blades ranges in size from only a few centimetres in small domestic machines up to fifty metres in the largest off shore machines. For example each rotor at Stanwell's Toora Wind Farm in Victoria has three thirty-two metre long blades and weighs 23 tonnes in total.

Rotor blades are made out of composite materials (i.e. reinforced polyester or epoxy resin). Most commonly the reinforcing material used in the blades is glass fibre. However, some manufacturers use timber laminates or exotic materials like carbon fibre or Kevlar as well as, or instead of, glass fibre as a reinforcing material. The root ends of the blades have steel inserts to allow for a solid connection of each blade into the rotor hub.



The blades are generally finished in an off-white colour with a matt finish. However in some places you may see the blades painted in alternating red and white colours where the machines are installed very close to an airport. In some very cold places where the build up of ice on the blades might be a problem the blades are black so that they absorb the warmth of the sun so as to avoid ice build up.

Lightning protection systems are installed to ensure that the blade can withstand several direct hits from lightning without serious damage.

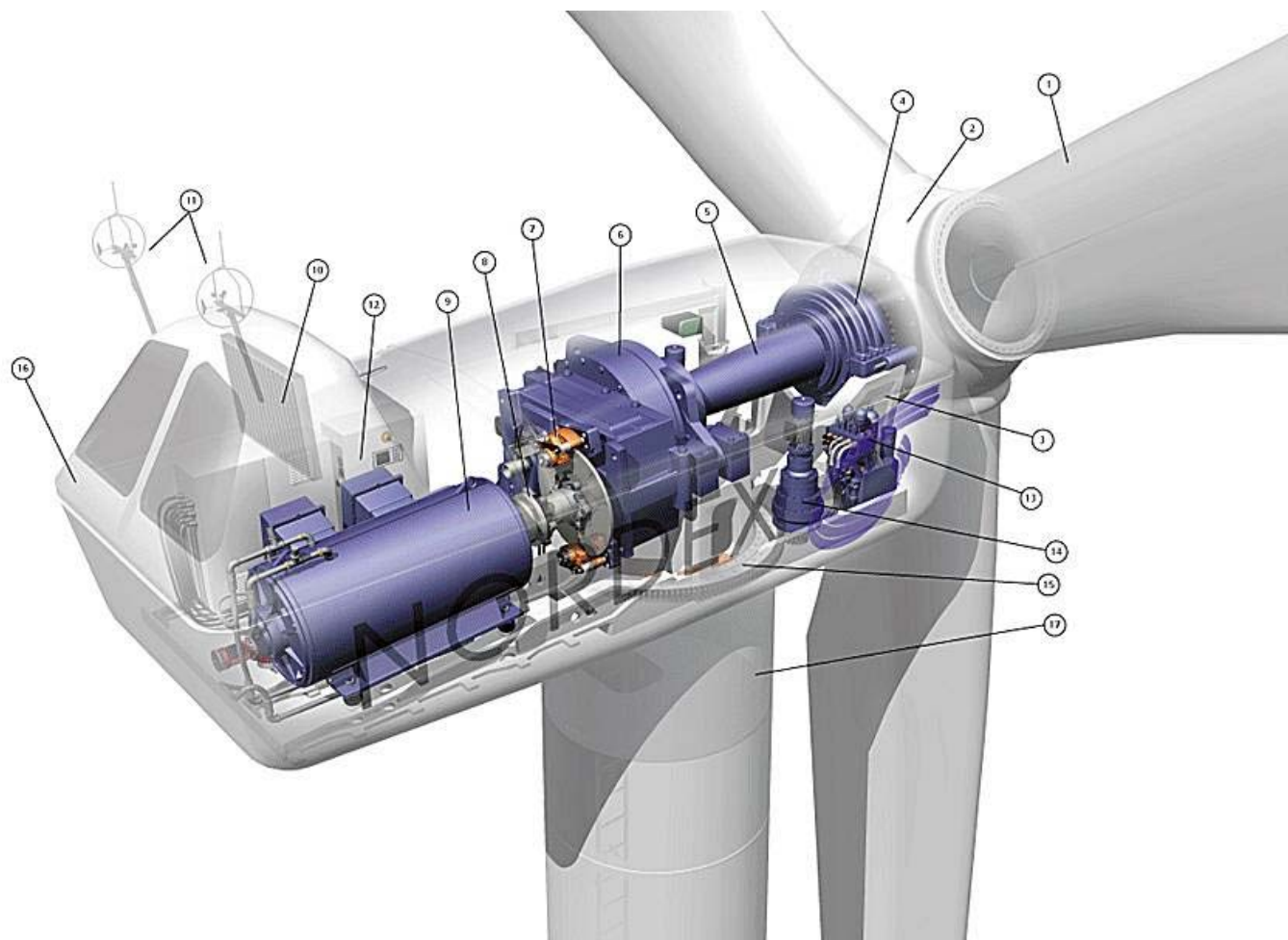
The design of wind turbine blades is a very complex process and tens of thousands of hours are spent in refining the designs. They are made from composite materials so that they can be very strong but still be relatively "light" and very flexible. In fact the blades are so flexible that they bend under their own weight (see above) and sweep backward several metres from the rotor hub in strong wind conditions.

WHY IS IT CALLED A WIND TURBINE GENERATOR?

Strictly speaking, the typical wind turbine generator used around the world today should actually be called a “3 bladed, upwind, horizontal axis, reaction air turbine driven electricity generator”. However this becomes tedious, so we use the shorter term – “wind turbine generator” (abbreviated to WTG) or “wind turbine” or simply “wind generator”. While these shortened terms are not strictly correct it is just like the traditional rural water pump almost always being called a “wind mill” even though it does not “mill” anything. The correct name is explained it below;

- 3 bladed – because it has three blades in its rotor.
- Upwind – because the blades are upwind of the generator and supporting tower
- Horizontal axis – because the axis of rotation of the blades is horizontal
- Reaction air turbine – because it is a vaned wheel that is made to revolve by the passage of a fluid (i.e. air) which completely fills the rotor. Regardless of the speed of rotation, anything that spins in this way is called a turbine – not just “jet engines”.
- Electricity generator – because the motor (the reaction air turbine) drives a generator of electricity. We could alternatively use the machine’s power to pump water, drive hydraulics, mill grain, etc. but in our case we are generating electricity.

HOW DOES A WIND TURBINE GENERATOR WORK?



The following list names the labelled elements in the diagram.

- | | | |
|------------------------|--------------------------|----------------------|
| 1. Rotor Blade, | 7. Mechanical Disc Brake | 13. Hydraulic System |
| 2. Rotor Hub | 8. Generator Coupling | 14. Yaw Drive Motor |
| 3. Turbine Frame | 9. Generator | 15. Yaw Ring Bearing |
| 4. Main Rotor Bearing, | 10. Cooling Radiator | 16. Nacelle Cover |
| 5. Rotor Shaft | 11. Wind Instruments | 17. Tower |
| 6. Gearbox | 12. Controller | |

The Rotor Blades are made of composite materials and use the power of the wind to turn the generator.

The Hub is made of cast iron and connects the rotor to the drive shaft and the rest of the drive-train.

The Turbine Frame, is made of ductile, cast iron and is generally cast as a single piece of steel. It acts as the chassis.

The Rotor Bearing, is a solid roller bearing carrying the weight of the rotor and is balanced by the rest of the drive train.

The Rotor Shaft, is made from spheroidal graphite (SG) cast iron. It transmits power from the rotor to the generator.

The Gearbox, is a custom design 3-stage gearbox (with helical planetary and helical spur gears). It increases the slow speed of rotation of the rotor (e.g. 9 to 30 rpm) to that appropriate for the generator (e.g. 1,500 rpm).

The Disk Brake, mounted on the high speed side of the gearbox, is used to bring the machine to a halt and in keeping the rotor still when the machine is furled out of the wind.

The Generator Coupling is a flexible coupling that connects the drive-shaft to the generator.

The Generator, is generally an asynchronous (induction) generator. In this picture the generator is liquid cooled, though many are air cooled rather than liquid cooled.

The Cooling Radiator, used in liquid cooled machines to keep the generator and gearbox cool.

The Wind Measuring System, measures wind conditions and provides signals to the turbine control system.

The Control System monitors and controls the fully automated operation of the wind turbine. The principle of operation is "fail-to-safe" so if something goes wrong the machine defaults to a safe condition.

The Hydraulic System provides hydraulic pressure to equipment such as the disc and yaw brake systems.

The Yaw Drive consists of planetary yaw gears, frequency controlled electrical motors and hydraulic brakes. This allows the nacelle to be rotated around the tower head so that it can always be brought into the wind.

The Yaw Bearing, mounted on the top of the tower, allows the nacelle to rotate around the top of the tower to follow the wind.

The Nacelle Cover, generally made of fibre glass or solid steel, provides protection to the equipment from the elements.

The Tower, is a tubular steel structure to hold the nacelle above the ground and allows access to the nacelle.

BASIC OPERATION

In simple terms the wind flows over the rotor blades and, because of the aerofoil shape and the angle of the blades, they generate lift, which results in a rotating force (torque) acting on the drive shaft. The drive shaft drives the generator. Essentially the kinetic energy of the wind causes the rotor to spin and this is converted to electricity by the generator and then transmitted to the grid.

As wind speed increases, more and more energy is delivered to the wind turbine's rotor. The relationship between the speed and the power of the wind is a cube relationship (i.e. if we double the wind speed the power increases eight-fold). This means that small changes in wind speed lead to significant changes in the power of the wind which is delivered to the wind turbine's rotor.

The power of the wind in a severe storm with 50 knot winds (in which the wind turbine will still be operating!) will be 244 times greater than that in a light breeze of 8 knots. Regardless of the huge variation of power in which the machine must operate, there is a limit to how much power can be usefully captured by the machine. So we need a way to regulate the power captured by the rotor.

There are three main strategies for regulating the amount of wind captured by the rotor; passive stall control, variable pitch control and active stall control. All three strategies are used in different models of modern wind turbine generators, each with its own advantages and disadvantages.

No matter which control strategy is used, we do not bother operating our wind turbines at very low wind speeds (below 3 - 4 m/s or 10 - 15 km/hr or 6 - 8 knots). There is so little energy in the wind that it is simply not worth the wear and tear on the machine to try catching it. Likewise in extremely violent winds (beyond 25 - 30 m/s or 90 - 110 km/hr or 50 - 60 knots) there is just too much energy in the wind and it is not worth the risk of damage to the machine to try capturing it. At most wind farm sites, winds like this are quite rare anyway; so we really don't miss that much energy.

The wind speed at which we try to start catching the wind's energy is called the cut in wind speed (because the generator "cuts in"). Conversely the wind speed at which we decide to stop trying to catch the wind's energy is called the cut out wind speed (because the generator "cuts out"). At low wind speeds the rotor may still be allowed to rotate (free-wheel) so that the next time the wind goes above the cut in speed we do not have to overcome the inertia of the rotor, and it can begin generating more quickly.

To date, no one power control strategy has taken the lead over the others. The cost of installation and maintenance needs to be balanced against the energy yields (i.e. what is the cost of production of each unit of electricity). However, as machines get larger and the strains greater there is a trend toward pitch control and active stall control.

Most generators use a standard three phase induction generator. These generators must rotate at a fixed speed (usually 1,000 or 1,500 rpm) so that they can provide electricity at 50 Hz (in the USA it is 1,200 and 1,800 rpm to give 60Hz). The gear box increases the slow rotating speed of the rotor up to this speed and, because the gearing ratio is fixed, the rotor will rotate at a fixed speed, regardless of the wind strength. This is achieved through the power control strategy of the rotor which adjusts the amount of power delivered to the drive train.

Most generators like this have been built so that they are able to electrically switch between the two generator configurations and speeds (i.e. switch between 1,000 and 1500 rpm). This means that the rotor will spin at two different speeds - one speed in low winds and a faster speed in stronger winds. An example is the Codrington Wind Farm (Vic.) where the rotors spin at either 13 or 19 rpm. The low rotational speed is chosen for low wind speeds to improve efficiency and reduce noise.

Another approach is to let the rotor operate at the optimal rotational speed for the wind conditions. In this case the speed of the rotor will increase with an increase in wind speed. While this means that the output of the generator has a variable frequency, the entire output is simply converted into direct current and then back into alternating current at the required 50Hz. These machines do not need a gearbox and are called direct drive machines. An example is the Albany Wind Farm (W.A.) where the rotors spin at between 10 and 22 rpm.

In the last couple of years yet another approach has been developed. In this case a normal drive train with a gear box is used but with a special double-fed, induction generator. In this case the rotor is again allowed to rotate at speeds that allow for optimisation of the aerodynamic performance of the machine. The difference here is that only a small part of the output of the generator is converted to direct current and back to alternating current. This alternating current is then fed back into the rotating part of the generator. A sophisticated computer controlled feed-back system controls this alternating current that is fed back into the generator such that the overall output of the generator is maintained at 50Hz despite the changes in the rotor speed. An example of this type of machine is the Toora Wind Farm (Vic.) where the rotors spin at between 10.5 and 24.4 rpm.

WHAT IS IN A WIND FARM?

“Wind Farm” is the name used for any group of wind turbine generators that are connected together into a single point for delivery of their energy. A wind farm consists of wind turbine generators, access tracks, underground cabling, hardstand areas, a switchyard, a control kiosk and a connection to the existing grid.

The wind turbine generators are the main component and come in a variety of physical sizes, rated capacities and operating paradigms. In Australia, best practice guidelines have been prepared by AusWEA that guide developers in how to locate the wind turbines within the wind farm but the specifics of the layout are really determined by site specific issues and local planning controls.

Access tracks provide access to each wind turbine, are usually five metres wide and constructed from locally obtained crushed limestone or gravel. The tracks are formed by laying the pavement material directly onto the existing ground surface to ensure adequate drainage and minimise ground disturbance. The access tracks are retained after the construction period for use by the landowner and for future maintenance, repair or replacement of the wind generator components.

A level area is required around each foundation for the assembly and erection of the wind turbine generator. These hardstand areas are constructed using the same material as the site access roads and are also retained after construction to facilitate future maintenance. Sometimes hard stand areas are also required for temporary equipment such as concrete batching plants, etc. As these are only required during the construction phase they can be removed and the site re-instated after construction is complete. Sometimes the landholder may request that it be left in place for their own use.

A “collector network” electrically connects each of the wind turbine generators. The collector network in Australia will always be placed underground. The cabling is usually steel wire armoured, electrically shielded and plastic insulated and is buried in a trench about 60cm to 80cm deep - typically next to the access tracks. Sometimes a small communications cable (copper wire or fibre optic) will share the same trench as the electrical cables to allow monitoring and control from a central point.

Each wind farm has a substation / switchyard to provide the overall interface between the wind farm and the local electricity network. It provides a control point for the flow of electricity in and out of the wind farm. The switchyard is fenced off to ensure that people do not inadvertently come into contact with the electrical equipment. The switchyard generally consists of a transformer, electrical isolators, circuit breakers, and associated metering and control equipment.

A control room (or kiosk) is generally located at the substation to house the electricity meters, control equipment, computer, etc. as well as to provide some basic amenities for maintenance staff. The wind farm links with the local distribution network system provider's supervisory control and data acquisition (SCADA) system via equipment contained in the control facility.

From the wind farms switchyard to the point of connection with existing high voltage grid, the electrical connection of the wind farm will generally be via overhead lines. Wherever possible the route used for these overhead lines will follow existing distribution (power-line) easements. Often new high voltage lines will need to be strung atop new - and taller poles - with the existing, lower voltage distribution lines, re-installed beneath. In some circumstances an entirely new power line will need to be installed.

WHY IS IT CALLED A WIND FARM?

The name "wind farm" is not a specific Australian name, although in some countries there is a subtle twist such as "wind ranch" in the southern states of the USA (where they have ranches rather than farms) or "wind park" in countries like Denmark and Germany.

Wind farming has strong parallels with traditional farming. They are generally located in rural or regional areas (though not always) and the principles of a wind farm are similar to that of most farming pursuits. Wind farming involves the harnessing and management of a natural resource. They tend to be very expensive to establish but relatively "inexpensive" to operate (and there is always something more to do around the place!) They have steady, modest financial returns over a long period of time rather than making huge returns in a short period of time. Wind farm success also relies heavily on extensive research and good long term planning.

Most importantly of course, they are at the mercy of the weather. Wind farms are exposed to good windy years where incomes are good and calm (or "wind drought") years where incomes are low just like traditional farming. However the fluctuations in wind farming are nowhere near as severe as we see with farming reliant on rainfall. The generation of electricity from the wind can really be thought of as a "vertical crop".

There are also historical links with agricultural and rural life. In fact some of the modern wind turbine manufacturers were previously involved in the manufacture of agricultural equipment. In European history wind energy has played an important role since about the twelfth century when it was used for milling grain. By 1840 England had about 10,000 wind mills across the country. Here in Australia our first wind mill was built in 1797 and the early Sydney skyline was dominated by wind driven mills. While most of the wind mills were replaced during the industrial revolution, even today the humble wind driven water pump is an important and iconic part of regional and rural Australia.

Many regional properties used wind energy in the 1920's to 1940's to charge battery systems (e.g. Dunlite's Windlite systems). The reduced cost of fossil fuels and the widespread introduction of electrical grid infrastructure during the 1950's meant a decline in the use of wind energy. Today many properties still use wind energy and other renewable energy sources to provide electricity in stand-alone power systems.

Sometimes you might see terms like "wind energy facilities" or "wind energy installations" used instead of "wind farm" by people who believe that "wind farm" is too benign a term for the highly sophisticated technology of a modern wind farm. However the technology of a modern wind farm is similar to that now used in traditional farming (consider a modern tractor or harvester with sophisticated control systems and even GPS guidance systems). It is likely that they will continue to be called wind farms all around the world for many years to come.

HOW DO WE TRANSPORT COMPONENTS?

Wind farm components are large and generally have special transport requirements.

Road making materials are sourced from within the site as much as possible to reduce vehicle movements in and out of the site. Generally they will be transported in standard bulk carriers. Concrete poses special problems because, for each foundation, some 250 cubic metres (80 agitator trucks) must be laid in a single continuous pour. Transport of this volume of concrete, especially over long distances, where timing is so critical is often very problematic and there are rarely enough agitator trucks in the area. On-site batching of concrete is usually performed, with only the dry materials brought to site. In this way only a small fleet of agitator trucks is required and only a short distance of internal tracks would be used in laying the foundations.



The towers, blades and nacelles pose some specific problems in terms of their physical size and weight. Specialist transport companies are used to transport these items within Australia - safely and cost-effectively. A standard low loader is used for the nacelles, which are transported one nacelle per truck. The trailer will have quite a few axles so that the weight of the heavy load can be evenly spread across the road surface. The prime mover will be quite powerful so that it is able to pull the weight effectively.

The towers and blades require special bogey arrangements that can be independently steered and are used together with powerful prime-movers. The towers are generally manufactured in two to four sections – each transported to site independently. Special brackets are bolted to each end of the tower sections so the steel tower section acts as its own “trailer”. The towers are usually fitted out with the internal ladders, platforms and electrical equipment at the factory so canvas covers are placed over each end to keep dirt and insect out during transport.



The blades are a similar length to the tower sections but because they are designed to be flexible they need a framework to support them during transport. They are transported in pairs (lying in opposite directions) in a steel framework that supports their weight. The steerable bogies are again placed at the end of the frame with the frame acting as the “trailer”.

The rotor hubs can be transported using the same low loader type transport equipment that is used for the nacelle. They are able to be transported two or three at a time.



Some of the components are not currently manufactured in Australia (though this will change soon). The blades, nacelles and rotor hubs are manufactured overseas and need to be transported to Australia by specialist ships because of their unusually size. Usually the ships are equipped with self unloading facilities so that they can come into a port near the site even if it is not equipped to handle this sort of cargo. It is possible to transport blades using large aircraft but its expensive.

WHY NOT BUILD WIND FARMS OFFSHORE?

In several European countries wind farms are being built off-shore. While still quite rare there is a significant number of wind farms planned for construction out to sea. Currently the largest off-shore wind farm is Middlegrunden, near Copenhagen in Denmark. You can visit the wind farm via the internet at http://www.middelgrunden.dk/MG_UK/ukindex.htm.

Off-shore wind farms have the advantages of;

- Higher wind speeds and less turbulence
- Reduced concerns about noise and visual impact
- Vast areas are available with few competing interests (it is becoming increasingly difficult to find sufficient space for wind farms on-shore in some countries).

Unfortunately, even though construction off-shore is well understood due to work in the petroleum industry it is still very expensive. To build an offshore wind farm we need an area of sea where wind speeds are good, waves are small, the water is shallow and it is still close to a large electrical load. Australia has a huge area of sea (twice the land surface area) and we do have areas that meet these criteria. However the added expense of off-shore construction, the very low wholesale electricity prices and the ready availability of on-shore sites means that we are unlikely to see off-shore wind farms in Australia – at least in the short term.

WHERE CAN I SEE A WIND FARM?

There are wind farms and wind turbines of various sizes all around the country and more are being built all the time. You can find locations by visiting the Australian Wind Energy Association's web site (www.auswea.com.au). Most wind farms have viewing areas with informative displays. Some have self guided tours (e.g. Western Power's 10 Mile Lagoon Wind Farm in Esperance, WA) where you can walk amongst the wind turbines. Others such as Pacific Hydro's Codrington Wind Farm have guided tours running on a regular basis (see <http://www.myportfairly.com/windfarmtours/>).

Many of the larger wind farm owners also have "virtual tours" of their wind farms on their web sites. This is also a good way to see wind farms overseas and offshore wind farms.

Please remember that most wind farms in Australia are located on private property. You should keep to the path and designated visitors' area and not enter private property uninvited.

HOW CAN I SUPPORT WIND ENERGY?

Join AusWEA or Attend the AusWIND Conference: as a way to support wind energy and also to be kept informed of recent news and participate in events and discussions in the wind energy community (www.auswea.com.au).

Write to Your Local Member: to remind them that you support and value wind energy development and that we need to tackle the problem of climate change. A polite and rational approach will always get a good response.

Talk to Your Local Council: about what they are doing about combating climate change and reducing greenhouse gas emissions.

Install Your Own Wind Mill – as the ultimate statement showing your support for wind. AusWEA has prepared a Best Practice Guide that provides a guide for appropriate wind farming. Your State Government's energy office will also be a help (e.g. SEAV in Victoria).

Encourage Your Friends: To learn about where electricity comes from and how we can produce it using something as clean and simple as the power of the wind.

Teach Your Children: about wind energy and where electricity comes from. Wind energy information specifically targeted for use by school children and to help teachers prepare classes is available on the internet (visit www.auswea.com.au for links).

Register Your Support For A Local Wind Energy Development: And do your bit by letting the government authority making the decision about a project (usually your local council) know that you support the project. Even a short letter of support in your local paper can help too.

Subscribe to WindInfo E-Zine: An electronic magazine from **TheWind** information site. All you need to do is to visit www.thewind.info and subscribe to the e-zine.

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No changes to cabling or power poles are required.¹ When you buy Green Power™ an amount of renewable electricity equivalent to your consumption is fed into the grid eliminating that amount of coal derived power. That means your electricity will be exactly the same as before, but your purchase directly reduces the greenhouse emissions and collectively the purchases of Green Power™ customers represents a significant benefit to the environment.

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Whether for the home or business a good way to reduce any impact on cost is to improve your energy efficiency. In this way you can reduce the amount of energy you use and reinvest the savings gained into the purchase of wind energy so as to minimize the impact on the environment by the generation of your electricity.

¹ from www.greenpower.com.au

MAIN DOCUMENT

Why is it called a wind farm?

“Wind Farm” is the name used for any group of wind turbine generators that are connected together into a single point for delivery of their energy. But where did this name come from?

The name “wind farm” is not a specific Australian name; it is used in many other parts of the world, though in some countries there is a subtle twist. For example in the southern states of the USA (where they have ranches rather than farms) they tend to be called a “wind ranch” and in countries like Denmark and Germany (where they have parks rather than farms) they are called a “wind park”.

Wind turbine generators and wind farms (like most wind energy conversion systems) have generally been located in rural or regional areas. There are some notable exceptions to this around the world with wind farms built very close to major cities in Europe and recently large off-shore wind farms have been built. Here in Australia the Kooragang Island wind turbine in Newcastle NSW is in an industrial area and the CERES wind turbine in Brunswick Victoria is built in suburban Melbourne.

The principles of a wind farm are similar to that of most farming pursuits in that it involves the harnessing and management of a natural resource. They tend to be very expensive to establish but *relatively* “inexpensive” to operate (and there is always something more to do around the place!) They have steady, modest financial returns over a long period of time rather than making huge returns in a short period of time. Wind farm success also relies heavily on extensive research and sound long-term planning.

Most importantly of course, they are at the mercy of the weather. Wind farms are exposed to good windy years where incomes are good and also to calm (or “wind drought”) years where incomes are low - just like normal farming. Fortunately the fluctuations in wind farming are nowhere near as severe as we see with farming methods that are reliant on rainfall. In this way the generation of electricity from the wind can be thought of as a vertical crop.

The wind energy industry is also historically linked to agricultural and rural life. Some of the modern wind turbine manufacturers were historically involved in the manufacture of agricultural equipment². In European history wind energy has been used since about the twelfth century for milling grain and has been very important in our history. In fact by 1840 England had about 10,000 wind mills across the country. Here in Australia our first wind mill was built in 1797 and the early Sydney skyline was dominated by wind driven mills³ and again they were very important to the development of our early history. Today the humble wind pump is an important icon of regional and rural Australia.

The generation of electricity from the wind also has a background in Australia’s regional communities. Many properties used wind energy in the 1920’s, 30’s and 40’s to charge battery systems (e.g. using Dunlite’s Windlite system). The reduced cost of fossil fuels and the widespread introduction of grid electricity during the 1950’s meant a decline in the use of wind energy but today many properties still use wind energy and other renewable energy sources to provide electricity in stand alone power systems (SAPS). Because electricity is such an integral part of our modern society and more people are choosing to build homes away from existing electricity grid infrastructure the use of SAPS is increasing.

Some believe that the term “wind farm” is too benign for the highly sophisticated technology of a modern wind farm. However the level of technology is similar to that now used in traditional farming - consider a modern tractor or harvester with sophisticated control systems and even GPS guidance systems!

It is likely that they will continue to be called wind farms all around the world for many years to come.

² Vestas A/S history (<http://www.vestas.com>)

³ Old Sydney Wind Mills. Fox L. Len Fox 1978. ISBN 0 9598 104 6 3. Page 7

Why is it called a wind turbine generator?

Strictly speaking the typical wind turbine generator used around the world today (the so called “Danish Concept”) should actually be called a “3 bladed, upwind, horizontal axis, reaction air turbine driven electricity generator”. However it becomes a bit tedious to use this term all the time so we tend to use a shortened name – such as wind turbine generator (WTG) or wind turbine or simply a wind generator.

While these shortened terms are not strictly correct, it is just like the traditional rural water pump almost always being called a “wind mill” even though it does not “mill” anything. The traditional water pump should be called a “multi-bladed, upwind, horizontal axis, reaction air turbine driven water pump”! In fact, some people even call wind turbine generators “wind mills”.

To explain the correct name of “3 bladed, upwind, horizontal axis, reaction air turbine driven electricity generator”, each part is broken up and explained below;

- 3 bladed – because it has three blades in its rotor
(Yes, there are designs with a different number of blades from one to many blades)
- upwind – because the blades are upwind of the generator
(Yes they can be downwind too, though they are quite rare today)
- horizontal axis – because the axis of rotation of the blades is horizontal
(Yes, there are vertical axis machines though they are also quite rare today),
- reaction air turbine – because it is a vaned wheel that is made to revolve by the passage of a fluid (air) which completely fills the motor,
(While the blades rotate slowly, anything that spins like this is called a turbine - it has nothing to do with how fast they spin –we use a gearbox inside the nacelle to speed up the drive shaft to that required by the generator.)
- electricity generator – because the motor (the reaction air turbine) drives a generator of electricity
(we could alternatively use the machine’s power to pump water, drive hydraulics, mill grain, etc. but in our case we are generating electricity)

What is a wind turbine generator?

A wind turbine generator consists of four major components (at least superficially). They are the foundation, the tower, the nacelle and the rotor (see picture to the right).

This picture shows one of the wind turbines at Pacific Hydro's Codrington Wind Farm in south west Victoria. The main components of the wind turbine are marked. For this machine the hub height (centre of the rotor) is 50 metres above the ground and each blade is 30 metres long, so the rotor tip at its highest point (or zenith) is 80m above the ground and at its lowest point (or nadir) is 20m above the ground.

The small dark green "box" next to the tower contains an electrical transformer to step up the voltage of the electricity to 22,000 Volts to reduce the losses within the underground cables that join the wind turbines together. For some wind turbines this transformer is housed within the wind turbine generator itself (either in the base of the tower or in the nacelle).

This wind farm is located on two grazing properties and a limestone on ground track leads up to the wind turbine for vehicle access across the paddocks.



FOUNDATION

While there is a variety of foundation techniques - used according to the ground and soil types encountered at each site - the foundation of a wind turbine generator is typically a thick slab of reinforced concrete.

For the wind turbines installed at Codrington (ANBonus 1.3 MW) the foundations are about thirteen metres across and three metres deep and shaped like a two layer wedding cake, with each layer one and a half metres thick.

The bottom layer extends across the entire thirteen metres but the top layer is only just wider than the tower (about five metres) and has tie-down bolts embedded in it as well as conduits for power and signal cables. The foundation is then back-filled so that it ends up being under the ground. This allows the host farmers to graze right up to the base of the tower.

Foundations of this type can be thought of as the base of a wine glass, in that it is wide and flat and essentially is designed to stop the wine glass (the tower and generator) from tipping over.

The foundations at Codrington consist of about 250 cubic metres of concrete and about 12 tonnes of reinforcing steel. Great care is taken by engineers to ensure the concrete is very strong and that the surface is very flat (less than one millimetre drop across the foundation). We don't want any leaning towers!

The exact type of foundation depends upon the ground conditions in which the turbine is placed. Its size depends upon the size and type of the wind turbine it needs to hold up. Other wind turbines may have slightly different foundation designs. Engineers make careful investigations of the site to determine the most cost-effective foundation design.



TOWER

The tower supports the nacelle above the ground. The towers are built to be extremely stable and absorb the vibrations created by the wind and movements of the rotor.

For large modern wind turbines there are two main types of tower – enclosed, tubular, steel towers and the open, steel lattice towers. Both are tapered slightly towards the top.

Here in Australia the tubular tower, while more expensive, is best practice for large wind turbines and used exclusively. The tubular tower is aesthetically more pleasing, provides better protection for equipment and personnel and does not provide any perching platforms for birds or access points for vermin.

The tubular towers consist of two to four segments, depending on the tower height. By being a very rigid structure we can ensure that the tower's resonant frequency is not transmitted by the turbine. When constructing wind turbines on tubular towers the top sections of the tower are not installed unless the construction crew is sure that the nacelle can be put in place on top of the tower. We need to be sure we do not end up building a giant pan flute! The frequency of the wind blowing across the top of the tower (just like blowing over the top of a bottle) could damage the tower. The nacelle is like putting the cap back on the top of the bottle.

The tower sections are put in place using a very large crane to lift each section in place which is then securely bolted into place before the next section is lifted into place. Usually a second smaller crane is used to help lift the bottom end of each tower section so that it does not drag along the ground. Generally the bottom sections (which are wider because of the taper of the tower) are shorter to keep the weight of each section to manageable levels.

A door is positioned in the foot of the tower, facilitating weather-protected access to the interior of the tower. Each tower segment is equipped with platforms and emergency lighting. Ladders, with a fall arrest system and resting and working platforms, are located inside the tower. Very tall towers sometimes have a small lift to reach the top, though to date none like this have been installed in Australia.

The switch cabinets for operation of the wind turbine are mounted in the foot of the tower. This makes it possible to operate all the key functions of the system without the need to climb up beforehand.

The tower is protected against corrosion by rust inhibitors and several coatings of paint. The corrosion protection of the tubular towers is provided by sandblasting the surface and adding an epoxy coating in accordance with ISO 12944. The paint is generally off-white in colour and has a dull mat finish to minimise reflections.

It is important that the tower complies with its design so all the steel sheets and welding seams are tested for defects by means of ultrasound or X-ray before being installed.



Lattice towers consist of a square, angled structure with inclination changes at three to four points, resulting in a hyperbolic (or curved taper) form. The struts consist of expansion and compression-proof diagonals with supporting latticework. Because the lattice work bolts together, it can be installed in locations where large cranes are not available or can be broken down into quite small sections where transport requirements are too demanding for the use of the large tubular steel tower sections.

The complete lattice tower is protected against corrosion by hot-dip galvanization in accordance with ISO 1461. Generally lattice towers are not painted.

A ladder is installed in one corner of the tower in order to provide access to the nacelle and has a fall arrest system attached and resting stages at various points. The switching cabinets, transformers and control equipment are located in a small building positioned between two feet of the tower.



Regardless of the tower type the nacelle needs to be above the ground so that the blades can rotate without hitting the ground. The wind also becomes stronger and less turbulent the higher you are above ground level. This is a determining factor for the height of the tower.

In low wind speed areas the machine can be placed on a taller tower to try to reach the stronger winds. The height of the tower is crucial to wind yield – especially in inland regions. A rule of thumb states that the yield improves by one per cent per metre of tower height⁴. However this will also mean the tower and its foundation will be more expensive to build. It then becomes an economic decision as to whether the extra energy yield is worth the expense of the taller tower.

It has been found that machines where the blades come about half way down the tower look more aesthetically pleasing. So a machine with a rotor diameter of 64 metres is most likely to be installed on a tower 64 to 68 metres above the ground. If the blades come too far down the tower then the machine may appear to be “squat” and if the tower is too tall it can appear to be detached from the ground.

For smaller “domestic” machines (e.g. those used to power a single house, etc) a third tower design can be used - a guyed tubular steel tower - where guy wires help stabilise the tower. By using guy wires, the tower does not need to be as wide or as heavily built because the guy wires help provide some stiffness to the structure. This method is not possible (or desirable) for larger machines though.

In the past, other tower types have been used overseas. An example is the tripod type of tower. This design has been used extensively for smaller machines (10 to 50 kilowatt machines) especially in the 1980's. As the capacity of the machines to generate electricity has increased and the generators have therefore become heavier, we no longer see these types of towers being used for modern large scale wind farms.



⁴ From www.nordex-online.com

NACELLE

The nacelle is the housing at the top of the tower which contains the drive-train, gearbox, generator and controlling equipment. The word nacelle is an aeronautical term which means the enclosed part of an aeroplane in which the engine is housed. The rotor blades are like wings and designed by specialist “aeronautical engineers” and the term has stuck.

The equipment inside the nacelle generally determines its size and shape. For a large megawatt size machine the nacelle is typically about the size of a medium sized truck (about 8 metres long, 3 metres wide and 3 metres high).



Personnel can access the nacelle by climbing the ladder in the tower and entering via a hatch in its floor. Larger machines have small cranes inside the nacelle to allow tools and equipment to be lifted to the nacelle rather than having to carry them up a ladder.

The roof of the nacelle often opens up so that personnel can move around the nacelle more freely.



The nacelle rests on a very large bearing and is able to rotate around the top of the tower. This allows the machine to follow the wind no matter which direction it blows from. Large scale wind turbines do not have fantails like a traditional water pump (they would be far too big) and so need to be driven to follow the wind using a system of yaw motors. Smaller domestic machines will generally have a fantail which will hold them into the wind.

All the equipment rests on the nacelle frame (or engine bed). In modern wind turbines this is generally made from a single cast piece of steel. Great care is taken in the design of the frame to minimize vibration and noise. The nacelle is enclosed with a cover which is often made from glass reinforced plastic but sometimes from steel. Just like the tower the nacelle cover is usually finished in a matt, off – white colour.

ROTOR

The rotor consists of three blades which catch the wind and rotate. The blades are held together by a hub.

Sometimes people incorrectly call the rotor a fan or propeller. This is quite misleading. A fan drives a current of air and a propeller causes propulsion through air or water. A wind turbine generator's rotor does not (and can not) do either of these things. A wind turbine's rotor is driven by the wind. Only on rare occasions, during maintenance, can the rotor be turned using the generator as a motor and then only very slowly.

For many years now the convention has been for all wind turbine rotors to rotate clockwise when looking from upwind. This is done because we do not want machines next to each other to rotate in the opposite directions – it is not pleasant to look at.

The blades of a rotor range in size from only a few centimetres long in small domestic machines up to forty-five metres or longer in the largest off shore machines. For example each rotor at Stanwell's Toora Wind Farm has three thirty-two metre long blades and weighs 23 tonnes in total.

They are made out of composite materials (i.e. reinforced polyester or epoxy resin). Most commonly the reinforcing material used in the blades is glass fibre. However, some manufacturers use timber laminates or exotic materials (carbon fibre or Kevlar) as well as, or instead of, glass fibre as a reinforcing material.

The blades are generally finished in a matt off-white colour. However in some places you may see the blades painted in alternating red and white colours where the machines are installed very close to an airport. In some very cold places where the build up of ice on the blades might be a problem the blades have been finished in black so that they more readily absorb the warmth of the sun in an attempt to avoid ice build up.

The design of wind turbine blades is a very complex process and tens of thousands of hours are spent in refining the designs. They are made from composite materials so that they can be very strong but still be relatively "light" and very flexible. The blades are so flexible that they bend under their own weight and sweep back considerably in strong winds.



The root ends of the blades are made of steel to allow for a solid connection of each blade into the rotor hub.



The centre of the rotor is called the hub. The hub is made out of steel and connects the blades to the drive shaft of the nacelle. On those machines where the pitch of the blades can be changed the hub also contains hydraulic equipment that turns each blade independently along its long axis. The hub generally has a cover over it (like a hub cap) which is called the “spinner”. The spinner is usually made from fibreglass and is essentially only for cosmetic effect.

During construction the blades are usually connected to the hub on the ground and then the rotor is lifted as a single entity and connected onto the nacelle. Two cranes are used to lift the rotor, one large one that performs the main lift and a smaller one to ensure the blades do not drag across the ground.



WHY ARE THEY WHITE?

Wind turbines obviously have to be highly visible, since they must be located in windy, open terrain to be economic. Better design, careful choice of paint colours - and careful visualisation studies before siting is decided - can improve the visual impact of wind farms dramatically.

Since wind turbines are visible in any case, it is usually a good idea to use them to emphasise natural or man-made features in the landscape rather than trying to make them disappear. More often than not, when we try to hide anything using colours we fail dismally and our attempts only serve to make the object more obvious.

This is a particular problem in most parts of Australia where landscapes can have dramatically different colours depending upon the season (e.g. a verdant green in winter and spring and yellow or brown during summer and autumn). Another problem is that we are usually looking at wind turbines from ground level and the sky will be the backdrop to the wind. The colour of the sky also changes dramatically.

Generally wind turbines are coated with an off-white or grey colour. These types of colours are passive colours and can help the turbines blend relatively well into the landscape. This does not mean that they will disappear or be invisible though. It simply means that these colours are quite neutral and do not stand out like reds or oranges.

The coatings are applied with a matt finish so that the surfaces do not reflect sunlight too much (though after a sun-shower the blades can glisten for a short period until they dry off). Even with a matt finish, the wind turbine generators can look quite different depending upon light and shadow on the site. For example at the Codrington Wind Farm, curious visitors have asked why some turbines are white and some a dark grey colour⁵. The turbines are in fact all the same colour! It is simply the changes in appearance of the turbines when the turbine is in direct sunlight or cloud shadow.

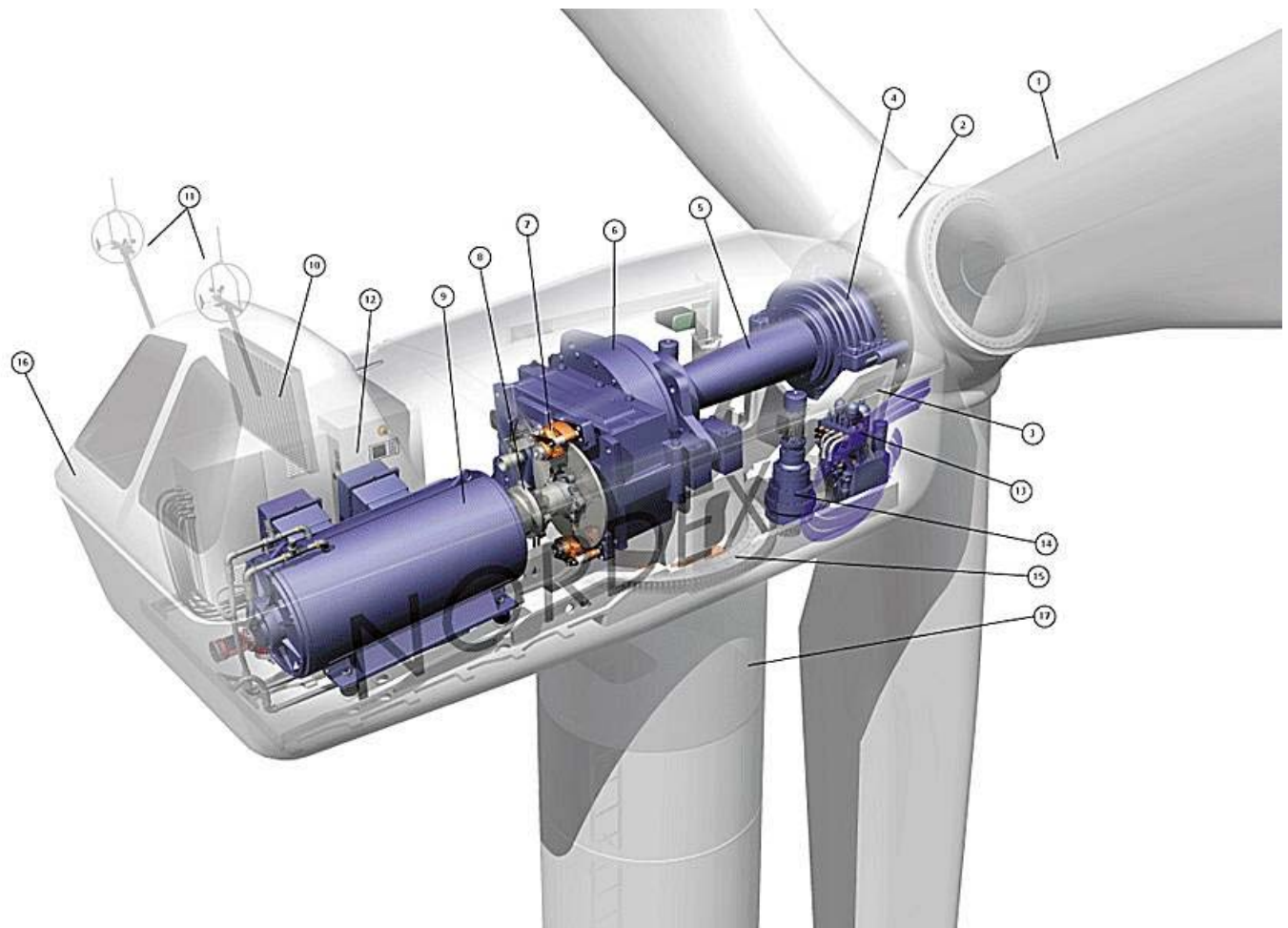
Like other man-made structures, well designed wind turbines and wind parks can give interesting perspectives and furnish the landscape with new architectural values. Wind turbines have been a feature of the cultural landscape of Europe for more than 800 years and are likely to do so here in Australia too.

⁵ Personal Correspondence, Grant Flynn, Sustainable Energy Australia 2003.

How does a wind turbine generator work?

BASIC COMPONENTS

There are many different types of cars and trucks but all of them have some common elements – an engine drives the wheels and a steering wheel is used to direct it. Wind turbines are just the same – there are lots of different types but they have some common elements. The diagram below shows a cut away picture of a Nordex N60 model wind turbine generator. We will use this to explain the basic “Danish Concept” wind turbine generator and then explain some of the variations that are also available.



The following list names the labelled elements in the diagram.

- | | | |
|--------------------------|----------------------|-----------|
| 1. Rotor Blade, | 9. Generator | 17. Tower |
| 2. Rotor Hub | 10. Cooling Radiator | |
| 3. Turbine Frame | 11. Wind Instruments | |
| 4. Main Rotor Bearing, | 12. Controller | |
| 5. Rotor Shaft | 13. Hydraulic System | |
| 6. Gearbox | 14. Yaw Drive Motor | |
| 7. Mechanical Disc Brake | 15. Yaw Ring Bearing | |
| 8. Generator Coupling | 16. Nacelle Cover | |
-

The Rotor Blades are made of composite materials and use the power of the wind to turn the generator.

The Hub is made of cast iron and connects the rotor into the drive-train.

The Turbine Frame is made of ductile cast iron and is generally cast as a single piece of steel.

The Rotor Bearing is a solid roller bearing which carries the weight of the rotor, balanced by the rest of the drive train.

The Rotor Shaft is made of spheroidal graphite cast iron and transmits the power from the rotor to the generator.

The Gearbox is a custom design 3-stage gearbox (with helical planetary and helical spur gears). This increases the slow speed of rotation of the drive-shaft at the rotor end (from 9 to 30 rpm) so that the high speed end of the drive shaft (generator end) spins at the appropriate speed for the generator (either 1,200 or 1,500 rpm). Some don't have a gearbox.

The Disk Brake is mounted on the high speed shaft of the gearbox. It is used for bringing the machine to a halt and keeping the rotor still when the machine is furled out of the wind.

The Generator Coupling is a flexible coupling that connects the drive-shaft to the generator.

The Generator is generally an asynchronous (induction) generator – essentially a three phase motor running “backwards”. In this picture the generator is liquid cooled. Some turbines are air cooled rather than liquid cooled.

The Cooling Radiator is used in liquid cooled machines and is connected to the generator and gearbox to keep both components cool.

The Wind Measuring System consists of an anemometer and wind vane (together with redundant backups), which measures the wind conditions and provides signals to the turbine control system.

The Control System monitors and controls the operation of the wind turbine. Each turbine in a wind farm operates completely independently of the others. The controller means the operation of the wind turbine is fully automated. The principle of operation is “fail-to-safe” so that even if something goes wrong the machine is naturally brought to a safe condition.

The Hydraulic System maintains and controls the hydraulic pressure to the equipment such as the disc brakes and the yaw brake system.

The Yaw Drive consists of planetary yaw gears, frequency controlled electrical motors and hydraulic brakes. This allows the nacelle to be rotated around the tower head so that it can always be brought into the wind.

The Yaw Bearing is mounted on the top of the tower and allows even the weight of the nacelle to be easily rotated around the tower using the yaw system.

The Nacelle Cover is generally made of glass fibre reinforced plastic on a steel frame. It provides protection from the elements to the equipment housed inside the nacelle. It can be opened so that it is easier to move around the nacelle.

The Tower is a tubular steel structure which holds the nacelle above the ground and provides personnel access to the nacelle.

BASIC OPERATION

In simple terms the wind (flow of air) presses against the rotor blades and, because of the aerofoil shape and the angle of the blades, they are able to convert the energy of the wind into a rotating force (torque). The torque acts on the drive shaft and causes it to spin. The generator is then driven by the drive shaft and generates the electricity, which is then transmitted to the electricity grid.

As the wind speed increases, more and more energy is delivered to the wind turbine's rotor. The relationship between wind speed and the power of the wind is a cube relationship (i.e. for each doubling of wind speed the power increases eight-fold). This means that small changes in wind speed lead to significant changes in the power of the wind which is delivered to the wind turbine's rotor.

The faster the air moves the more power is available for conversion by the wind turbine generator. The power of the wind in a severe storm with 50 knot winds (in which the wind turbine will still be operating) will be 244 times greater than that in a light breeze of 8 knots. This is a huge power range in which the machine must operate. Obviously there is a limit to how much power can be usefully captured by the machine. So a means of regulating the amount of power captured by the rotor is required.

There are three main strategies for regulating the amount of wind captured by the rotor; stall control, variable pitch control and active stall control. All three strategies are used in different models of modern wind turbine generators and each strategy has its own set of advantages and disadvantages.

No matter which control strategy is used, we do not bother operating our wind turbines at very low wind speeds (less than 3 or 4 metres per second or 10 to 15 km/hr). There is so little energy in the wind that it is simply not worth the wear and tear on the machine to try catching it. Likewise, in extremely strong winds (beyond 25 to 30 metres per second or 90 to 110 km/hr) there is just too much energy in the wind and it is not worth the risk to the machine to try to capture it. At most wind farm sites, winds like this are quite rare anyway so we really don't miss out on that much energy.

The wind speed at which we try to start catching the wind's energy is called the cut in wind speed (because the generator "cuts in"). Conversely the wind speed at which we decide to stop trying to catch the wind's energy is called the cut out wind speed (because the generator "cuts out").

You should note that at low wind speeds the rotor may still be allowed to rotate (free-wheel) even when it is not generating electricity. This generally occurs when the wind has been blowing but dies away for a short period of time. This is done so that, when the wind goes back above the cut in speed again, we do not have to overcome the inertia of a rotor at standstill. This allows generation to re-commence more quickly. This does not happen at high wind speeds though. Once the wind speed exceeds the "cut out" wind speed the machine takes action to bring the rotor to a halt and yaw out of the wind. It will generally not attempt to generate again until the wind has slowed down significantly (to say 22m/s or 80km/h). In this way the machine will shut down and stay shut down during the gusty winds of a passing storm front.

In general the rotor of a wind turbine spins only because of the pressure of the wind upon the blades. Because the generator is like a large electric motor, it is possible for the wind turbine to be driven electrically rather than by the wind. However this is only ever done during specific maintenance operations and, even then, only at very, very slow speeds (less than ½ rpm). By electrically driving the machine in this way it is possible to safely bring the rotor to specific positions (to allow access from the nacelle into the rotor hub or out onto a specific blade for inspection or maintenance) without yawing the machine into the wind. The misconception that wind turbines are routinely electrically driven so that they appear to be generating even if there is no wind is utterly false.

In a stall controlled machine, the control of the power delivered by the rotor is achieved through specific design of the rotor blades. The aerofoil shape of the blades in any wind turbine is similar to an aeroplane wing in that it creates a lift on one side of the blade. Just as a wing's lift acts at right angles to the wing, and pulls the plane up, a blade's lift acts at right angles to the blade and makes it move around the hub in a circular motion.

Again, just like an aeroplane wing, the motion of the aerofoil through the air also creates drag. It is the angle of attack of the aerofoil and the relative speed of the aerofoil through the air that determines how much lift and how much drag is created. As the pitch of an aerofoil is increased the angle of attack increases. Its lift will also increase, initially more so than its drag, but eventually a point is reached where the lift is overcome by the drag and the aerofoil goes into a state called "stall".

For an aeroplane, stall is not a very good thing (without enough lift they can fall out of the sky). However for a stall controlled wind turbine it can be very useful. The aerofoil shape of a stall controlled blade is designed with a twist such that at low wind speeds the blade derives maximum lift. In this way the turbine can capture as much of the energy as possible. As the wind speed increases, more and more power is captured by the rotor until it reaches the point at which the designers have decided to limit the power. As the wind speed continues to increase beyond this point, the stall control blade will begin to go into a state of stall. However the blade is designed so that not all of it goes into stall at the same point. Initially only a small part at the centre of rotor goes into stall and as the wind speed increases still further, more and more of the blade goes into stall until only a tiny bit of the blade is actually experiencing lift. The machine still operates though because there is such a large amount of power in the wind that only a small part of the blade tip is required to drive the machine with enough power to maintain maximum electrical output.

So in stall controlled machines the blades do not rotate on their long axis and the pitch angle is set at a fixed angle at the time of installation. This means that to "turn off" a stall controlled wind turbine, a method is required to spill off ALL the energy being delivered to the rotor. In a stall controlled machine this is achieved by using tip brakes, where the last ten to fifteen percent of the blade can be turned perpendicular to the rest of the blade. This not only spoils the aerofoil shape of the blade, it also acts as an air brake and can quickly bring the machine to a halt.

The tips are turned by hydraulically driven shafts up the centre of the blades. For fail safe operation, hydraulic pressure is required to act against a spring to turn the blade tip in line with the rest of the blade; otherwise the spring holds the blade tip in the "brake" position. In this way, any fault in the control system will automatically deploy the tip brakes.

The advantage of the stall controlled machine is that it is relatively simple to construct and to operate. It is therefore much cheaper to purchase. The principal disadvantage of stall control machines is that because the blade design is a compromise, the ability to convert the wind to electricity is less than that seen in other control strategies. Another less important problem is that the tip brakes need to be serviced and it is difficult to reach the end of the blades (a crane or climbing gear is required as shown in the image below of a very large stall controlled machine in Europe).



The Nordex turbines used at Hydro Tasmania's Huxley Hill wind farm on King Island and those at Pacific Hydro's Challicum Hills Wind Farm in Victoria are examples of a stall controlled machines being operated here in Australia.

Another way to control the power captured by the rotor is by varying the pitch of the blades (pitch control). In this method the angle of attack or pitch of the blade can be changed through a full ninety degrees as the wind speed changes. In low wind speeds the pitch is set to capture as much wind as possible. As the wind speed increases the pitch is continually changed to capture the maximum amount of power. Once the power limit is reached the pitch is changed so as to begin spilling the energy from the rotor.

Unlike stall controlled blades, the blades of a pitch controlled machine tend to be relatively "flat" and instead of parts of the blade going into stall, the amount of lift is simply reduced by changing the angle of attack of the whole blade. Because we are able to turn the entire blade through ninety degrees we can also "turn off" the machine by simply turning the blade perpendicular to the wind so the whole blade acts as an air brake.

The pitch of the blades is changed by sophisticated hydraulic motors controlled by microprocessors. The pitch angle of each blade is changed independently and because the whole blade is moved, even a single blade is able to bring the rotor to a stop if there is a failure in the other two pitch controllers. The pitch angle is reviewed very rapidly (usually many times per second) and can be changed by large amounts (several degrees) quite quickly. In this way it can respond to wind gusts and lulls and optimise the pitch of the blades to optimise the energy capture of the rotor.

The advantage of the pitch control machine is that it produces much more energy than a stall controlled machine. Another minor advantage is that the machine can also be detuned so as to reduce noise levels. The biggest disadvantage of a pitch controlled machine is that it is much more complex and so more expensive to build and maintain.

The Enercon turbines used at Western Power's Albany Wind Farm in Western Australia are an example of a pitch controlled machine in Australia.

The third strategy for control of power delivered to the rotor is called active – stall. This technique is a combination of stall and pitch control. The blades are designed in a similar way to stall control blades but the entire blade can still be turned to adjust its pitch. Because the blades can be rotated a full ninety degrees, blade tip brakes are not required.

In this technique, the rotor blades are rotated only by small amounts and less frequently than in pitch control. The idea is that by changing the pitch angle of the blade we are able to better optimise the performance of the blades over the range of wind speeds, especially low wind speeds. However the ultimate method of power control is by adjusting the amount of the blade that is in a state of stall.

The motors and control equipment used to alter the pitch of the blades are much less sophisticated than those used in pitch control and are therefore less expensive. So the active stall control machines are not quite as expensive as pitch control machines but produce more energy than stall control machines.

The AN Bonus wind turbines used at Pacific Hydro's Codrington Wind Farm in Victoria are an example of an active stall controlled machine in Australia.

So which control strategy is better? Well each site needs to be considered on its merits and the various power control strategies ranged against the others. The cost of installation and maintenance needs to be balanced against the energy yields (i.e. what is the ultimate cost of production of each unit of electricity).

To date no one strategy has taken the lead. However as machines get larger, and the strains greater, there is a trend away from passive stall control toward pitch control and active stall control.

Of course the story does not end here. There are different ways to transmit the power to the generator and different types of generator too. Traditionally the generators inside a wind turbine have been "squirrel cage, asynchronous induction generators". In very simple terms, this is similar to an electric motor; except that it is being driven by the drive-train and generates electricity, rather than driving the drive-train by consuming electricity.

These generators have a stationary set of tightly wrapped electrical coils (called the stator) surrounding the rotating part (called the rotor) connected to the drive shaft. The stator and rotor are separated by a very thin air gap. A rotating magnetic field is established between the rotating and stationary parts of the generator so that the spinning rotor induces a voltage in the stator and electricity flows out of the generator's terminals. As the rotor sweeps the circle of rotation, a wave of energy is transferred to the stator – alternating backwards and forwards.

The coils in the stator are arranged in three sets so that we end up with three alternating waves of voltage (called phases) each 120 degrees out of phase with the others. Each phase is carried in a separate wire. One phase reaches its peak at one instant, shortly followed by the next phase and then the next phase and then shortly afterward the first phase reaches its peak again.

We could have any number of phases but we would need a separate wire for each one. If we only have one phase then the power comes and goes in a wave pattern. This is fine for small machines but causes uneven power flows in larger loads such as large motors or the fans in city skyscraper air conditioning systems. To get more even power flows we want to use as many phases as we can, so one phase is at its maximum power flow – or close to it - at any one time. However, having lots of wires for all these phases becomes complicated to manage and very expensive. In the end, for most general applications three phases have been found to be the best compromise between cost effective wiring and even power flow.

The frequency at which the voltage alternates in each of the phases depends upon the rotating speed of the generator's rotor. This is where we strike a problem. Our electricity in Australia must be fifty cycles per second (50 Hertz, or 50 Hz). We must not allow it to deviate more than half a cycle per second away from this ($\pm 0.5\text{Hz}$). In the USA and some Asian countries electricity cycles at 60 Hz but the principle is the same.

For an induction generator to generate at a fixed rate of 50 Hz, its rotor must spin at a fixed speed. We can change the way the generator is arranged so that the rotor speed is either 1,500 or 1,000 revolutions per minute (for the technically minded this is by changing the number of pole pairs in the generator).

Of course the blades of a large scale wind turbine do not spin at anywhere near this speed. The rotational speed of the blades rotate is limited by the speed of the tip of the blade, which we limit to between 250 to 280 kilometres per hour (mainly because of blade efficiency and tip noise). The longer the blades of the rotor the slower they must spin to keep the tip from moving faster than this limit. Even for quite small (twelve metre long) blades, like those at Hydro Tasmania's Huxley Hill wind farm on King Island, this means the rotor can only rotate at about 44 rpm, still no where near fast enough to rotate the generator at a speed capable of delivering 50 Hz electricity.

To increase the speed the rotation, a gearbox is used so the rotor can still spin slowly but the generator can spin quickly. Unfortunately it is not feasible to vary the speed of rotation by way of a clutch and we cannot "change gears". The problem with this is that the energy capture of rotor cannot be fully optimised if the blades can only rotate at one speed. A number of techniques have been used to ameliorate this problem.

One method is to configure the generator so that it can switch between the two speeds of 1,000 and 1,500 rpm (by pole changing). Unfortunately, at the slower speeds the generator's maximum power output is much lower. But this doesn't really matter because we only want to turn the wind turbine blades more slowly in low wind speeds when there is less power in the wind anyway. When the power in the wind exceeds the capacity of the generator in its low speed configuration it automatically switches over to its faster and larger capacity mode of operation.

Many wind turbines use this technique and the wind turbines at Codrington Wind Farm operate in this way.

The wind generators will start to rotate at low wind speeds of around 3 to 4 metres per second. This wind speed is called the "cut-in" wind speed. As the wind speed increases the amount of electricity generated increases until the wind speed reaches a point at which the generator achieves its rated capacity. This wind speed is called the 'rated' wind speed and is typically between 12 and 15 metres per second. Above this rated wind speed, the generator output continues at its maximum output until the wind speed reaches the 'cut-out' wind speed (typically 25 metres/sec).

At wind speeds above the cut out wind speed (which will typically occur approximately 1% of the time) the generator is shut down and turned out of the wind to protect the generator from these extreme wind speeds so as to maintain the longevity of the generator.

The generators will typically maintain the same rotor speed (approximately 19 revolutions per minute for the Codrington Wind Farm) regardless of increasing wind speeds. At wind speeds below the rated wind speed the varying power in the wind is converted into varying the amounts of electricity by changes in the magnetic fields the generator. Once the rated wind speed is reached the generator has become saturated and the mechanical load delivered by the rotor is limited by slightly varying the pitch the blades (active stall control).

Another approach used in some generators is to change the electrical characteristics of the rotating part of the generator in response to changes in the speed of rotation of the drive shaft in real time. Because the changes must be made in real time and within a rotating machine, these changes are typically effected through the use of slip rings (electrical contacts that are able to move relative to each other). Variable resistors are connected to the rotor through slip rings and by changing the electrical resistance of the rotor it is possible to compensate for small changes in rotational speed without altering the output frequency of the generator. Unfortunately the contacts of the slip rings wear quickly, because of the movement, and there are limits to how much power can be directed through the slip rings.

One design that obviated this wear problem is the "Opti-Slip" system developed by Vestas. Because a magnetic field induces electrical current in the rotor, it is possible to mount a small "computer" inside the rotor using this current as its power supply. The

computer can then control changes in the electrical characteristics of the rotor – all it needs is to be told how to change. In the “Opti-slip” system, the information is communicated into the rotating drive shaft using an optical signalling device which does not require any physical contacts and so does not wear out.

Unfortunately there is a limit to how this type of approach (called variable slip control) can be used. It will generally only cope with small changes in speed - up to only 10% from nominal speeds. Consequently these machines operate in essentially the same way as a typical fixed speed machine.

The wind turbines at Blayney Wind Farm and Hickory Hill Wind Farm in NSW use these sorts of turbines.

Yet another approach is to let the generator rotate at whatever speed it wants to and then simply convert the entire uncontrolled alternating current output of the machine into direct current (DC - like in a torch battery) and then to convert it all back to alternating current (AC) using sophisticated, computer-controlled power electronics. Advances in the technology of power electronics during the 1990's have meant that high power levels of electricity can be dealt with in this way and this sort of approach can now be used in large utility scale machines.

This approach releases the rotor from a fixed rotational speed. In fact it means that with the use of a special generator it is possible to have the generator rotate at the same speed as the rotor of the wind turbine. This means that the gearbox could be removed as well. These sorts of machines are called direct-drive machines because the rotor drives the generator directly.

The perceived benefits of direct-drive systems for large wind turbines are:

- lower cost than a gearbox system;
- reduced tower-head mass and nacelle length;
- efficiency savings of several percent.
- Direct drive machines always take advantage of the opportunity for variable-speed operation allowed by the AC/DC/AC converter.

Turbines with direct drive systems range from 200 kW to 1.5 MW.

While it might appear to be optimistic to expect large mass or cost savings in large wind turbines purely by the introduction of a direct drive system, fully integrated and simple designs (i.e. those with common bearings for the generator rotor and wind turbine rotor) with a wide and variable range of rotor speeds and the elimination of gearbox maintenance have all favoured the continuing development of direct drive systems.

However a significant proportion of the savings gained are lost by the losses of the power electronics systems, so these direct drive machines have not dominated the market as yet. However their ability to deliver power in whatever configuration the operator may desire and their ability to change that configuration in real time, means that they can be very useful in assisting the utility maintain grid stability. This is especially important in “small” or remote systems.

The Denham and Albany Wind Farms in Western Australia and the Windy Hill Wind Farm in Queensland all used this type of wind turbine.

Yet another approach that has emerged in recent times is a combination of the previous two. These machines still have a gearbox but also allow the rotational speed of the rotor to vary quite dramatically (as much as from 9 to 36 rpm). In these machines a small proportion (say 10% to 20%, rather than the total output) is converted to DC and then back into AC. This power is then fed into the rotor through slip rings to change the electrical and magnetic properties of the generator so that the output of the generator is at the frequency and reactive levels desired by the operator. This technology is called a

double fed induction generator and has become possible because of significant advances in slip ring technology that allow for efficient and long wearing operation.

To achieve this, the small portion of power fed back into the rotor is rapidly adjusted by a computer, not to the standard frequency of the grid but rather to the frequency, voltage and current levels required to achieve a constant output at the generator's main terminals. Because only a small portion of the output is converted in this way, the power electronics involved are a lot less expensive in comparison to converting the entire output of the generator. This is particularly important in large capacity machines (i.e. over 1 MW).

The generators installed at Toora Wind Farm in Victoria use this type of approach.

A wind farm, regardless of its mode of operation, is designed to operate within the electrical and safety parameters of the grid connection and if the parameters are exceeded - by either the grid or the wind farm - the integral safety devices that form a part of each wind turbine will shut down the wind farm until normal conditions are restored. The wind generators will detect any disruption to the electricity grid and will shut down automatically and remain shutdown until they detect a return of the proper grid conditions.

Individual generator faults can be detected by the control system and the affected generator shut down while allowing all other wind generators within the wind farm to continue operating. The supervisory control and data acquisition system linked to each wind generator also allows the wind farm to be monitored remotely for operational performance, overall output and for the development of fault reports. The wind generators can also be started or stopped and their condition interrogated remotely by dialling-in to the on-site controlling computer.

When normal conditions are restored the generators will restart randomly to avoid a large draw of power from the grid that may otherwise be caused by yawing the generators back into the wind and the restarting the systems.

WIND GENERATOR MAINTENANCE

Wind farms are designed to operate generally without intervention and are unattended for the majority of the time. Each wind generator is able to operate completely independently of all other wind generators. If conditions outside of the operating and safety parameters occur the generator will fail to a safe condition. All safety and control systems have full redundancy to ensure safe operation.

Under normal circumstances, routine scheduled maintenance will be carried out approximately once every six months. This scheduled maintenance of each wind generator will consist of oil changes, brake pad replacement, bolt tightening, etc and takes approximately one day per generator. The major component parts of the wind turbine generator are designed for the lifetime of the machine but may occasionally require repair or replacement (this is not common).

The first few months of operation of the wind farm will require regular attendance at site by several technicians to ensure that the wind generators 'bed in' properly and that all final construction and commissioning tasks are attended to. On-going performance and reliability are continuously monitored, including site inspections and if necessary a service team can carry out any unscheduled maintenance.

ACCESS TRACK MAINTENANCE

The site access tracks and hardstand areas are left in place following installation of wind generators for use by maintenance crews. Tracks do not need to be highway standard and it is quite common for grass to grow over the verge and road surface. The important thing is that there is a solid base so that vehicles can safely gain access to each machine any time of the day or night.

What Are The Components Of A Wind Farm?

WIND GENERATORS

The main component of a wind farm is of course the wind turbine generators. These come in a variety of physical sizes, rated capacities and operating paradigms. In general terms though they consist of a 3 bladed rotor connected to a generator compartment (called a nacelle) all mounted on top of a tubular steel tower. In Australia best practice guidelines have been prepared by AusWEA that guide developers in how to locate the wind turbines within the wind farm but the final layout will be determined by site specific issues.

ACCESS TRACKS

Access tracks are required for access to each wind turbine. They are usually about five metres wide, assuming the use of a mobile crane for erection of the wind generators. They are generally constructed from locally obtained crushed limestone or gravel. On-site pits are used wherever possible, so as to minimise the amount of traffic on local public roads and to remain in keeping with other existing farm tracks. Where local material is not available or needs to be supplemented, material will be imported from near-by quarries.

The tracks are formed by laying the pavement material directly onto the existing ground surface to ensure adequate drainage and minimise ground disturbance. The access tracks are retained after the construction period for use by the landowner and for future maintenance, repair or replacement of the wind generator components.

UNDERGROUND CABLING

All the wind turbine generators need to be connected electrically so that we can get the electricity out to the local grid. This is done with a system of electrical cabling called the collector network, which in Australia will be placed underground.

The cabling used is usually steel wire armoured, electrically shielded and plastic insulated. The large amount of electrical power being carried means that these cables are quite thick (and very expensive). They are buried in a trench about 60cm to 80cm deep. The cables are protected by a layer of soft sand below and above the cable. A PVC cable marker is laid over the top of the sand. The soft sand provides mechanical protection from rocks or other sharp objects in the surrounding material and the cable marker helps alert anyone who is digging in the area that the cable is underneath. The trench is backfilled with excavated material and topsoil is then reinstated over the trench once backfilling is completed.

Sometimes a small communications cable will share the same trench as the electrical cables. Just like a telephone cable, this communications cable can be a simple copper cable or an optical fibre cable. These communications cables allow communication to each of the wind turbines for monitoring and control from a central point.

As the foundations are completed, underground cabling is installed between each wind generator and progresses in parallel with the delivery and erection of the wind generators. Underground cabling is installed beside the site tracks wherever possible to minimise the extent of site disturbance.

In some circumstances the route of the trench may need to be marked every few hundred meters with small marker posts in a similar way to buried telephone cables, gas lines, etc.

ELECTRICAL SUBSTATION / SWITCHYARD

Each wind farm has a substation and or switchyard. This provides the overall interface between the wind farm and the local electricity network. It also provides a control point for the flow of electricity in and out of the wind farm.

The switchyard is fenced off in accordance with local standards (usually two-metre high mesh fencing) to ensure that people do not inadvertently come into contact with the

electrical equipment. The switchyard generally consists of a transformer, electrical isolators, circuit breakers, and associated metering and control equipment. The transformer is required only if the voltage of the wind farm's collector network is not the same as the local electricity network's voltage.

The switchyard may also be at the point where all of the underground collector network cables come together at a single point - though this is not always the case. Connection from this point to the local electricity network - the grid connection - will generally be run along standard overhead cables.

SWITCHYARD CONTROL FACILITY / KIOSK

There is a control facility (or kiosk) at the substation to house the electricity meters, control equipment, computers, etc. It also provides some basic amenities for maintenance staff. The wind farm links with the local distribution network system provider's supervisory control and data acquisition (SCADA) system via equipment contained in the control facility.

INTERCONNECTION TO EXISTING GRID

From the wind farm's switchyard to the point of connection with existing high voltage grid - the grid connection - overhead power lines will generally be used. Wherever possible the route used for these overhead lines will follow existing distribution (power-line) easements. In this case the new high voltage lines will be strung atop new (taller) poles, with the existing lower voltage distribution lines beneath.

In some circumstances an entirely new power line will need to be installed. In either case the line will be installed using techniques and equipment typical to the area (e.g. Stobie poles in SA, concrete or timber poles in Vic, etc).

SITE PREPARATION WORKS / HARDSTAND AREAS

An area is required around each foundation that needs to be relatively level, for the assembly and erection of the turbine elements. Hardstand areas are constructed with the same material as for the site access roads and will be retained after construction to facilitate future maintenance, repair or replacement of the generator parts.

Sometimes hard stand areas are also required for temporary equipment such as concrete batching plants, etc. As these are only required during the construction phase they can be removed and the site reinstated after construction is complete. Sometimes the landholder may have a need for a hard stand area, in which case it may be left in place.

HOW ARE WIND FARM COMPONENTS TRANSPORTED TO SITE?

The main components that might need transport to site include;

- Blades and hubs
- Nacelles
- Towers
- Concrete for foundations
- Road making materials
- Cables
- Switchyard parts

The complexity of transporting these and other components will depend upon their source and the specific location of the wind farm. Some of these components are relatively simple to transport to site – such as switchyard components and cables – because they are generally sourced from within Australia and can fit onto a standard road transports (i.e. a semi-trailer). Others, such as road making material and concrete, have very large volumes and numerous vehicles will be required to transport them to site.

Road making materials are sourced from within the site as much as possible, to reduce the amount of vehicle movements into and out of the site and also to reduce the risk of weed introduction through the use of non-indigenous soils. If the materials cannot be sourced from within the site then they will be brought from a location as close to the site as possible to keep transport costs to a minimum. Generally they will be transported in a standard bulk carrier (tip truck) with a trailer or large bulk carrier (semi-trailer or “b-double”).

Concrete poses some special problems. Each wind turbine foundation will required in the order of 250 cubic metres of concrete (about 80 agitator truck loads) and each foundation must be laid in a single continuous pour. Transport of this volume of concrete, especially over long distances, where timing is so critical is often very problematic. There are rarely enough agitator trucks in the area to have 80 or more lined up in a row. If there is a hold up on the roads between source and site, or a truck breaks down, the foundation may not be able to be poured as a single mass. This may result in a sub-standard foundation, meaning that it must be removed and work re-started from scratch. This would be very expensive and exasperating.

Consequently on-site batching of concrete is usually performed and only the dry materials (and perhaps the water depending upon the quality and volume of the on-site water supply) would be brought in to site prior to the batching of the concrete. This means that only a small fleet of agitator trucks is required and only a short distance of internal tracks would be required to lay each of the foundations.



The towers, blades and nacelles pose some specific problems in terms of their physical size and weight. The nacelle of a large wind turbine may be 8 or so metres long and 3 metres high and weigh as much as 80 to 90 tonnes. The towers are manufactured in sections and each section may be as much as 5 metres wide, 20 to 30 metres long and weigh in the order of 40 tonnes each. The blades can be as much as 40 metres long, 3 metres high and 2 metres wide and weigh as much as 10 tonnes each.

Specialist transport vehicles are used to transport these items within Australia and there are companies that specialise in the transport of these sorts of items and have the experience and equipment to do so safely and cost-effectively. These companies are able to establish the safest route through the road network and determine the best time to move the vehicles and what sort of escort vehicles would be required.

A standard low loader is used for the nacelles, which are transported one nacelle per truck. The trailer will have quite a few axles so that the weight of the heavy load can be evenly spread across the road surface. The prime mover will be quite powerful so that it is able to pull the weight effectively.





For the towers and blades specialist bogey arrangements that can be independently steered are used together with powerful prime-movers. The towers are generally manufactured in two or three sections and the sections are transported to site independently. Special brackets are bolted into the flanges at each end of the tower sections and these are then connected to the steerable bogey wheels. The stiffness and strength of the steel tower essentially acts as its own “trailer”. Because the towers are usually fitted out with the internal ladders, platforms and electrical equipment at the

factory canvas covers are placed over each end to keep dirt and insects out during transport. These also help to stop other little surprises, like snakes, from crawling in while the tower is stored either at the factory or on site.

The blades are a similar length to the tower sections but because they are designed to be flexible they need a framework to support them during transport. Blades are usually transported in pairs (lying in opposite directions) in a steel framework that supports their weight. The steerable bogies are again placed at the end of the frame and the frame acts as the “trailer”.



The rotor hubs can be transported using the same low loader type transport equipment that is used for the nacelle. They are able to be transported two or three at a time.



Some of the components are not currently manufactured in Australia (though this will change soon). The blades, nacelles and rotor hubs are manufactured overseas and so need to be transported into Australia. So far, this has only been done by ship for Australian wind farms and because of their weight this is the typical way for international freight of wind turbine components. It is possible though to transport blades – at least the smaller ones - using large aircraft but its very expensive.

The ships used for the transport of wind turbine components are generally specialist ships, because of the unusually size of the goods. This is further complicated by the fact that the blades need to be top-loaded – i.e. they cannot have other loads laid on top of them. Usually the ships are also equipped with self unloading facilities so that they can come into ports near to the site, even though the port may not be equipped to handle this sort of cargo.





Where can I get a close look at a wind farm?

There are wind farms and wind turbines of various sizes all around the country and more are being built all the time. You should check the Australian Wind Energy Association's web site for the latest details (www.auswea.com.au).

Most large wind farms have viewing areas with informative interpretation boards. Some have self guided tours (e.g. Western Power's 10 mile lagoon wind farm just west of Esperance) where you can walk amongst the wind turbines. Others such as Pacific Hydro's Codrington Wind Farm have professional guided tours running on a regular basis (see <http://www.myportfairy.com/windfarmtours/>).

Many of the larger wind farm owners also have "virtual tours" of their wind farms available via their web sites and are well worth a visit. This is also a good way to see overseas wind farms and some of the offshore wind farms. Again you should check the AusWEA web site for the latest details.

Please remember that most wind farms in Australia are located on private property. You should keep to the path and designated visitors' area and not enter private property uninvited.

Wind Farms Are Temporary

Wind generators will generally be removed from site after their designated life-time. This is usually not less than 20 years for a modern wind turbine but some have design lifespan of up to 30 years. Some older machines had shorter life-spans such as the WestWind wind turbine generators at Salmon Beach Wind Farm in Esperance WA where the design life was only 12 to 15 years.

At the end of the life of a wind farm there are two simple choices – remove it completely and generate the electricity in another way, or replace it with another modern wind farm. If the wind farm is dismantled (called decommissioning) then the site is rehabilitated, usually back to its original state or very close to it (see below). If a wind farm is to be replaced with newer wind turbine generators then three important things need to happen – the host of the wind farm (the owner of the land) must agree, the operator of the wind farm (owner of the wind turbines) must agree and the local community must agree (the planning process will need to be repeated). Essentially it is almost like starting all over again.

In some overseas wind farms decommissioning has occurred before the machines are worn out to allow for the installation of new turbines with modern designs and better performance. This process is called re-powering a wind farm. Today's wind turbines are larger and more efficient than the turbines of the 1980's. They are also much quieter, the blades rotate more slowly, and each turbine produces much more energy than the older machines.

The decision to dismantle a wind farm before the end of its design life is based on a cost benefit assessment. This is just like a decision to replace the family car, it will cost money to do but the benefits (in terms of better performance or suitability to needs) may outweigh that cost. Because of the dramatic improvements in the technology over the last 20 years re-powering is often a financially attractive option.

Here in Australia only one large scale wind farm has been dismantled so far. Western Power decided to decommission its Salmon Beach Wind Farm (Australia's first, built in 1987) in 2002 after 15 years of service. Salmon Beach was decommissioned because of urban encroachment and the age of the machines.

Four of the six turbines from Salmon Beach have been sold to a Queensland company for re-use. Western Power donated the remaining two turbines to the Esperance community - one will remain on site as a monument for the town and another will be housed at the Esperance Museum. The land upon which it was built is vested with Western Power but will be transferred to the Shire of Esperance as a reserve for Conservation and Heritage.

The departure of the Salmon Beach Wind Farm does not mean that Esperantos don't like wind energy though. The wind farm was replaced by the 9 Mile Beach Wind Farm (immediately east of the 10 Mile Lagoon Wind Farm) and this new wind farm has increased the supply of wind energy to the Esperance community.

DECOMMISSIONING AND REHABILITATION

At the end of the life of a wind farm the blades, nacelle and towers will be dismantled and loaded onto trucks for removal from site. For the most part the wind turbine components can be reused or recycled.

If the wind farm site is not to be used as a wind farm again (i.e. if the wind turbine generators are not to be replaced with modern equivalents) then the foundations would be cut-off below ground level and covered over and the switchyards would be dismantled and removed.

The cables and tracks would generally be left in place because of the disruption it would cause to the wind farm host. As you can imagine after 20 or so years of having a nice network of all weather tracks around the farm, it is unlikely that the farmer would want to loose them and so the wind farm operator will come to an arrangement to leave these in

place. Likewise the removal of the cables would require all the trenching to be opened up again which can be a real problem if there is a bumper crop of barely over the top of it. Again this can be dealt with by the host and operator – e.g. if the copper in the cable is worth more than the barley crop then they may decide to pull the cables all up again for recycling.

If the wind farm site is to be reused then the foundations may be able to be left in place (only if they are suitable for the new wind turbines) and the wind generators would be replaced with their modern equivalent.

WHAT COMPONENTS OF A WIND GENERATOR CAN BE RECYCLED

The scrapping of a turbine requires energy. But recycling the metal parts will recover slightly more energy than what is required for the scrapping process.

The modern large scale wind turbines used in Australia have rotor blades made of glass fibre reinforced polyester (GRP) or epoxy. The towers are usually tubular steel towers. The foundations are reinforced concrete.

As an alternative to dumping the used rotor blades, the blades may be shredded and used in the manufacture of certain plastics or aggregate in concrete. Alternatively, they may be incinerated at high temperatures. In embodied energy calculations we assume that the incineration method is used, but the amount of energy thus recovered is very modest.

Concrete foundations may be fragmented and used in the manufacture of concrete or as landfill. Again in embodied energy calculations the amount of energy recovered in these processes is approximately zero.

Gear oil may be recycled or burned as a fuel.

The rest of the turbine consists of mostly steel, iron and copper which may be sorted, shredded, refined and recycled. The scrap value of the metal in a 600kW wind turbine nacelle is approximately \$15,000, more than 75 per cent of which, by value, is copper.

During the past ten years the weight of wind turbines per kW nameplate electrical power has been halved. That obviously contributes significantly to energy balance improvement. Danish 600 kW wind turbines, on average weigh approximately 60 metric tonnes plus 4.5 tonnes weight for the rotor blades.

THE ENERGY BALANCE OF MODERN WIND TURBINES

It is possible to calculate the energy balance in the manufacture, operation, maintenance and scrapping of a typical modern wind turbine and these calculations have been done for a 600 kW Danish wind turbine⁶. The energy balance is the ratio between the amount of energy used for manufacturing, operation, maintenance, repairs, and scrapping of a wind turbine – and the energy which the turbine will supply throughout its lifetime (20 years).

In addition to its own use of energy, each sector needs supplies of goods and services manufactured in other sectors which in turn use energy and supplies of goods and services from other sectors. It is also possible to calculate direct and indirect use of energy for each and every sector in the chain of production which ends up in the final output of the sector we are investigating.

One of the results is that the energy balance in the scrapping-recycling process is positive, since a substantial amount of energy from the original manufacture of metal components may be recovered in the subsequent recycling of metals.

In performing these calculations it is assumed a single wind turbine is installed. In Australia there will be lower installation energy costs since they usually place turbines in

⁶ From Wind Power Note 16: The Energy Balance of Modern Wind Turbines. Danish Wind Energy Association

wind farms. Furthermore, in Australia we have generally installed much larger capacity wind turbines (and will continue to do so) and so the amount of embodied energy is also going to be lower per unit of installed capacity. It is also assumed that wind turbines have a lifetime of 20 years corresponding to the design lifetime, and that the foundations are not reused for another wind turbine. In connection with the scrapping of the turbine it was assumed that all components except for the transformer are destroyed and that the material is not reused but only recycled to the extent that this is economical.

The energy balance may therefore be slightly better than that indicated by the calculation.

A wind turbine located in the moderate wind regimes of Denmark will typically recover the energy spent in its manufacture, installation, operation, maintenance, and scrapping, some 80 times over. Because the annual electricity production from a wind turbine is approximately proportional to the energy content of the wind, in areas where the wind turbines are exposed to stronger wind regimes (e.g. in Australia), they may recover the energy spent on their manufacture and operation in as little as one month.

There is little difference to these calculations if the turbine is manufactured in Australia or manufactured in Denmark and then transported to Australia by sea freight. Even if a 65 tonne wind turbine has to be shipped 10,000 nautical miles, it will only affect its net energy use by 1.5 per cent. However the poor efficiencies of Australia coal technology (25 to 35% compared to 45+% in Denmark) may have a more significant impact on the calculations given that the Australian manufacturing process will generally derive its energy for this less efficient coal fired energy source.

There are offshore wind farms overseas why not here in Australia?

In some European countries wind farm developers and planners are considering the siting of wind farms offshore. While off-shore wind farms are still quite rare (less than 20 in the world) there are a lot of wind farms planned for off-shore in European over the coming years. This is due to the many competing uses for onshore sites and to the higher speeds and reduced turbulence of the wind at sea. However, the cost of manufacture, construction and maintenance of offshore wind farms is considerably higher than onshore, and as such they are only be viable for very large offshore wind farms.

Several offshore wind farms have now been built, so it is possible to assess the economics in the light of this limited operational experience. A number of factors combine to push up the cost of offshore wind farms relative to their onshore equivalents:-

- The cost of the cable connection from the wind farm to the shore
- the need for more expensive foundations
- Operation and maintenance costs are increased with the risk of lower availability due to difficulties in obtaining access to the wind turbines during bad weather
- the need to "marinise" the wind turbines, to protect them from the corrosive salt spray

The cost of the Vindeby wind farm – the first off-shore wind farm - was 85% higher than the cost of an onshore installation. However the anticipated energy yield was 20% higher and production statistics show that the energy production is even higher than expectations. Concerns about lower availability offshore - due to problems of access - have not been realised.

To try and minimise the increase in cost when going off-shore developers look for areas that are windy but are also close to significant electrical loads and where landing of the electrical cable is relatively simple. They will also use a smaller number of generators with larger rated capacities. This helps to keep the cost of the electrical connection down. To help keep the cost of foundations down the developer will look for sites where the depth of the water is relatively shallow (generally less than 15 metres) and the waves are not too strong. Being close to a launch area also keeps operational costs down too.

In Australia we have a lot of windy sites on-shore. Our coast is dominated by areas that are far too deep, waves too strong and generally too far away from suitable grid landing locations. However, we do have quite a few areas off-shore where the wind resource is acceptable, water depth suitably shallow and wave energies low enough for it to be technically possible to build off-shore wind farms. Contrary to this, our very low electricity prices, combined with the added expense of off-shore construction, means that on-shore development will continue to dominate at least for the next few years.

Overseas, several large wind farms are currently being considered for the relatively shallow sandbanks around Ireland and the UK. Off-shore projects are also being developed in the shallow waters around Denmark and Germany.

DESIGN DIFFERENCES FOR OFF-SHORE WIND FARMS

The design of off-shore wind turbines is subtly different to their on-shore cousins. Several manufacturers have now gone into serial production of purpose built off-shore wind turbines. Having fewer maintenance points and fewer interconnections between turbines favours the use of large wind turbines in the off-shore market and the rated capacity of machines is now routinely 2MW or more (machines in excess of 4MW are proposed).

In off-shore locations constraints imposed on the turbines by noise emission limits and near field visual effect can be relaxed. This means there is a greater tolerance of more unusual design configurations that may have economic merit.

So the trend is toward larger machines with higher tip speeds, which means the cost of the wind turbine component of the offshore system can be significantly reduced compared

to land based designs. Obviously this is very desirable to help offset the increased costs of foundations and electrical transmission associated with offshore projects.

Another key objective for the design of cost effective off-shore wind turbines is a reduction of inspection and maintenance requirements. Design for high reliability is an important priority and there is an emphasis on minimising long term operation and maintenance costs, even if at the expense of a somewhat higher wind turbine capital cost.

Contrary to popular belief, corrosion is not a major concern with off-shore steel structures. Experience from off-shore oil rigs has shown that they can be adequately protected using cathodic (electrical) corrosion protection. Surface protection (paint) on off-shore wind turbines is routinely delivered with a higher protection class than for on-shore turbines. Oil rig foundations are normally built to last 50 years and the foundations for wind turbines are no different.

FLOATING WIND FARMS?

There have been a number of studies throughout Europe to investigate the feasibility of floating wind farms installed in deep water. Various concepts for floating systems have been considered. The FLOAT⁷ study undertaken in the UK investigated the outline design and costing of an offshore wind farm with floating turbines for water depths up to 100 metres. According to this study, however, the cost of the floating platform, the cost of moorings and of transmission to land would seem to clearly indicate that floating wind turbine systems would only be exploited (if at all) in a second generation of off-shore projects, after systems on sea bed foundations are generally established.

THE FUTURE OF OFF-SHORE IN EUROPE

Off-shore wind has the potential to deliver substantial quantities of energy - at a price which is cheaper than most of the other renewable energies, but more costly than onshore wind. Offshore wind energy has minimal environmental effects and, broadly speaking, the best European resources are reasonably well located relative to the centres of electricity demand.

Wind speeds are generally higher offshore than on land. Offshore wind power is therefore most attractive in locations such as Denmark and the Netherlands where windy hill top sites are simply not available. In these areas off-shore winds - which increase with distance from land - may be 0.5 to 1 ms⁻¹ higher than on-shore, depending on the distance off-shore.

The major challenge for offshore wind energy is cutting costs: Undersea cabling and foundations have until recently made offshore wind energy an expensive option. New studies of foundation technology, plus megawatt-sized wind turbines are now on the point of making offshore wind energy competitive with onshore sites, at least for shallow water depths up to 15 metres (50 ft.).

Since offshore wind turbines generally yield 50 per cent higher output than turbines on nearby onshore sites (on flat land), offshore siting may be quite attractive in the future.

According to The Danish Governments' Action Plan for Energy, Energy 21, four thousand megawatts of off-shore wind power should be installed before year 2030. With another fifteen hundred megawatts installed on-shore in Denmark they will then be able to cover more than 50 per cent of total electricity consumption by wind energy.

⁷ Technical and economic aspects of a floating offshore wind farm. Tong K C. Proc. OWEMES Conference, Rome, February 1994.

How can I buy wind power?

Almost all electricity retailers around Australia now have GreenPower™ product. Every unit of energy purchased by Green Power™ customers will be supplied into the grid from a renewable source and one less unit of energy will come from coal-fired stations. No changes to cabling or power poles are required.⁸

So when you buy Green Power™ an amount of renewable electricity equivalent to your consumption is fed into the grid eliminating that amount of coal derived power. That means your electricity will be exactly the same as before, but your purchase directly reduces the greenhouse emissions. The collective purchasing by Green Power™ customers represents a significant benefit to the environment.

Some of these products include a proportion of electricity derived from wind farms and some such as Origin Energy's Earth Plus, is 100% wind power. By purchasing products like this instead of standard electricity sourced from coal-fired generation, you can help support wind farms. You should contact your electricity retailer to ensure their GreenPower™ product includes wind energy or alternatively contact your state government energy department for more information.

IS IT GUARANTEED GREEN?

Electricity suppliers use a variety of brand names to identify their renewable energy schemes. When you see the Green Power™ logo on an electricity scheme, it means that it has been approved by the National Green Power Accreditation Steering Group. A National Accreditation Program has been developed to ensure that Green Power™ offered by electricity suppliers is generated from approved renewable energy sources. Green Power products sold by accredited electricity retailers are rigorously monitored under a National Green Power Accreditation Program, administered by government energy agencies in all states and territories.

An accredited Green Power product is one where the generation source:

- results in greenhouse gas emission reductions
- has nett environmental benefits
- is based primarily on a renewable energy source

Primarily means that more than half of the electricity output can be attributed to a renewable source and only the renewable part can be counted as Green Power™. This is to allow for co-firing of generators, where the renewable fuel makes a significant contribution to the power output (i.e. more than 50%).

A generation source that could cause significant environmental or cultural damage, even if considered renewable, will not be approved. For instance, major flooding hydro projects would not be approved.

Accredited Green Power™ retailers must submit regular reports to ensure that sufficient approved renewable energy is purchased to meet customer needs. Revenue from the schemes must be independently auditable and retailers themselves must purchase Green Power™ for their own purposes.

Retailers must commit to the development of new renewable generation. Retailers must source a minimum of 80% of their Green Power™ from 'new' renewable sources developed since 1997. This acts as an incentive for a viable renewable energy industry in Australia. Under the national accreditation program, a 'new' generation source is one commissioned after 1 January 1997.⁹

⁸ from www.greenpower.com.au

⁹ From www.seav.vic.gov.au

How can I support wind farms in Australia?

There are a variety of ways that you can support wind energy in Australia, depending upon how much involvement you wish to have and whether you wish to make financial investments or not.

BUY WIND ENERGY

One very good way to provide some support is to simply buy wind energy from your electricity retailer through their GreenPower™ product. If your electricity retailer does not have a GreenPower™ product that includes wind energy, or it is not 100% wind energy, you may wish to consider changing to one that does.

This doesn't just apply to your electricity at home either, you can ask your business to buy wind energy too. Businesses that purchase GreenPower™ can even display logos to help let their employees, customers, suppliers and the general community know that they care about where their electricity comes from and the effect it has on our climate.

For many businesses, electricity is only a small fraction of their total costs and the increase in cost caused by purchasing GreenPower™ is often quite acceptable and there are usually ways to offset this small increase. Why not suggest to the boss that the next time the electricity supply contract is negotiated that a proportion of the electricity is GreenPower™.

Several large energy customers around the country have already started purchasing GreenPower™. The Victorian Government has set a target of 5% of its electricity supply to be GreenPower™. The City of Melbourne is a principal centre for the Cities for Climate Protection programme here in Australia. It undertook a programme of energy efficiency measures and then ploughed the savings back into the purchase of GreenPower™ and now purchases 10% GreenPower – they use a lot of electricity to keep all those street lights burning.

When Ararat Rural City heard about Pacific Hydro's plans to build the southern hemisphere's largest wind farm inside their shire at Challicum Hills they thought it was such a good idea that they decided to purchase 20% of their total electricity from the wind farm through GreenPower™.

To find out more about energy efficiency and Greenpower contact your local electricity retailer and your State Government's energy office (e.g. SEAV in Victoria and SEDA in NSW).

JOIN AUSWEA AND ATTEND AUSWIND CONFERENCE

Another way to support wind energy (and to be kept informed of and participate in events and discussions in the wind energy community) is for you or your organisation to become members of AusWEA: Australian Wind Energy Association. You can join as an individual member or as a business member.

Alternatively you may only wish to attend AusWEA's annual conference which is held in a different state each year in the last week of July (2004 in Launceston).

WRITE YOUR LOCAL MEMBER

Politicians whether they are at a local, State/Territory or Commonwealth level are busy people and have to deal with lots of conflicting points of view about a range of issues. Sometimes they might seem to lose touch with the values and objectives that we feel are important to us. There is an easy way to remind them – drop into their office or write them a letter. A polite and rational approach will always get a good response.

You might also like to ask your local council about what they are doing about combating climate change and reducing greenhouse gas emissions.

INSTALL A WINDMILL

The ultimate statement showing your support for wind energy is the installation of your own wind turbine. There is a lot of effort and not an inconsiderable expense involved in installing a windmill and you will need a bit of open space to fit it in. If you live in a suburban area it is unlikely that you will have enough room to install even a small wind mill but if you live in a country area with a bit more space you may wish to consider it.

AusWEA has prepared a Best Practice Guide that helps give you a few pointers about how to go about it and some of the Do's and Don'ts for appropriate wind farming. Your State Government's energy office may also be able to help (e.g. SEAV in Victoria and SEDA in NSW).

ENCOURAGE YOUR FRIENDS AND CHILDREN

Do you know about the Accelerated Greenhouse Effect, how your electricity is generated and why we should reduce how much of it we use? Now that you have ready some of the basic facts about wind energy we hope that you know at least a little more than you did before and that you may feel comfortable bringing up wind energy in conversation with your friends.

You might also like to encourage your children to learn about where electricity comes from and how we can produce it using something as clean and simple as the power of the wind. This might be your big chance to actually know something more than the kids – about something that they might care about anyway!

There is lots of information about wind energy on the internet specifically targeted for use by school children and to help teachers prepare classes about energy and the wind. Check out the AusWEA web site at www.auswea.com.au for links to wind energy sites all around the world.

BUY SHARES IN A WIND FARM OR WIND FARMING COMPANY

If you wish to make a significant investment you may wish to purchase shares in a company involved in the wind energy industry (make sure you speak to your financial adviser first though). You never know you may already be investing in wind energy through your superannuation fund or cash management fund. If not, you might want to consider asking your fund to look into these sorts of investments.

You might also wish to consider investing in ethical investment funds that specifically target organisations that adopt a sustainable approach to business and assess the social and environmental impacts of their business as well as how much money they will make for their shareholders.

In some overseas countries wind farms are actually owned by the local community. For example the Middlegrund Wind Farm –located in the sea off the Copenhagen harbour in Denmark is owned by ordinary Danish citizens. While this has not yet occurred in Australia to date it may not be that far away.

REGISTER YOUR SUPPORT FOR A LOCAL WIND FARM DEVELOPMENT

All wind farm developers appreciate support for their projects. If you hear about a wind farm development in your area and you think it is a good project then don't be a part of the "silent majority". All too often when a project is put up to the local government or state government for planning approval the planners only hear from people that want to stop the project. It doesn't take long before they begin to think that everyone in the area is against a project.

You can do your bit by letting the government authority that is to make the decision as to whether the project will proceed or not (usually your local council) know that you support the project. Even a short letter of support in your local paper can help too.

SUBSCRIBE TO THEWIND.INFO E-ZINE

You can subscribe to an electronic magazine (an e-zine) from TheWind information site. All you need to do is to visit www.thewind.info and subscribe to the e-zine. Why not register your support for an Australian target of 10% new renewable energy by 2010 while you are there.

USE YOUR CLOTHES LINE, FLY A KITE, GO SAILING, ETC

Every time you use the wind instead of another energy source you are supporting wind energy – even if only in a very small way. More often than not you will be saving yourself some money or having fun anyway. So why don't you collect the kids and go fly a kite.

Basic terms used in wind energy development

Sometimes wind farm developers will use terms you may not be familiar with. They are not necessarily trying to confuse you - they simply forget what others don't know. The following is a list of some common terms and what they mean. You should also refer to the Glossary of Australian Wind Energy terms.

ANEMOMETRY MAST

A mast, on which is fixed equipment (including an anemometer) measures the wind speed and wind direction over a particular site. Anemometry masts are usually slender structures fixed to the ground with guy wires. They may also be called monitoring masts or meteorological masts or automatic weather stations.

DECOMMISSIONING

This is the final phase of a development when the site is cleared of above ground equipment associated with the wind energy project and the land restored to a state fit for its original use or some other agreed use.

ENVIRONMENTAL MANAGEMENT PLAN

An Environmental Management Plan is a document which crystallises agreed proposals to minimise the environmental impacts of construction activities and working practices. It may specify a method of construction, and it may contain provisions for monitoring environmental effects during operation.

ENVIRONMENTAL ASSESSMENT / ENVIRONMENTAL STATEMENT

This is usually a quite large document prepared by a developer with help from specialist consultants. It is used for projects which may have an affect on the environment that cannot be controlled or managed through the normal development authority (or town planning) process. The specifics of how it is laid out and what it does or does not contain will be determined by its scope of work – usually set by a State Government, the Commonwealth Government or both.

HUB HEIGHT

This is the height of the wind turbine tower from the ground to the centre of the turbine rotor hub.

LOCAL ELECTRICITY DISTRIBUTION SYSTEM

The electricity distribution network normally incorporates the overhead poles and wires (sometimes underground wires are also used) which connect individual properties and areas to the regional grid at a variety of power levels.

MEGAWATTS, KILOWATTS AND WATTS

A megawatt (MW) is equal to 1,000 kilowatts (kW) or 1,000,000 watts (W). It is a measure of power and is typically used as a measurement of electrical generating capacity.

POWER CURVE

The Power Curve is a graph or table which shows the relation between the power produced by a wind turbine according to the wind speed to which it is exposed. It can be used to estimate the power delivered to the grid at a certain wind speed and also in calculating the expected yield in a year.

REFLECTED LIGHT

Under certain conditions sunlight may be reflected from wind turbine blades when in motion. The amount of reflected light will depend on the finished surface of the blades and the angle of the sun.

SCOPING DOCUMENT

The scoping document establishes the full scope of the environmental assessment and should be agreed in writing with the local planning authority.

SHADOW FLICKER

Under certain combinations of geographical position and time of day, the sun may pass behind the blades of a wind turbine and cast a shadow. When the blades rotate the shadow flicks on and off. The effect only occurs inside buildings when the flicker appears through a window opening. The seasonal duration of this effect can be calculated from geometry of the machine and the latitude of the site.

SUBSTATION

The electrical substation connects the local electricity network to the electrical system of the wind energy project through a series of automatic safety switches.

TELECOMMUNICATIONS (AND ELECTROMAGNETIC) DISTURBANCE

Telecommunications systems broadcast information at a variety of frequencies and in a number of ways. The telecommunications systems currently in operation over land, use microwave, very high frequency (VHF) and ultra high frequency (UHF) systems. Interference with telecommunication systems is known as electromagnetic disturbance or interference, or by the shorthand initials EMI.

TENDER

A tender is the assignment for all the works to a specific contractor with agreed terms. A number of contractors may bid for the tender and the assignment of the contract will occur after a selection procedure is applied to the different bids.

ZONE OF VISUAL INFLUENCE

A zone of visual influence provides a representation (usually presented as a map with markings or colourings) of the area over which any part of a proposed development may be visible. These maps ignore all topographical features (trees, buildings, etc) except for terrain. They also ignore the visual acuity of the observer as well as the visual conditions that may be expected. In this way they provide an absolute worst possible case of visibility of a proposed development.