

The Structure of a Modern Wind Turbine – An Overview

A wind turbine is made up of the following components:

1. Tower
2. Foundation
3. Nacelle
4. Rotor blade
5. Hub
6. Transformer (this is not a part of the Wind Turbine)



1. Tower and foundation

a. Tower

The tower construction doesn't just carry the weight of the nacelle and the rotor blades, but must also absorb the huge static loads caused by the varying power of the wind. Generally, a tubular construction of concrete or steel is used. An alternative to this is the lattice tower form.

A wind turbine generator tower is a component subjected to high loads. The nacelle often weighs several hundred tonnes and there is also stress from the rotor blades and the force from the wind.

A wind turbine generator tower, constituting 15 - 20 % of the costs, plays a substantial role in the economic feasibility of a project. However, higher towers also increase the returns – the height of the tower or hub height is a vital factor in the energy yield.

As a rule, which height is suitable for a wind turbine generator (WTG), depends on several factors (e.g. costs) and must be decided individually for each location.

❖ *Types of towers*

The following types of towers are available. However concrete and steel towers are much more common than steel lattice towers:

- **Steel towers** usually consist of two to four segments.
- **Concrete towers with climbing formwork** are constructed on site and make transport and fitting easier (called in-situ concrete.) But great care must be taken at significant heights and in winter.
- **Pre-cast concrete towers.** Here the segments are placed on top of one another on site and braced with steel cables in the wall.
- **Steel lattice towers** are very common in India, but can also be found in other countries, like in the USA (western mills) and in Germany.
- **Hybrid towers** consist of components of the above-mentioned types of tower.
- **Guyed poles** are very common in small wind generators, as on the one hand they are light and on the other can be set up without a crane.

Higher towers over 80 m usually have a car or a lift on the inside of the tower to facilitate the ascent.



Wind turbines with steel lattice towers in Costa Rica. ©WWEA e.V.

❖ **Examples of tower heights:**

- hub height 40-65 m: approx. 600 rated power and approx. 40 to 65 m rotor diameter
- hub height 65 to 114 approx. 1.5 to 2 rated power and approx. 70 m rotor diameter
- hub height: 120 to 130 approx. 4.5 to 6 rated power and approx. 112 to 126 m rotor diameter

b. Foundation

In order to guarantee the stability of a wind turbine a pile or flat foundation is used, depending on the consistency of the underlying ground. The foundation anchors the wind turbine to the ground.

The foundation fixes the wind generator into the ground. In order to guarantee the stability of the wind generator, pile foundations or shallow foundations are constructed depending on how stable the subsoil is.

- **Plate foundations/shallow foundations:** Here a large reinforced concrete plate under the earth forms the footing of the generator. It is one of the most commonly used types of foundation.
- In **pile foundations**, the foundation plates (plate foundations) are fixed with piles into the earth. This is particularly necessary in soft subsoil.



*Uetersen wind farm, Germany.
Foundation of the wind turbine is completed.
© Bundesverband WindEnergie e.V.*

The following foundations are used offshore. At the moment a lot of research is still being done and tried out here.

- **Gravity foundations** are often used and placed on the sea floor. These, huge concrete weights for example, are so heavy and stable that they do not need any more fixation to the sea bed.
- **Tripod:** Here the wind generator is put on a tripod. The piles below the tower are connected with a steel frame that distributes the tower's forces over three steel piles, each of which are fixed approx. 10 - 20 metres deep in the sea bed.
- **Bucket foundation:** This consists of a steel cylinder open towards the bottom which gave it its name. First of all the cylinder is placed on the sea bed and then pumped out. The negative pressure generated inside the foundation presses the foundation into the ground. The material at the bottom of the inside of the cylinder supports the foundation and fixes it to the sea bed.
- **Monopile:** Here a single mast, a steel pile with a diameter of approx. 4 metres, is sunk into the sea bed. Depending on the bed, the monopile is driven approx. 10 – 20 metres deep into the sea floor.

2. Rotor and rotor blades

a. Rotor

The rotor is the component which, with the help of the rotor blades, converts the energy in the wind into rotary mechanical movement.

Currently, the three-blade, horizontal axis rotor dominates. The rotor blades are mainly made of glass-fibre or carbon-fibre reinforced plastics (GRP, CFRP). The blade profile is similar to that of an aeroplane wing. They use the same principle of lift: on the lower side of the wing the passing

air generates higher pressure, while the upper side generates a pull. These forces cause the rotor to move forwards, i.e. to rotate.

b. Rotor blades

Rotor blades are a crucial and elementary part of a wind turbine. Various demands are placed on them, and they must withstand very great loads.

❖ *How they work*

Rotor blades take the energy out of the wind. They "capture" the wind and convert its motive energy into the rotation of the hub. The profile is similar to that of airplane wings. Rotor blades utilize the same "lift" principle: below the wing, the stream of air produces overpressure; above the wing, a vacuum. These forces make the rotor rotate.



Rotor blade at Bonn International Renewable Energies Conference venue 2004, Photo by WWEA e.V.

❖ *Number of rotor blades*

Today, most rotors have three blades, a horizontal axis, and a diameter of between 40 and 90 meters.



*Three bladed wind turbine at wind farm
Sintfeld, Germany, Photo by WWEA*

In addition to the currently popular three-blade rotor, two-blade rotors also used to be common in addition to rotors with many blades, such as the traditional windmills with 20 to 30 metal blades that pump water in the United States.

Over time, it was found that the three-blade rotor is the most efficient for power generation by large wind turbines. In addition, the use of three rotor blades allows for a better distribution of mass, which makes rotation smoother and also provides for a "calmer" appearance.

❖ ***The material used***

The rotor blades mainly consist of synthetics reinforced with fiberglass and carbon fibers. The layers are usually glued together with epoxy resin. Wood, wood epoxy, and wood-fiber-epoxy compounds are less widely used. One of the main benefits of wooden rotor blades is that they can be recycled.

Aluminum and steel alloys are heavier and suffer from material fatigue. These materials are therefore generally only used for very small wind turbines.

❖ ***Design and profile***

Each manufacturer has its own rotor blade concepts and conducts research on innovative designs; there are many variations that are quite different. In general, though, all rotor blades are constructed similar to airplane wings.

c. Hub

The hub is the center of the rotor to which the rotor blades are attached. Cast iron or cast steel is used.

The hub directs the energy from the rotor blades on to the generator. If the wind turbines have a gearbox, the hub is connected to the slowly rotating gearbox shaft, converting the energy from the

wind into rotation energy. If the turbine has a direct drive, the hub passes the energy directly on to the ring generator.



Rotor Hub Enercon E82 at Hannover Energy International Fair, Photo by WWEA

The rotor blade can be attached to the hub in various ways: either in a fixed position, with articulation, or as a pendulum. The latter is a special version of the two-blade rotor, which swings as a pendulum anchored to the hub.

Most manufacturers currently use a **fixed hub**. It has proved to be sturdy, reduces the number of movable components that can fail, and is relatively easy to construct.

d. Power control

The power that a wind turbine absorbs has to be controlled. If the wind is too strong, power is reduced to prevent damage to the system. There are basically two concepts of power regulation:

- **Stall control (regulation by flow separation)**

Rotor blades with stall control are attached to the hub at a fixed angle. The profile of the rotor blade is designed to cause turbulence behind the rotor blade at a particular wind velocity. At the same time, when the wind is too strong the asynchronous generator also limits power generation automatically. It restricts the speed of the system to the frequency of the power grid, so that the rotor cannot turn faster when the wind blows stronger. In this concept, the rotor blades are designed to cause flow separation at a certain wind velocity (**stall**), the power input is reduced even though the blades are not themselves pitched.

In active stall control, the pitch of the rotor blades can also be changed. This control system is used mainly in large wind turbines (> 1 MW). When the wind is too strong, the rotor blades are turned *into* the wind, increasing turbulence.

Active stall regulation allows for power to be regulated more accurately than passive stall regulation does.

- **Pitch control**

This control concept was developed from 1990 up to 2000. Here, each individual rotor blade can be infinitely turned into or out of the wind. The drive for pitch adjustment is either mechanical (for systems with an output below 100 kW), hydraulic (starting at 300 kW), or electric (the most common one, especially for large turbines > 500 kW).

A controller constantly monitors the turbine's power output. If the wind is too strong, the rotor blades are turned out of the wind along their axis, generally only by a fraction of the degree. This reduces the lift, so that the rotor continues to generate power at rated capacity even at high wind speeds.

3. Nacelle with drive train

The nacelle holds all the turbine machinery. Because it must be able to rotate to follow the wind direction, it is connected to the tower via bearings.



Transport of a nacelle which includes the drive train, Photo by Fuhrländer

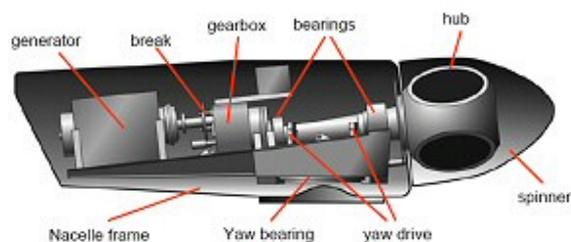
a. Components in the drive train

The drive train consists of the following components:

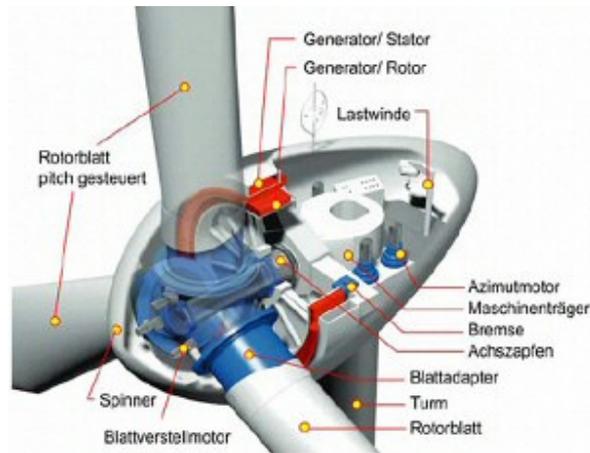
- ❖ *Rotor shaft with bedding*
- ❖ *Gear box (direct drive turbines have none)*
- ❖ *Brake(s) and coupling*
- ❖ *Generator.*

There are many ways to arrange the components, and the arrangements vary from one manufacturer to another.

Certification organizations have specifications for noise levels, oscillation response, and load profiles for these components. These specifications are very important because these components are subject to tremendous loads.



Drive Train: with Gearbox



Drive Train: Direct Drive System (German Only)

The build-up of the nacelle shows how the manufacturer has decided to position the drive train components (rotor shaft with bearings, transmission, generator, coupling and brake) above this machine bearing.

b. Gearbox

In order to achieve their design potential as credible alternative providers of energy, wind turbine systems have to employ highly efficient, reliable and robust components. Among the most important of these components are gearboxes; in particular, planetary gearboxes

The gearbox converts the rotor motion of 18-50 rpm into the approx. 1,500 rpm which the generator requires.

The rotational movement of the turbine rotor is connected to the electrical generator via a three-stage, overdrive gearbox, whose transmission ratio depends on the rotor diameter (the larger the diameter, the higher the transmission ratio). In particular, the gearbox must increase the rotation speed from 30 to 60rpm (which is insufficient for producing electrical energy) to 1,500rpm. The unit has gears generally in parallel on the input side and a planetary gear stage on the output side. The gearboxes are shaft-mounted units with a double torque arm. They are selected based on a requirement for 20 years of continuous life, and are usually equipped with a cooling system including oil filters and an oil recycling unit. The use of a shaft-mounted unit offers several benefits: it eliminates the cost and complexity of couplings, and also the time and labor involved in ensuring correct alignment of the gearbox and the equipment it is driving. In addition, the direct drive provided by shaft mounting avoids radial loads imposed by chain drive arrangements.

The gearbox thus takes on the task of matching the rotation speeds of the slow-moving rotor and the fast-moving generator, and generally has several steps to cover for various wind conditions.

If a specially developed multi-pole ring generator is used, the gearbox is no longer required (best-known manufacturer of direct drive turbines: ENERCON).

The application of the planetary gearboxes to all the key operating areas of wind turbines is the result of a number of factors. Firstly, planetary gear trains are able to deliver high reduction ratios in small packages, and to transmit several times the torque of similarly sized, conventional gear units. Secondly, they are compact and lightweight, and require little installation space. Thirdly, the planetary drive is up to 98% efficient and, critically, is able to provide extremely low speeds without any loss of efficiency.

Finally, there is the facility of modular design, based upon the epicyclic cell, to provide ultra-compact multiple reduction units. The advantages of this arrangement to the designer are twofold. The planetary stages can be combined to match the increasing torque being transmitted through a gearbox. They can also be assembled to provide reduction ratios right up the scale: to a value of 15,000:1 if required.

c. Generator

The generator in a wind turbine converts mechanical energy into electrical energy.



For high power wind turbines, doubly-fed asynchronous generators are most frequently used. Here, the operating rotation speed can be varied somewhat, unlike when using conventional asynchronous generators. Another concept uses synchronous generators. A grid connection of synchronous generators is only possible via transformers, due to the fixed rotation behavior. The disadvantage of requiring complicated control systems is countered by the overall efficiency and better grid compatibility.

In general, a distinction is made between asynchronous and synchronous generators. Asynchronous generators are used most often; they allow for synchronization with the grid and are very robust and low-maintenance. However, synchronous generators are also used because they are more efficient. Synchronous generators can be directly connected to the grid, or an inverter can be used. But they require additional equipment for synchronization with the grid. All generators have to be cooled. Usually, a ventilator is used for air cooling. Sometimes, water cooling is also used.

Slow-running multi-pole ring generators do without a gearbox as mentioned above.

d. Coupling and brake

❖ *Coupling*

Because of the enormous torque, the **coupling** between the main shaft and the transmission is a rigid one. The type of **brake** depends on the control mechanism for the blades.

❖ *Brake*

There are generally two types of brakes: aerodynamic brake systems and mechanical systems.

The certification guidelines of Germanic Lloyd specify that two independent brake systems must be used: aerodynamic brakes (the tips of the blade can be adjusted or the entire rotor blade can be pitched) and another brake. The latter brake is generally a mechanical disc brake in most wind turbines. This type of brake is mainly used when the aerodynamic brake fails or the turbine is undergoing repairs.

The type of mechanical brake used depends on how power is controlled. In turbines with stall control, the mechanical brake has to take up all of the rotor's and the generator's motive energy in case of emergency; this brake therefore has to be very high-performant. In contrast, the mechanical brake used in turbines with pitch-controlled rotor blades can be smaller.

4. Electronic equipment

The electronic equipment of a wind turbine is composed of the generator (see above), the system for the grid infeed of the electricity, and various sensors.

A wind generator's electrical equipment can be divided into the generator, to be explained elsewhere, into the system for feeding electricity into the grid and the sensors for controlling and monitoring the generator.

❖ *System for feeding electricity into the grid*

The system for feeding electricity into the grid depends on the generator used: the majority of modern wind generators in the megawatt category use grid-connected asynchronous induction generators running at almost constant speed and direct connection to the grid. This means that rectifiers or inverters are not necessary.

In variable speed turbines with synchronous generators, the alternating current generated fluctuates constantly in frequency and quantity. In order for the electricity to be fed into the grid, it is converted into direct current using a **rectifier**, filtered and then converted back into alternating current using an **inverter**.

In both types of generator the voltage is then converted for connection to the level of the grid using a **transformer** and the wind generator and a measurement device are connected to the transmission grid.



Foundation and transformer for a wind turbine. ©Bundesverband WindEnergie e.V.

❖ **Sensors for controlling and monitoring the generator**

The nacelle has sensors or measurement devices that constantly record the following parameters: wind speed and wind direction, speed of the rotors and the generator, the ambient temperature and individual components, oil pressure, pitch and azimuth angle (yaw mechanism based on the wind direction) and electrical values, as well as vibrations or vibrations in the nacelle.

This data is used to control the generator, for example the direction of the wind is transmitted directly to the yaw mechanism or the data controls, when the generator is put into operation or switched off.

These sensors and the capture and analysis of these data monitor the wind generator providing the basis for good operational management.

The sensors for measuring temperature, wind direction, wind speed and many other things can be found in and around the nacelle, and assist in turbine control and monitoring (see chapter “Operation and maintenance”).

5. Other components

Finally, the wind turbine components include (1) systems to track wind directions, (2) cooling and heating elements, (3) lightning protection equipment, (4) cranes and elevators, and finally (5) fire extinguishing equipment.

a. Tracking wind directions

The purpose of these components is to turn the turbine's rotor into the wind at an optimal angle. Generally, information measured by the weather station is used to determine the direction of the wind.

In general, a distinction is made between passive and active systems in horizontal axis wind turbines (HAWTs):

- **Passive systems** do not need electric yaw drives. Turbines whose rotors are behind the tower (downwind) follow the wind automatically, while upwind turbines have weather vanes.

Weather vanes are well known parts of the windmills used historically in the United States to pump water; here, the direction of the wind is determined in a very simple fashion. The additional loads and the forces that occur when the direction of the wind changes suddenly mean that passive wind tracking systems are only used with wind turbines whose rotor diameter does not exceed approx. 10 meters.

- **Active systems.** These systems are used both on upwind and downwind rotors. Here, a drive (actively) rotates the nacelle on the tower. Such active systems ("rosettes") were already used in the late 18th century in Dutch windmills. Nowadays, *azimuth motors* (also called yaw drives) are most commonly used, either singly or as multiple motors at a time. A weather vane on the nacelle provides information to the azimuth drive. The motors are on the azimuth ring, which slides the nacelle into its optimal position when driven by the motors.



Azimuth drive. © Bundesverband WindEnergie e.V.

b. Cooling and heating

❖ **Cooling**

The temperatures inside a nacelle can be quite high due to the waste heat from the gearbox and the generator. Special ventilators are therefore installed in the nacelle to keep it cool.

In addition, there are usually special cooling units for the individual components of a wind turbine, such as the gearbox.

❖ **Heating**

During the winter, temperatures often fall below freezing where wind turbines are set up. When the oil in the gearbox freezes, it is hard to get the system running again after it has been motionless for some time. Therefore, heaters are often used to warm up the oil in the gearbox.

In addition, rotor blades are also heated to prevent them from icing over or being damaged by condensed water.

Finally, anemometers and weather vanes also have to be heated in cold regions to prevent them from malfunctioning and damaging the turbine.

c. Lightning protection

Wind turbines are tall structures that are generally exposed and therefore vulnerable to lightning. Lightning often strikes the tips of rotor blades.

The following solutions are available to absorb lightning:

- Round metal discs called "receptors" at the tip of the rotor blade,
- Multiple receptors along the blade,
- Aluminum blade tips

The current is then passed along inside the rotor blade along metal conductors and then over the nacelle before being directed down the tower to the ground anchor. Especially sensitive areas are avoided.

d. Cranes and elevators

Most wind turbines contain winches to haul small spare parts and tools into the nacelle. Inside the nacelle, swinging crane and gantry cranes are used.

e. Fire extinguishers

Fire extinguishers are also provided within wind turbines to combat any fire that may occur in the hardware or electronics.

Often, the fire extinguishers are manual tanks, but automatic fire detection and extinguishing systems are also used.