

COMPONENTS OF WIND MACHINES

© M. Ragheb
2/28/2014

INTRODUCTION

Early wind machines ranged in their rated powers from 50 to 100 kW, with rotor diameters from 15 to 20 meters. Commercial wind turbines now have ratings over 1 MW and machines for the land based and offshore applications have rated power outputs reaching 5 and even 7-10 MW of rated power for off-shore wind applications.

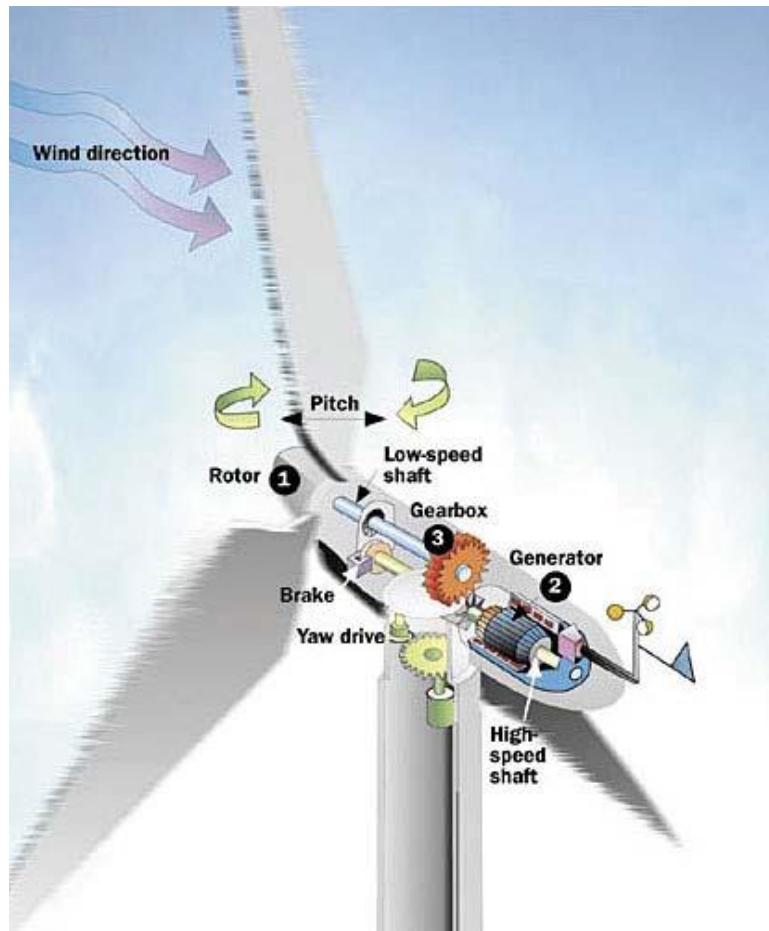


Figure 1. Schematic of a wind turbine components.

Larger sizes are mandated by two reasons. They are cheaper and they deliver more energy. Their energy yield is improved partly because the rotor is located higher from the ground and so intercepts higher velocity winds, and partly because they are more efficient. The productivity of the 600 kW machines is around 50 percent higher than that of the 55 kW machines. Reliability has improved steadily with wind turbine manufacturers guaranteeing availabilities of 95 percent.

Wind energy systems include the following major components: the rotor and its blades, the hub assembly, the main shaft, the gear box system, main frame, transmission, yaw mechanism, overspeed protection, electric generator, nacelle, yaw drive, power conditioning equipment, and tower (Fig.1).

NACELLE

The nacelle is the housing that protects the main frame and the components attached to it. This enclosure is particularly important for wind electric systems, but does not exist in water pumping machines (Fig. 3).

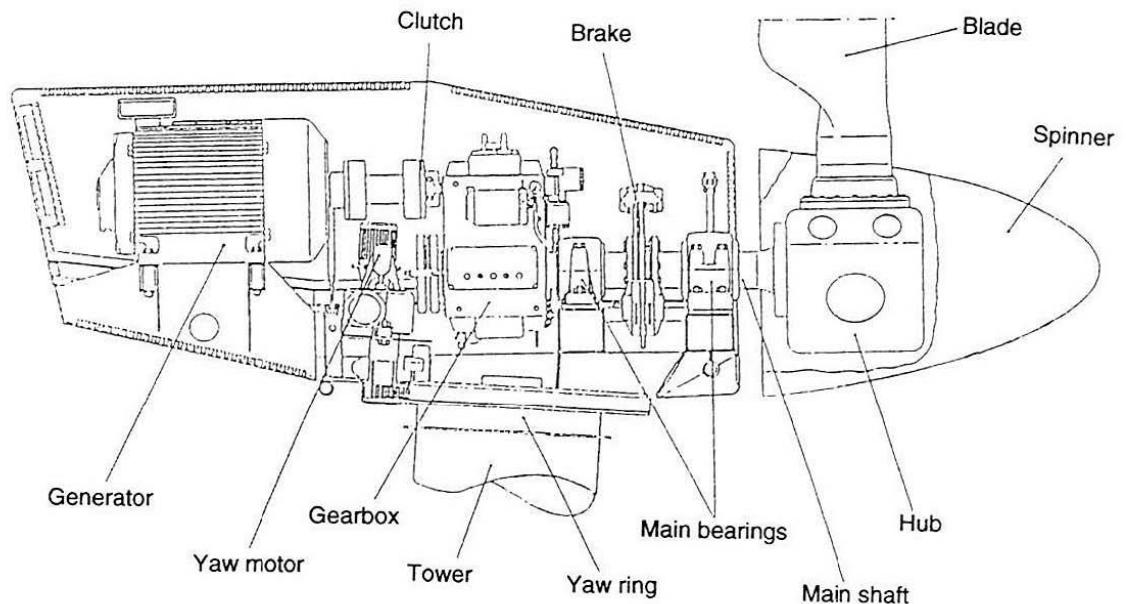


Figure 2. Wind turbine components inside the nacelle.



Figure 3. Open nacelle with two anemometers appearing in the back.



Figure 4. Nacelle interior of the Saab Scania wind turbine.

ROTOR DESIGN

INTRODUCTION

Rotor blade design has benefited from airplanes wind technology. It uses the Bernoulli aerodynamic lift force that an airfoil feels in a moving stream or air. The shape of the rotor blade and its angle of attack relative to the wind direction affects its performance.

The rotor assembly can be placed in two locations:

- a) Upwind of the nacelle and tower receiving the wind stream unaffected by the tower's presence.
- b) Downwind of the tower which allows yawing or the self-alignment of the rotor in facing the wind. However this arrangement deflects the wind causing a tower shadow that consists of a turbulent wind stream reaching the rotor.

The rotors inherent mechanical properties and its design affect its useful service lifetime. The latter is dependent on the variable loadings and the environmental conditions during its operation.

The majority of the world's wind turbines have three glass reinforced plastic blades. The power-train includes a low speed shaft, a step-up gearbox and an induction generator, with either four or six poles. Gearless wind turbines with multi-pole generators are increasingly replacing the gearbox-equipped machines. There are numerous other possibilities, however. Wood epoxy is an alternative blade material and some machines have two blades.

ROTOR MATERIALS

High speed wind machine rotors usually have blades with an airfoil cross section. The blades are usually made of wood solid or laminated, fiberglass, or metal. Slower machines usually use flat or curved metal plates or sails mounted on a spar.

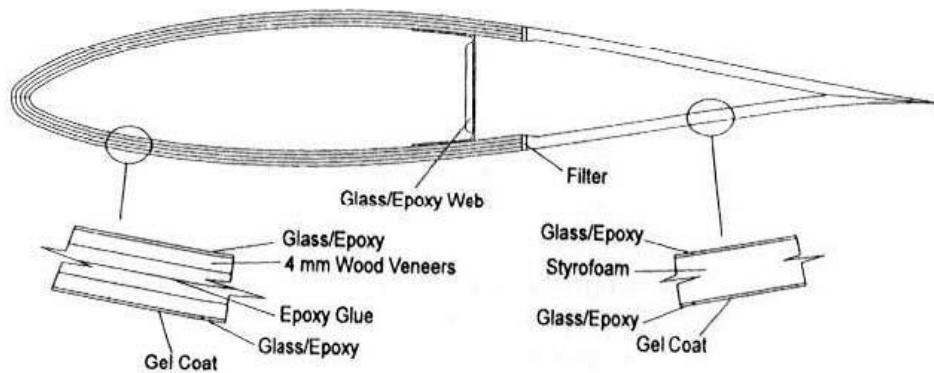


Figure 5. Wood epoxy blade design.

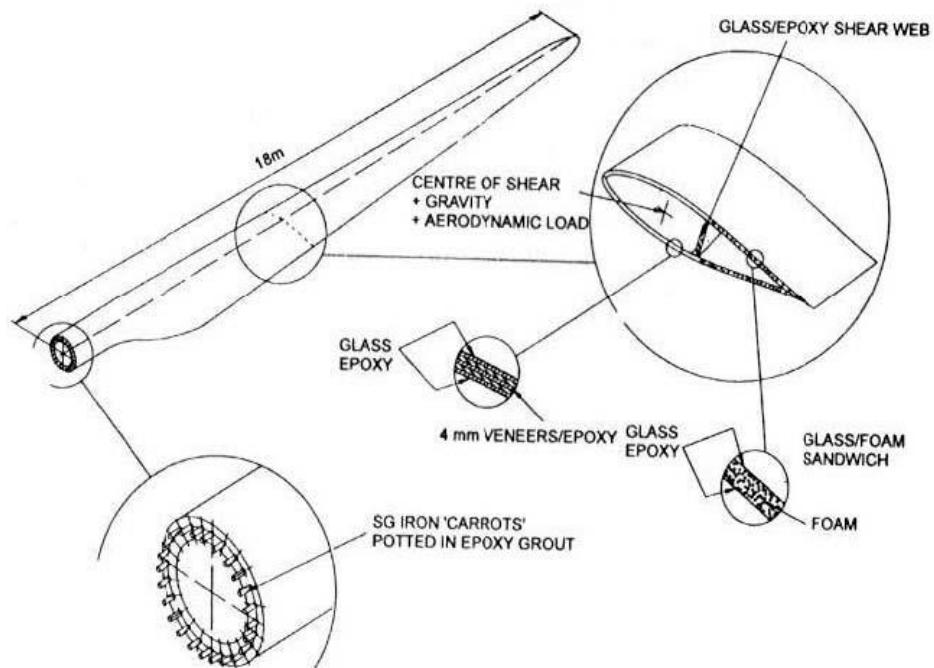


Figure 6. Composite wood epoxy blade construction.

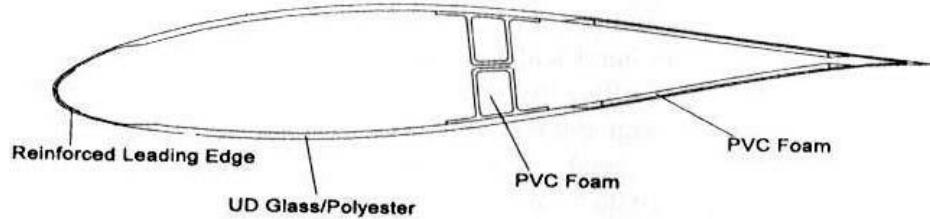


Figure 7. Fiber Glass Reinforced Plastic (GRP) blade section.

The following materials have been considered for rotor design:

1. Metals:

Aluminum and steel alloys have been used. The mechanical properties of steel are well known. It has good fatigue strength. However, it is relatively dense so that steel blades would be rather heavy. Their weight would cause large oscillatory gravity loads on the rotor components and bearings. As the blades rotate, in their upward position they press the components causing compression on the bearings, and in their downward position they pull on the bearings causing tension. Steel has been used for large turbine rotors using the spar and skin construction method.

For the same weight aluminum has better tensile properties than steel and at some time was the favored blade construction material in the USA. It is versatile and can be extruded and used in sheet form. Sheets are supported over ribs or a spar and riveted into place. For this type of construction, the fatigue strength deteriorates quickly in service leading to serious consequences when the stress amplitudes and the number of cyclic loadings are large. These problems can be compounded with flawed component design leading to catastrophic failure.

2. Wood:

This includes laminated wood composites. Wood has a natural composite structure that has a low density, good strength and good fatigue resistance as nature has developed in tree branches. Small turbine blades of up to 5 meters in length are usually hand shaped or are machined from prepared lengths of solid wood using the same technique used in manufacturing airplane propeller blades. These are then varnished or painted for weather protection and their leading edge protected by an epoxy resin impregnated tape that is also used on the leading edge of helicopter blades.

An improved use of wood is to shape the blades from bonded layers of wood sheets using composites technology. The blades are constructed from vacuum bonded sheets glued with epoxy resin using a technique also used for the building of racing boats and yachts. With the use of different types of wood and choosing the appropriate direction of the grain, a composite wood material can be produced with a good specific

strength as well as flexural and fatigue resistance properties.

3. Synthetic composites:

These consist of a polyester or epoxy matrix that is reinforced with glass fibers. They have the benefit of a low density compared to metals and good tensile properties. Glass Reinforced Plastic (GRP) blades are economical, strong, with moderate fatigue properties. It is versatile in forming and can be laid up in female half-moulds using glass fiber mats soaked in a polyester or epoxy resin, before the two airfoil halves are glued together. Long term fatigue test data are not readily available for wind turbine so the ultimate fatigue life of such blades is unknown.

The filament winding process developed to make projectile sabots and missile bodies can be used for constructing rotor blades giving good strength and flexibility. A resin soaked glass strand is wound around a form to make the airfoil shape and the box shaped reinforcing spar.

Carbon and aramid fibers such as Kevlar reinforced composites offer the best mechanical properties of all the blade materials. Their high performance is negated by their costs leads to just a few manufacturers to use them. The aramid class of materials is a cheaper route than carbon fibers and their material properties are a compromise between expensive carbon fibers and cheaper glass. One major advantage of the aramids is that unlike carbon fibers, they are non conducting to electricity preventing the need for protection against lightning strikes, electromagnetic interference and reflection, and galvanic corrosion which can occur at the blade root and hub junction.

4. New materials:

Turbine blade technology is moving toward the adoption of composite materials. Hybrid composite would offer a combination of the constitutive materials properties. A wood and fiber and epoxy laminate would include good strength and fatigue properties at a small weight. A laminated sheet material designated as ARALL has been developed in Holland combining aluminum with thin aramid and epoxy layers, exhibiting good fatigue crack growth and tensile strength properties. Hybrid composites could compete in the future with conventional blade materials as their production cost is reduced.

Self-healing and carbon or boron nitride nanotube reinforced materials are worthy of investigation.

HUB ASSEMBLY AND MAIN SHAFT

The blades are attached by a hub assembly to a main shaft. The main shaft rotates in bearings supported in the main frame. If the blades are designed for pitch control, the hub can be fairly intricate. With fixed pitch, attachment is relatively simple

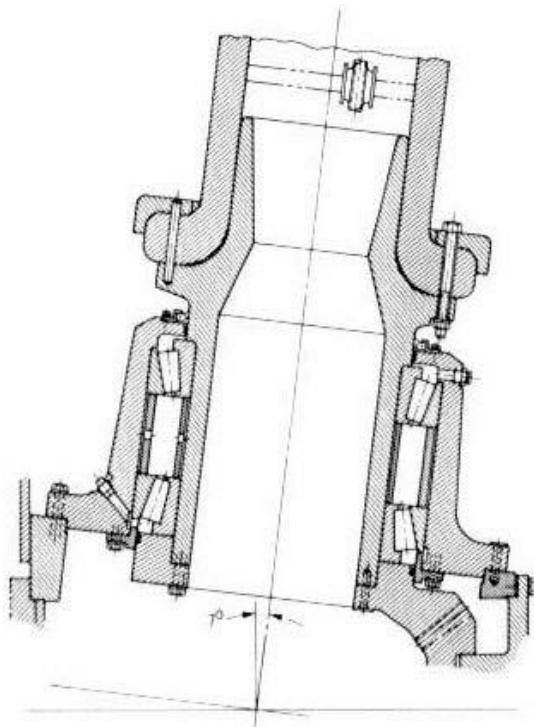


Figure 8. Rotor blade root and bearing assembly.

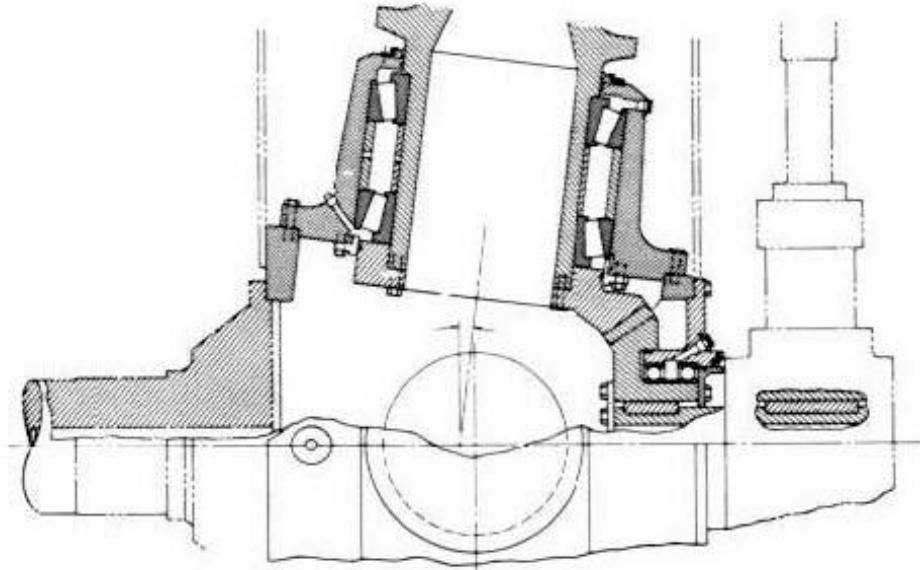


Figure 9. Hub with pitch change assembly.

The main frame of the wind machine serves as the point of attachment for various components, such as the main shaft, transmission, generator, and nacelle. It usually contains a yaw bearing assembly.

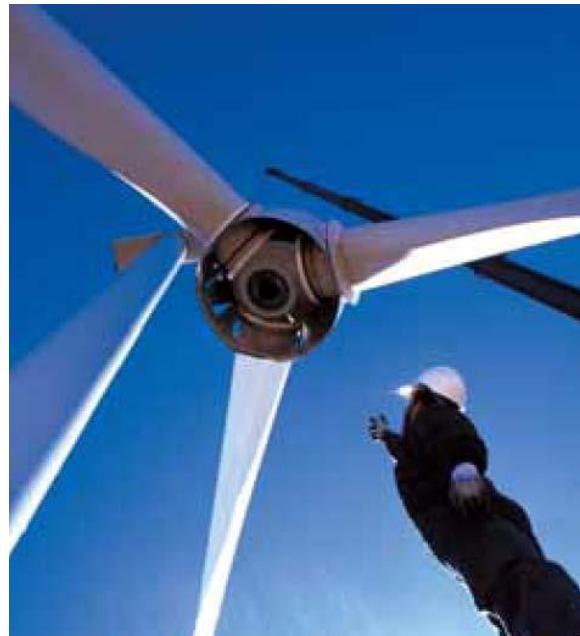


Figure 10. Installation of the hub assembly. Source: Gamesa.

TRANSMISSION MECHANISM

A transmission assembly consisting of a gear box or chain drive is required to properly match the rotational speed to the desired speed of the electric generator, or air compressor because the rotational speed of the rotor does not match that of the pump or electric generator to which it is to be connected.

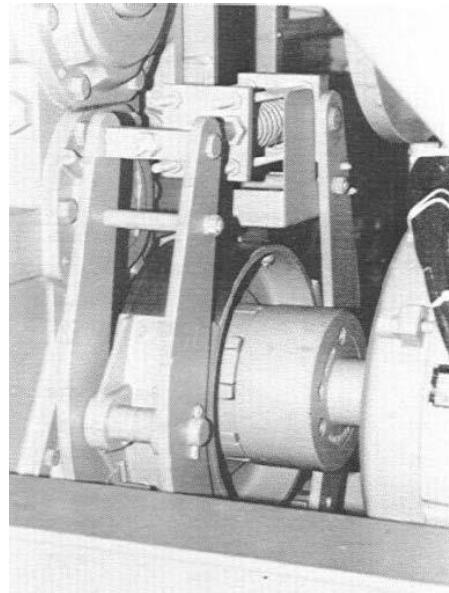


Figure 11. Gearbox or transmission on right, electric generator on left inside nacelle.

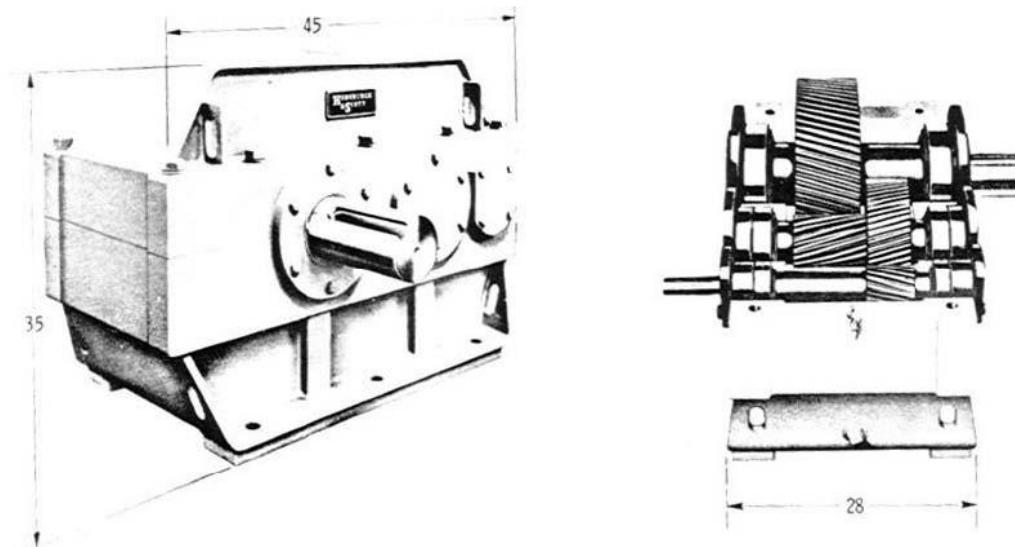


Figure 12. Gearbox exterior and interior.



Figure 13. Gearbox of modern wind turbine. Source: Gamesa.

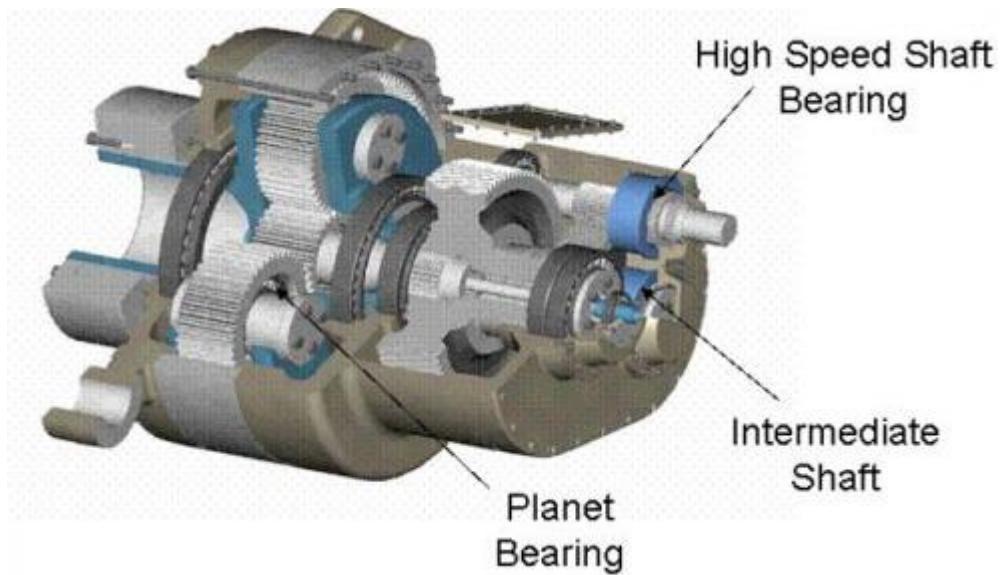


Figure 14. Gearbox cut-out showing components. Source: National Renewable Energy Laboratory (NREL).

YAW MECHANISM

Horizontal axis machines must be oriented to face the wind by a process called yawing. Upwind machines with blades upwind of the tower incorporate instead a tail vane, small yaw rotors or fantails, or a servo mechanism to ensure that the machine always faces upwind.

Downwind machines with blades downwind of the tower have the blades tilted slightly downwind or coned so that they simultaneously act as a tail; this angle ensures proper orientation.

Vertical axis machines are affected by the wind from all directions and thus do not need yaw control.

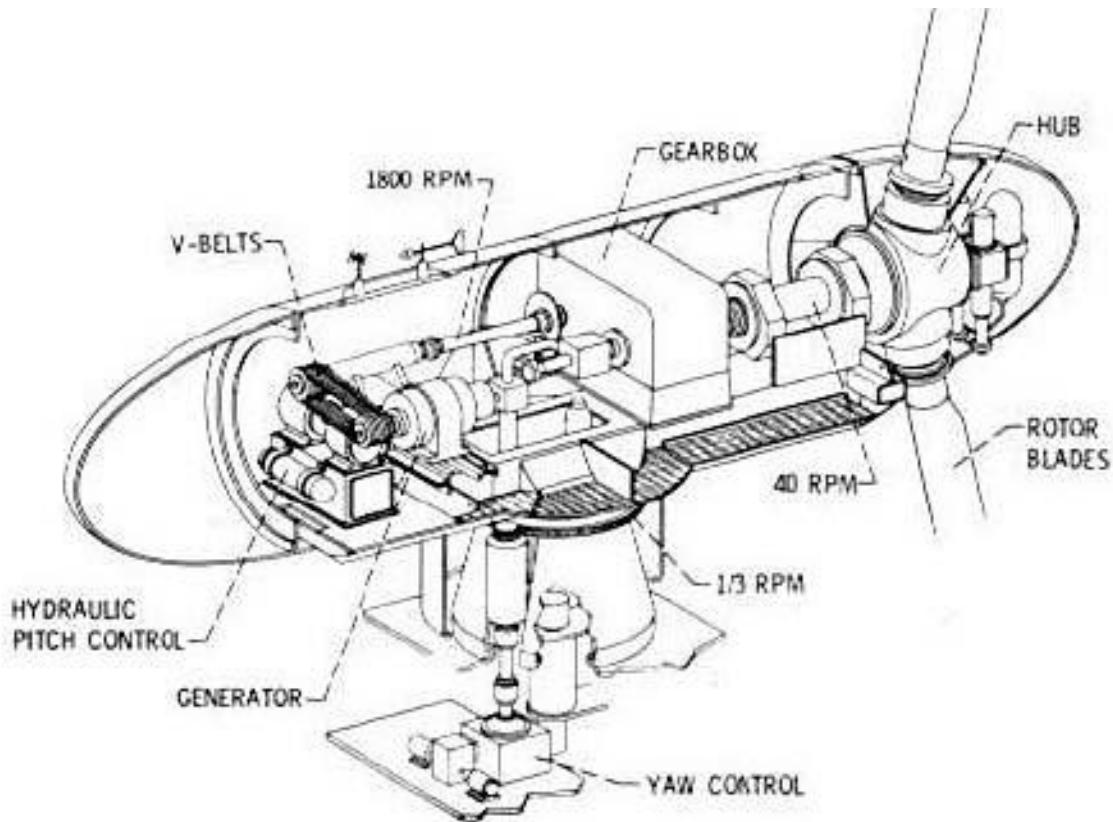


Figure 15. Drive train components of 100 kW wind turbine showing the yaw control mechanism.

OVERSPEED PROTECTION

Wind machines must be protected from wind gusts. In some machines, the blades can be turned around their long axis or pitch control and aligned so that they do not produce any lift, hence no power. Stall control of the blades is also used to reduce the lift on the blades.

Blades with fixed pitch often use brakes to slow the machine. The brakes are either aerodynamic such as tip brakes, or mechanical such as disc brakes on the main shaft. Other machines use various mechanical means to turn the rotor out of the wind.

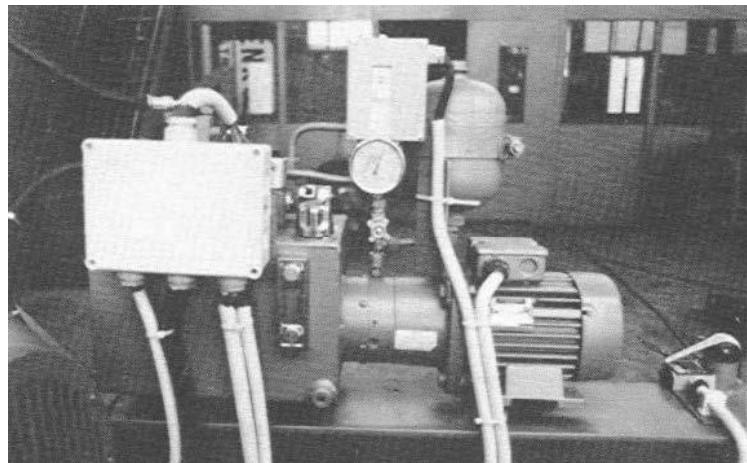


Figure 16. Hydraulic brakes components inside nacelle.

ELECTRIC GENERATOR

Variable speed machines are common and most generate power using an AC/DC/AC system. Variable speed brings several advantages. It means that the rotor turns more slowly in low wind, which keeps the noise level down. It reduces the loadings on the rotor and the power conversion system is usually able to deliver current at any specified power factor.

Some manufacturers build direct drive machines, without a gearbox. These are usually of the variable speed type, with power conditioning equipment.

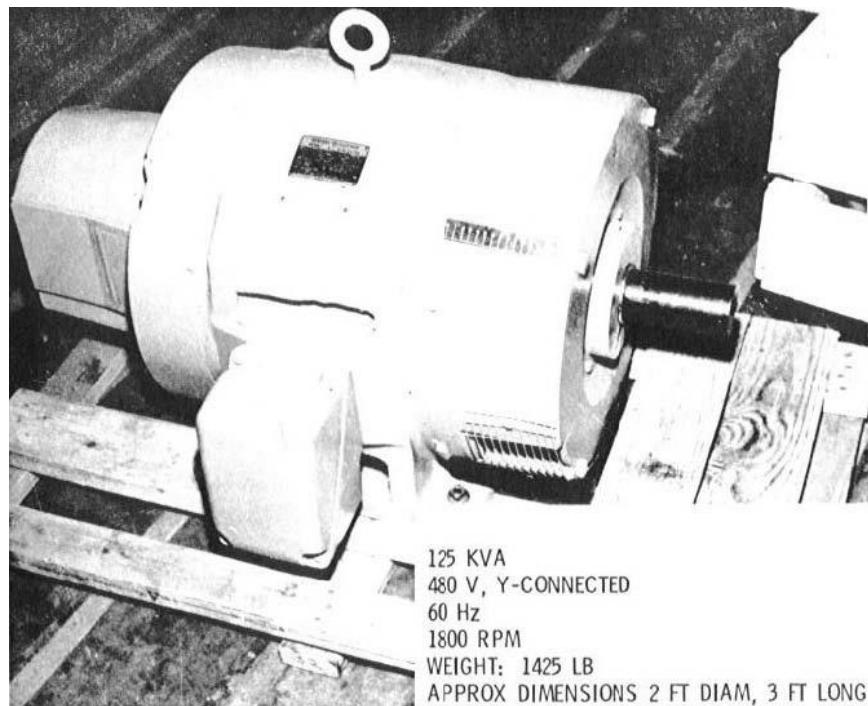


Figure 17. Synchronous generator.

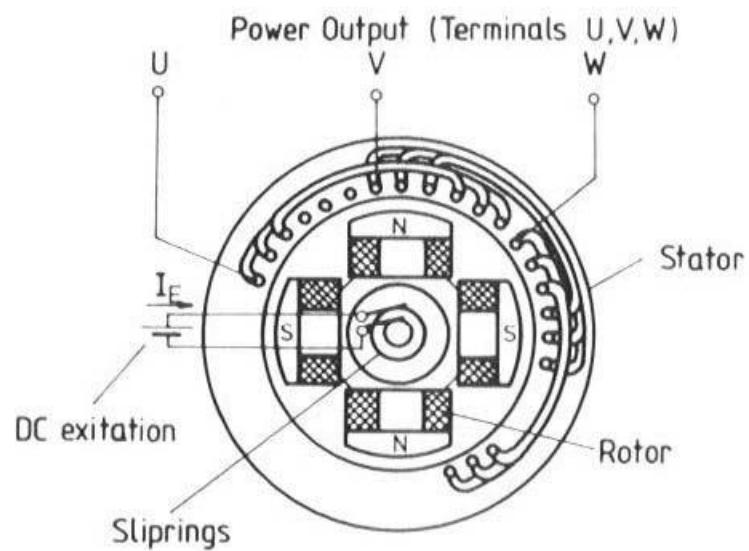
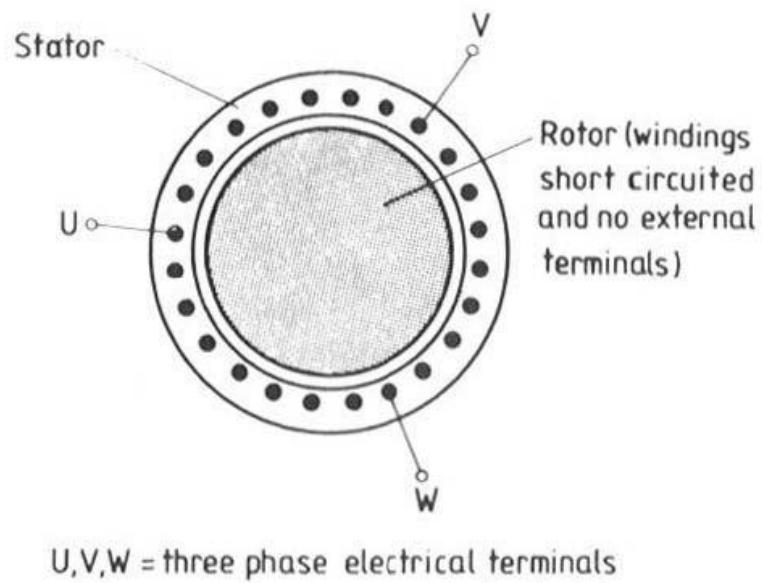
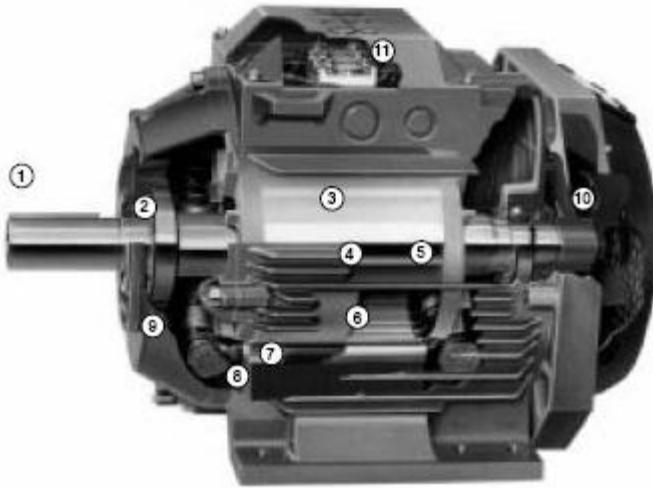


Figure 18. Wiring of three phase synchronous generator.



U, V, W = three phase electrical terminals

Figure 19. Induction three-phase asynchronous generator.



- | | |
|-------------------------|--------------------|
| 1. Generator shaft | 7. Coil |
| 2. Rolling bearings | 8. Stator plates |
| 3. Rotor | 9. Coil heads |
| 4. Rotor aluminium bar | 10. Ventilator |
| 5. Rotor aluminium ring | 11. Connection box |
| 6. Stator | |

Figure 20. Asynchronous Generator components, 1999. Source: Bonus AG.

The electric generator in a wind machine is attached to the main support frame and coupled to the high speed end of the transmission shaft. Alternating current generators often run at 1,800 rpm in the USA or 1,500 rpm in much of the world to maintain system frequencies of 60 Hz and 50 Hz, respectively. The most popular types are:

1. For small independent wind systems, Direct Current (DC) generator alternators with built-in rectifier diodes are often used to change AC to DC.
2. For larger independent systems, or those that are run in conjunction with a small diesel electric grid, synchronous generators are common. These machines produce Alternating Current (AC) and must be able to be regulated precisely, to ensure proper frequency control and matching.
3. Wind machines connected to a utility grid may have induction generators. These induction machines produce AC current, but are electrically much simpler to connect to a grid than a synchronous generator. They normally require a utility connection to maintain the proper frequency and cannot operate independently without special equipment.

ELECTRIC POWER CONDITIONING EQUIPMENT, INVERTER

The need for electrical equipment in addition to the generator will depend primarily on the type of generator. For small DC systems, at least a voltage regulator is needed. Battery storage is often used to provide energy in times of low winds.

An inverter to convert DC to AC is used if some of the load requires alternating current.

Because the mains grid operates on AC current, it is important that the current fed into the mains grid is properly synchronized. This is a key role of the inverter system.

The inverter system is also designed to cut the power to the mains grid in the event that the mains grid connection is lost. This is a safety feature for the electrical utility workers.

For grid connected systems, a control panel is needed that will typically include circuit breakers, voltage relays, and reverse power relays. Synchronous machines require special synchronizing equipment and frequency relays.

STRUCTURAL TOWER

A structural tower is needed to get the wind machine up into the air, away from the slower and more turbulent winds near the ground. A wind machine should be at least 10 m higher than any obstructions in the surroundings such as trees.

Small wind machines towers are typically of truss design or of poles supported by guy wires. Guy wires are cables attached to the tower and anchored in the ground so that the tower will not move or shake from the force of the wind.



Figure 21. Conical wind machines towers.

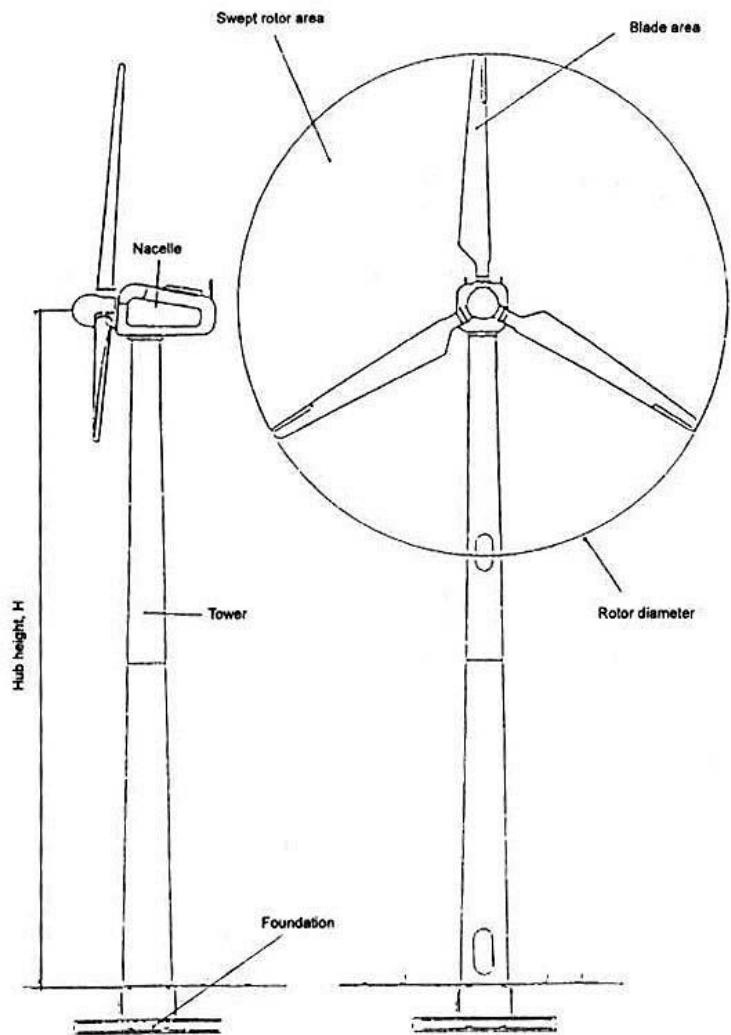


Figure 22. Conical tower of horizontal axis wind turbines.



Figure 23. Lattice or truss tower for wind turbines.



Figure 24. Guy wire poles for small wind turbines.

Large wind machines towers are usually made of steel and the great majority is of the tubular or conical type. Some towers have been built out of reinforced concrete sections. Lattice or truss towers, common in the early days are now rare, except for very small machines in the range 100 kW and below. Guyed pole towers are used for small wind machines.

Towers must be designed to resist the full thrust produced by an operating windmill or a stationary wind machine in a storm. Special concern must be given to the possibility of destructive vibrations caused by a natural frequency mismatch between the

wind machine and tower.