COMPONENTS OF ONSHORE WIND TURBINES

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Overview

- Introduction to wind power
- Historical synopsis
- Onshore wind turbine ‘radiography’
- Basic elements of wind turbines analysis and design

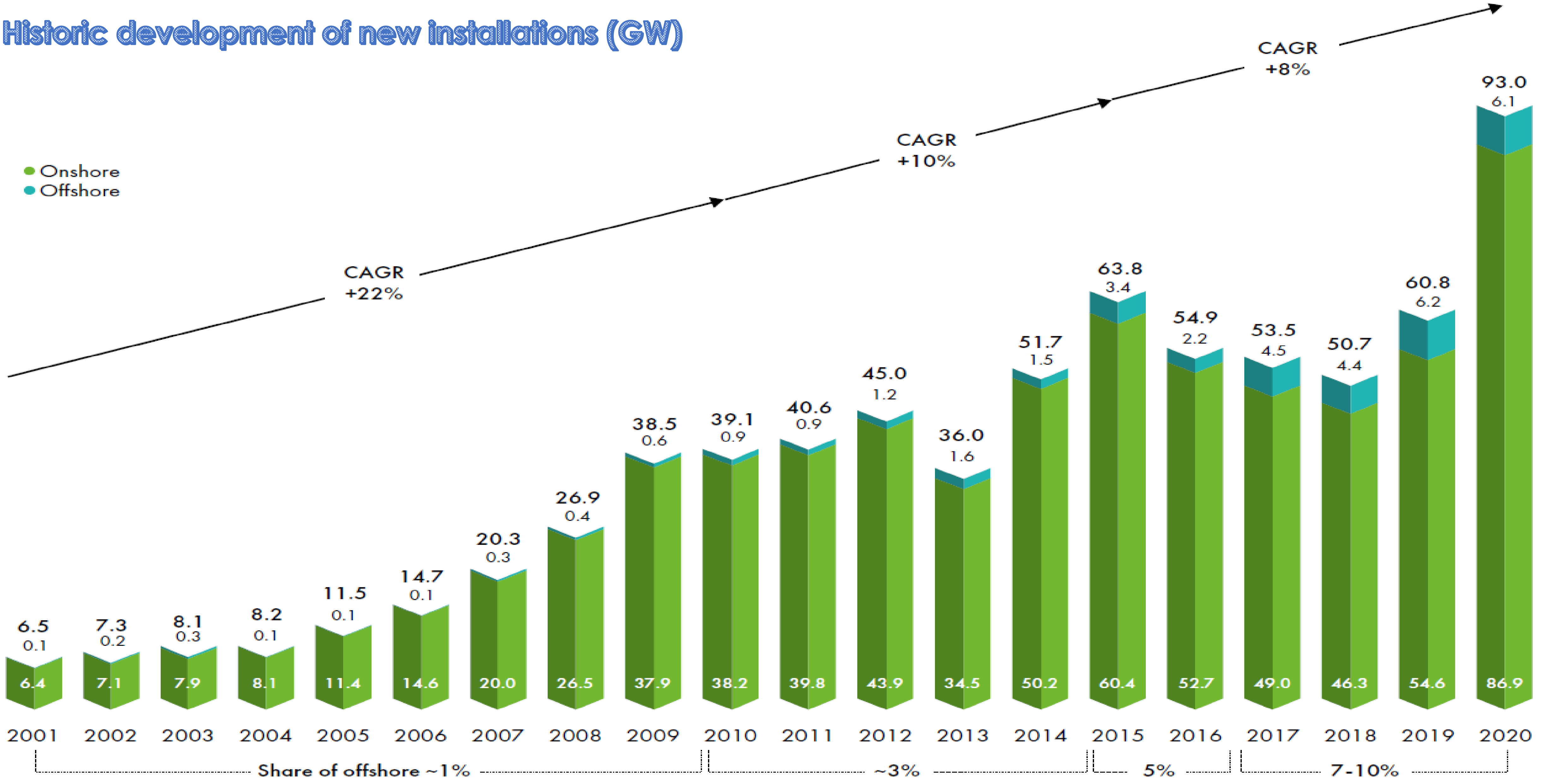
Wind energy has emerged as one of the primary renewable power sources and as such comes laden with a complex manufacturing process involving numerous key turbine components.

Wind-power park. (Patras, Greece)

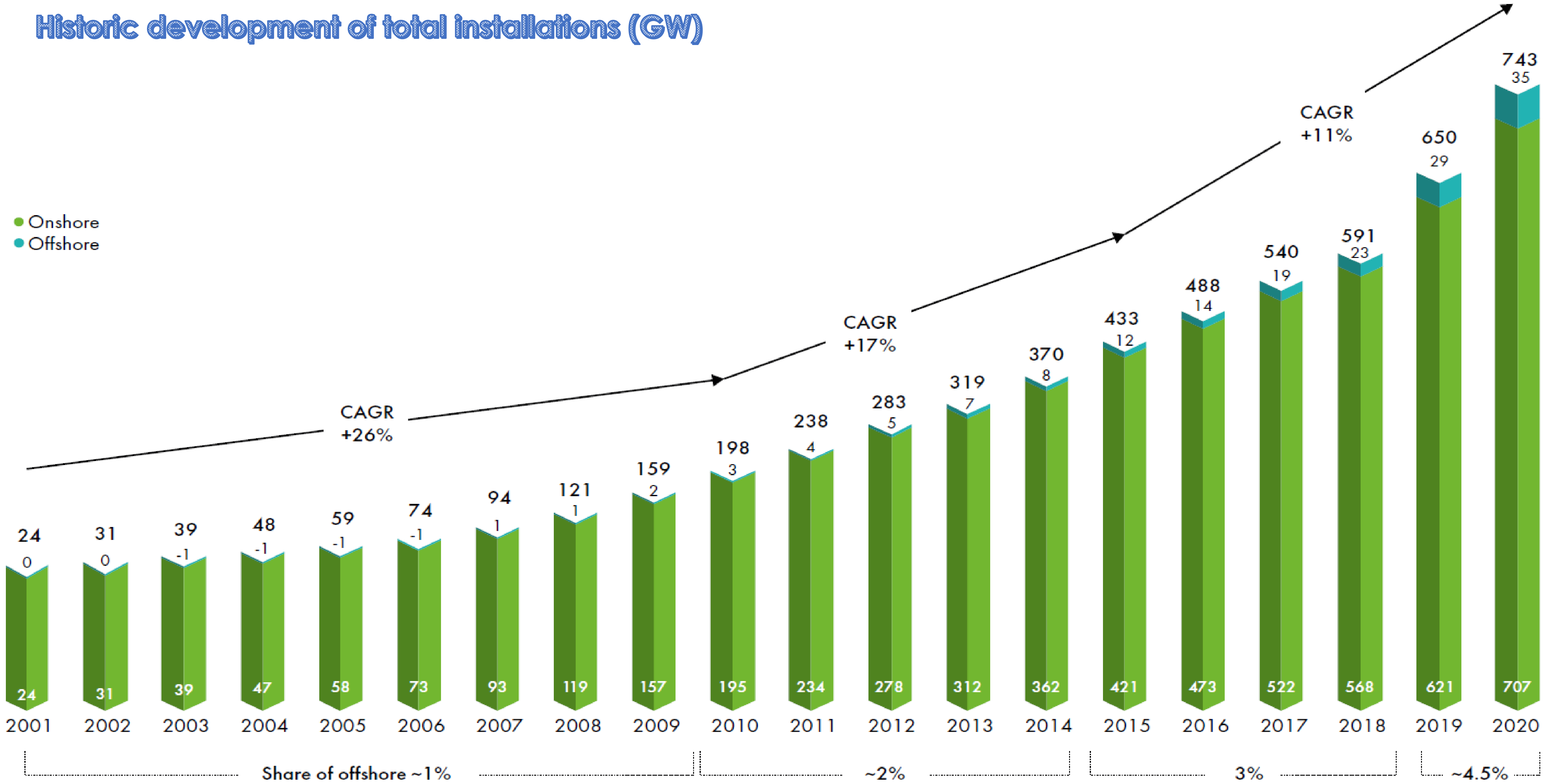
By the end of summer 2021, global capacity of the clean energy generation method surpassed 743 gigawatts (GW).

Total annual global investment in clean power and enabling system infrastructure needs to rise from US$380 billion in 2020 to $1.6 trillion by 2030.

Historic development of new installations (GW)



Historic development of total installations (GW)



Windmills – The origins of Wind Turbines

Vertical-axis windmill for milling grain, Afghanistan

Ancient Chinese windwheel for pumping water

Some authors maintain that they have discovered the remains of stone windmills in Egypt, near Alexandria, with a supposed age of 3000 years. There is no convincing proof, however, that the Egyptians, Phoenicians, Greeks or Romans really knew windmills.

The first reliable information about the existence of windmills from historical sources originates from the year 644 A.D. It tells of windmills from the Persian-Afghan border region of Seistan.

A later description, including a sketch, dates back to the year 945 and depicts a windmill with a vertical axis of rotation. It was obviously used for milling grain. Similar, extremely primitive windmills have survived in Afghanistan up to the present time (see Figure).

Windmills – The origins of Wind Turbines

Greek tower windmill

Dutch windmill

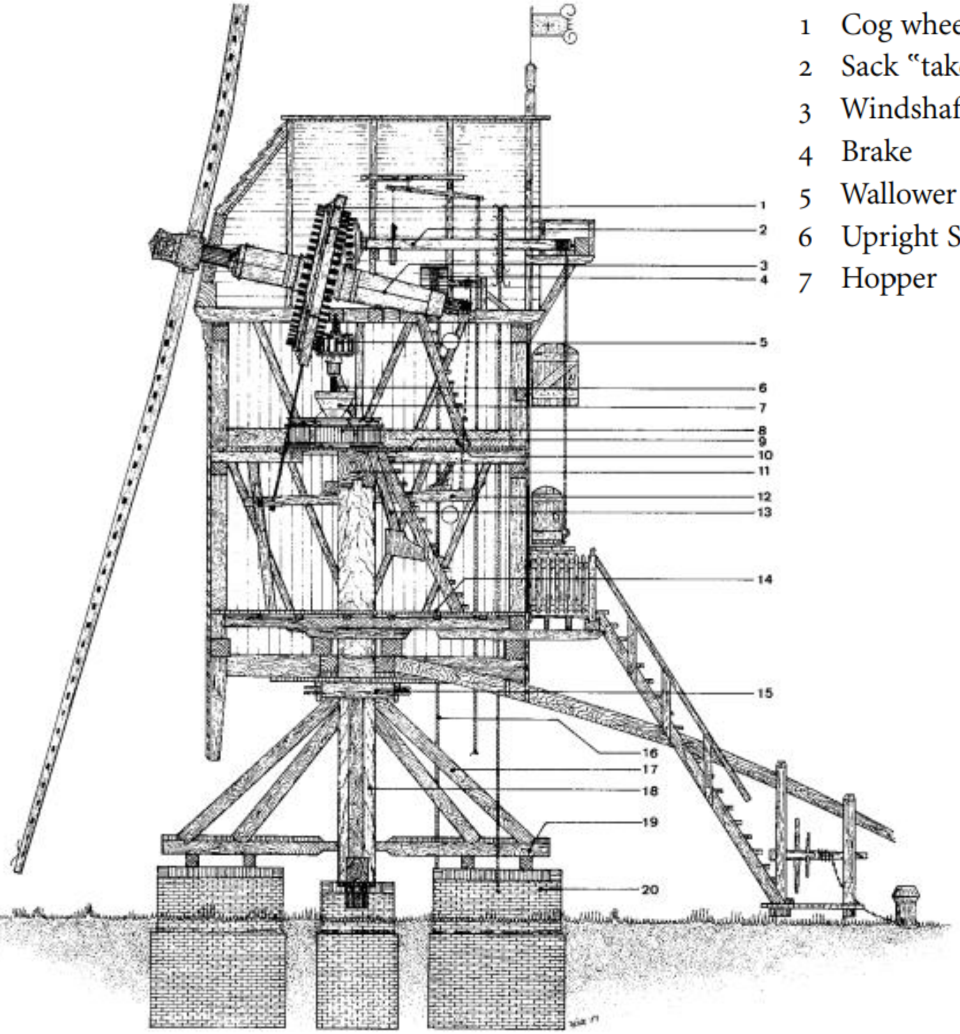
In the eastern Mediterranean regions the medieval tower windmills typically had **windwheels with triangular sails**

In other regions **framed sails** were also commonly used.

Large tower windmills were built much later. They should rather be regarded as variants of the Dutch windmill and probably developed independently from the Mediterranean type.

Windmills – The origins of Wind Turbines

German post windmill



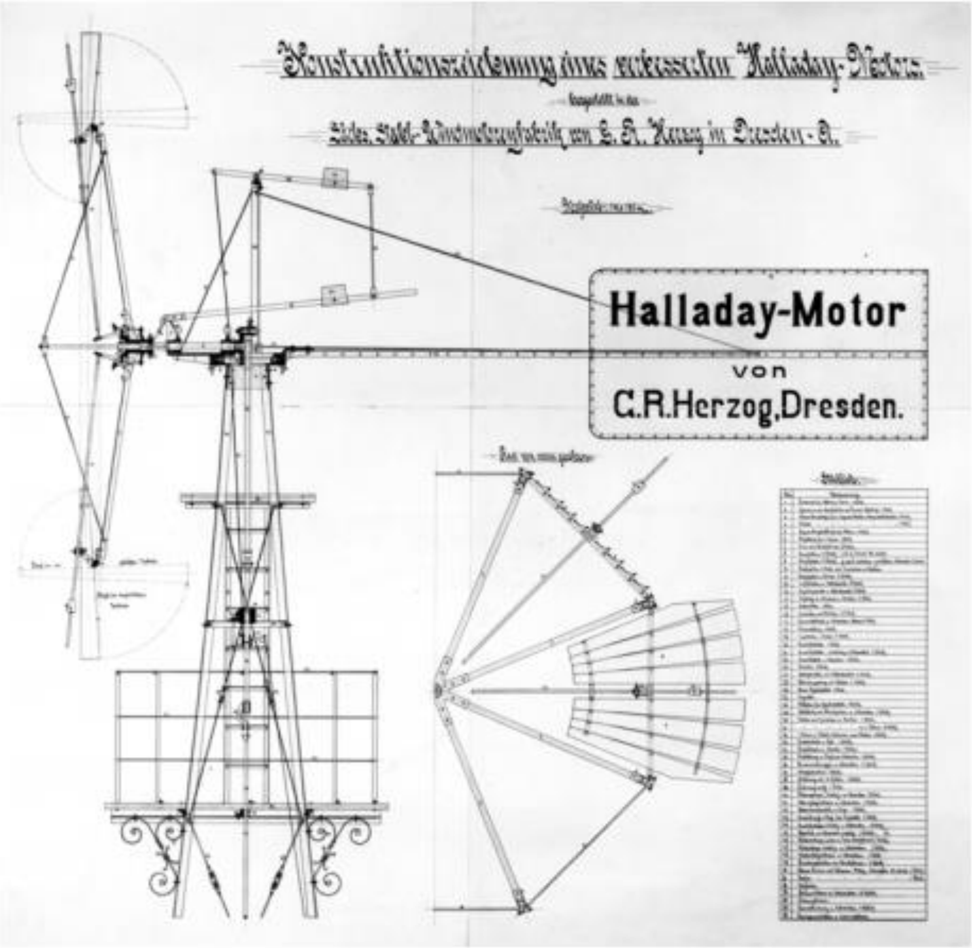
Construction of a post windmill

post windmill

1 Cog wheel
2 Sack "take-off"
3 Windshaft
4 Brake
5 Wallower
6 Upright Shaft
7 Hopper
8 Millwork
9 Stone floor
10 Meal boad
11 Meal beam
12 Brake beam
13 Meal spout
14 Meal floor
15 Crown tree
16 Brake chain
17 Quarter bars
18 Main post
19 Cross trees
20 Piers

Windmills – The origins of Wind Turbines

The contribution of Daniel Halladay (Connecticut, about 1850).



In steam engines Halladay had seen flyweight governors which opened a safety valve in the case of overspeeding. With this concept in mind, he designed a windwheel the blades of which were not directly joined to the shaft, but suspended loosely on a ring.

Using a second movable ring collar, the blades were connected such that a movement of the ring effected a change in the blade pitch angle. The movement of the ring was triggered by flyweights. He also divided the wheel into six sections

At low wind speeds, the windwheel turned slowly, with the flyweight governor keeping the blade pitch at a shallow angle. With increasing wind speed and higher revolutions, the blade-pitch angle became continuously steeper, until ultimately the six wheel sections swung completely out of the plane of the wheel (see Figure).

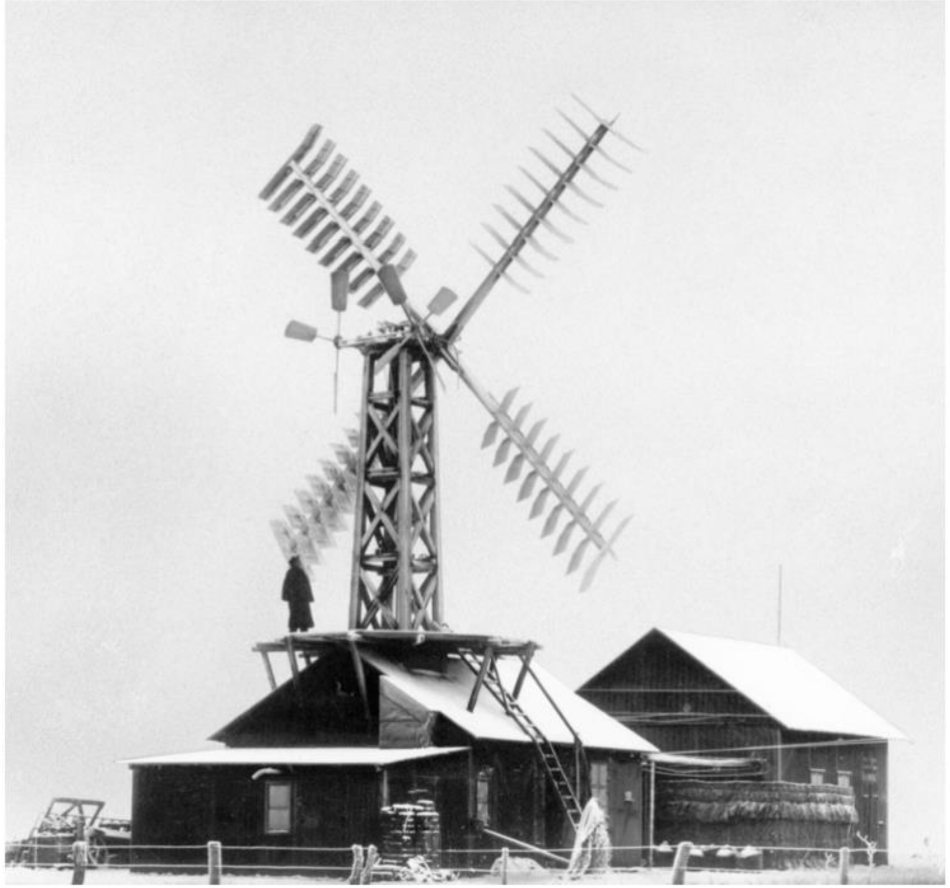
Windmills – The origins of Wind Turbines

Initially, Halladay used only a few thin wooden blades, but he increased their number until the entire wheel surface was covered with blades, like a turbine. A wind vane took care of yawing.

A wind vane took care of yawing. The aerodynamic characteristics of such a “ wind turbine” thus differed greatly from the previously known windmill sails.

Halladay started manufacturing wind turbines and soon sold large units to the American railroad companies. These had an increasing need for water pumps for refilling their water tanks en route (see Figure)

Windmills – The origins of Wind Turbines



Poul La Cour's first electricity producing wind turbine in 1891 in Askov, Denmark

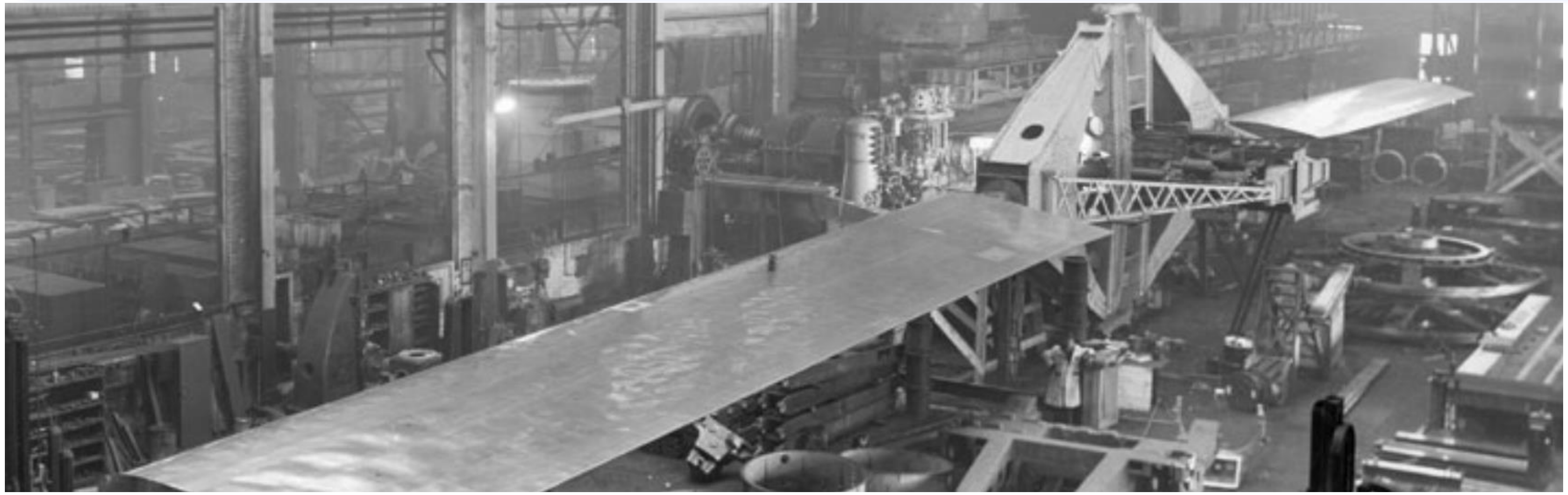
The **first attempts to generate electric current** with the help of wind power were being made in that period of time when the large cities were already being supplied with electricity, but complete coverage of users in rural areas was not yet feasible.

The spread of traditional windmills in Europe and of wind turbines in America was still nearly at its peak. It was probably inventive do-it-yourself enthusiasts in America who were the first to try to drive electric" dynamos" with their wind turbines which were actually designed for pumping water.

However, the **first systematic development** aimed at utilizing wind power for the generation of electricity took place in Denmark.

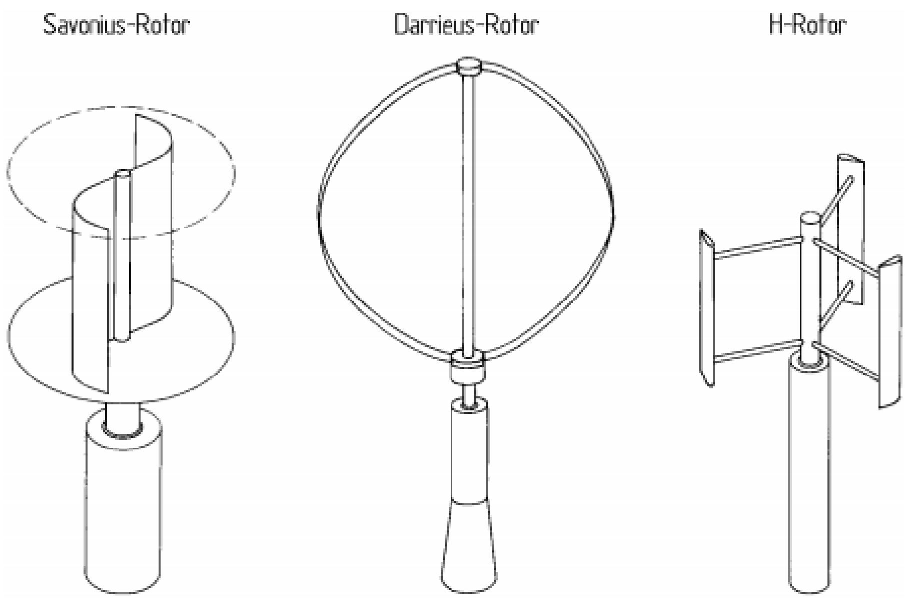
Early Wind Turbines

A decade before the beginning of the rural electrification program, first efforts were made in the US to develop advanced **electricity-generating wind turbines**.



Smith-Putnam wind turbine, in Vermont, USA (rotor diameter 53.3 m, rated power 1250 kW), 1941

Basic Concepts of Wind Energy Converters : Rotors with a Vertical Axis of Rotation



Rotor concepts with a vertical axis of rotation

Darrieus wind turbines of the former American Flowind company (rotor diameter 19 m, power output 170 kW)

At the beginning vertical-axis rotors could only be built as pure drag-type rotors.

The "Savonius rotor", which can be found as ventilator on railroad carriages or delivery vans, and the cup anemometer used to measure wind velocity are well-known examples of rotors with a vertical axis of rotation.

The oldest design of wind rotors features rotors with a vertical axis of rotation (see Figures).

Basic Concepts of Wind Energy Converters : Horizontal Axis Rotors

Horizontal-axis wind turbine: Bonus/Siemens Wind Power, (rotor diameter 107 m, rated power 3.6 MW) prototype, 2005

Wind energy converters which have their axis of rotation in a horizontal position are realized almost exclusively on the basis of “ propeller-like” concepts (see Figure).

This design, which includes European windmills as much as the American wind turbine or modern wind turbines, is the dominant design principle in wind energy technology today.

Basic Concepts of Wind Energy Converters : Horizontal Axis Rotors

The undisputed superiority of this design to date is largely based on the following characteristics:

- In propeller designs, rotor speed and power output can be controlled by pitching the rotor blades about their longitudinal axis (blade pitch control). Moreover, rotor blade pitching is the most effective protection against overspeed and extreme wind speeds, especially in large wind turbines

- The rotor blade shape can be aerodynamically optimized and it has been proven that it will achieve its highest efficiency when aerodynamic lift is exploited to a maximum degree

- The technological lead in the development of propeller design is a decisive factor.

Horizontal-axis wind turbine: Bonus/Siemens Wind Power, (rotor diameter 107 m, rated power 3.6 MW) prototype, 2005

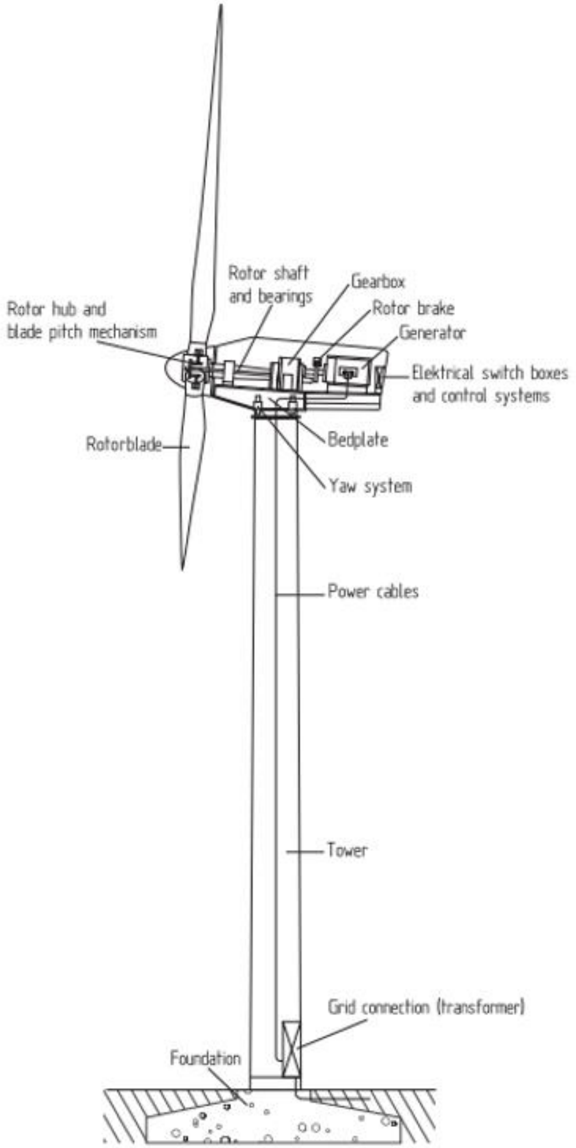
Commercial wind turbines generally are classified in three size ranges:

1. Small Wind turbines generally are defined as having a capacity output of less than 100 kilowatts (kW). These units comprise 30 to 80 parts; provide 120/240, single- or three-phase AC or DC output; and are used on a home, farm or small business.

2. Community Wind turbines typically have output ratings of between 100 kW and 1,000 kW (1 megawatt, MW), provide 600-V, three-phase output; and comprise between **1,000 and 3,000 parts**.

3. Utility-grade wind turbines are generally classified as those with output capacities of 1 MW and larger. They provide three-phase output and are designed to feed into a transmission grid that services a distant load center. Utility-grade wind turbines are installed 300 feet in the air, with the nacelles consuming a 60- by 14- by 13-ft.-sq.-ft. area. These turbines have as many as **22 major component groups and 8,000 subcomponents**.

Basic Concepts of Wind Energy Converters : Horizontal Axis Rotors



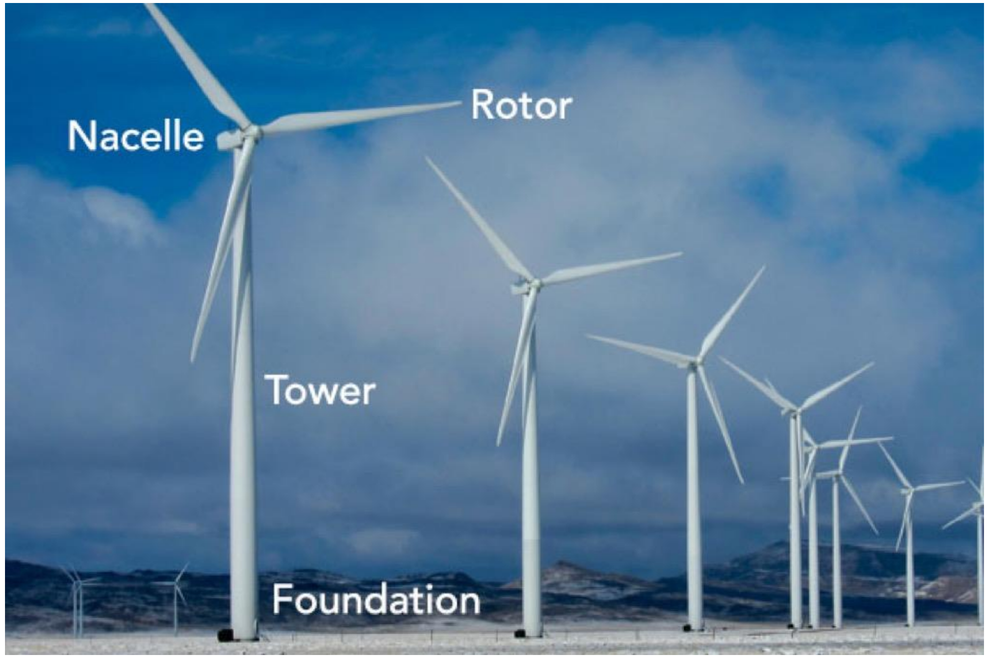
Components of a horizontal-axis wind turbine

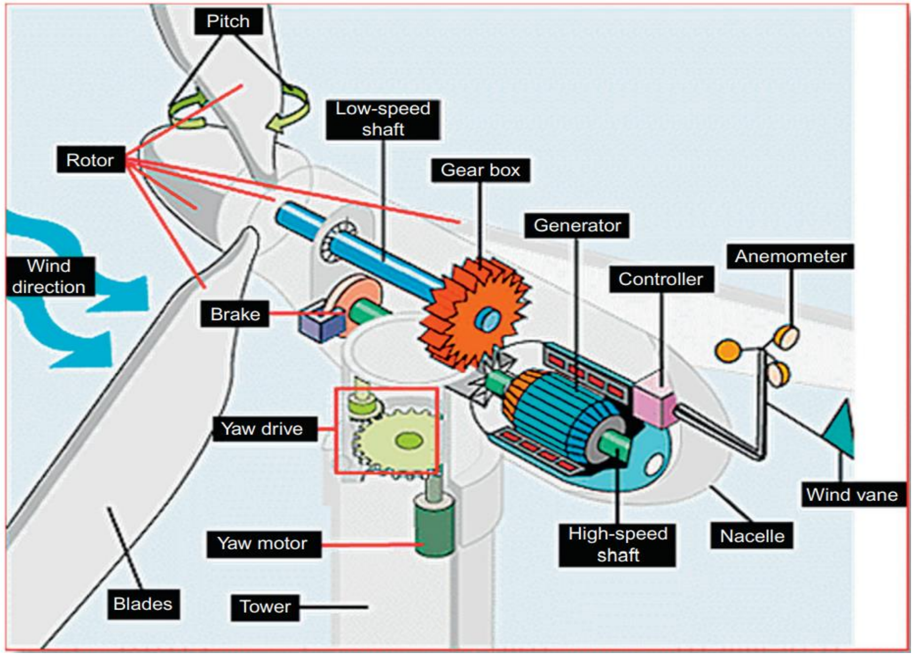
Figure shows the schematic arrangement of a **horizontal-axis wind turbine**.

The components and their configuration are typical of a large modern wind turbine.

Naturally, designs differing from this standard concept are also possible and constructional simplifications such as the absence of pitch control can be found, particularly in small wind turbines.

The plethora of **sub-components**, which can number up to 8,000, needed to construct a wind turbine involve myriad manufacturing processes, from metal fabricating and casting to heat treating, machining and grinding.





Four parts, however, are vital: The generator, nacelle, tower and blades.

All of this combines to create a product with a typical life span of 20 years and enough generational capacity to power the equivalent of 750 homes for a year.

Tower

Tubular steel tower | Tubular concrete | Lattice tower | Three-legged tower | Guy-wired pole tower

Wind turbine towers are produced at various different heights, with the average being roughly 50m and the tallest surpassing 200m.

They are usually coated with a zinc-based finish and epoxy and urethane layers to provide ultraviolet resistance.

The average weight typically exceeds 40 tons, and a tower can often account for more than 10% of the total cost of a wind turbine.

Tower Configurations

Free-standing steel tubular towers - The most common tower type currently in use is the free-standing steel tube tower (see Figures).

Mastery of the vibrational behaviour has made it easier to use this type so that steel tubular towers with very low design stiffness can be implemented.

Tower Configurations

Lattice Type - The simplest method of building high and stiff tower constructions is as a three-dimensional truss, so-called lattice or truss towers.

Lattice towers were the preferred design of the first experimental turbines and in the early years also for smaller commercial turbines (see Figure).

Today, the lattice tower has again become an alternative to the steel tubular tower in the case of the very high towers required for large turbines sited in inland regions.

Tower Configurations

Concrete Type In the thirties, steel-reinforced concrete towers were used for the so-called "Aeromotors" in Denmark. These towers were also characteristic of the earlier large experimental Danish turbines (see Figure).

Later, steel towers became dominant also in the commercial turbines in Denmark.

Concrete towers have recently gained favour again for tower heights of more than 80 m.

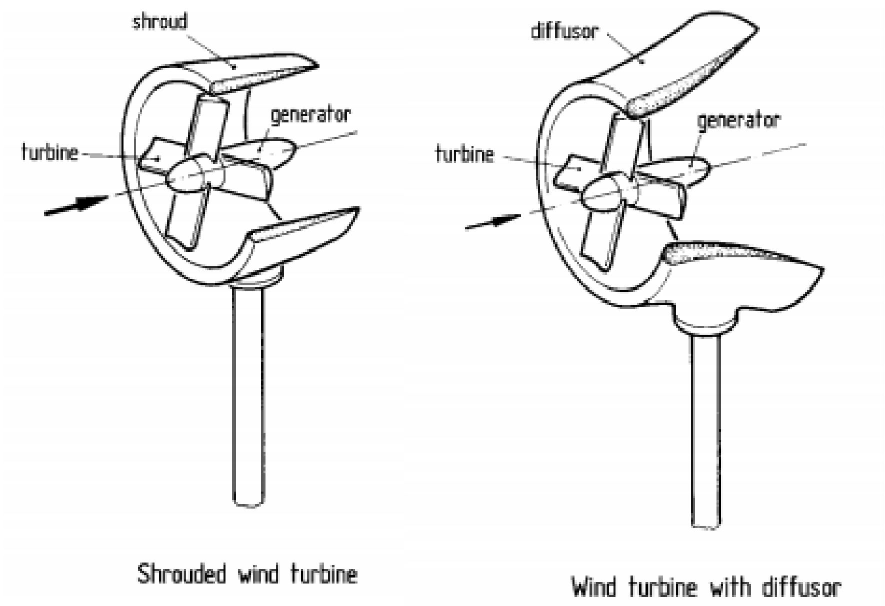
Tower Configurations

Guyed steel tubular towers - Down-wind rotors made it necessary to use slender steel tubular towers in order to keep the tower shadow effect as small as possible.

These were anchored with steel cables or in some cases with stiff trusses to ensure the required bending stiffness (see Figure).

Despite their comparatively low overall mass, guyed towers are not very cost-efficient. The guys and the additional anchoring foundations required inflate the total cost.

Basic Concepts of Wind Energy Converters : Wind Energy Concentrators

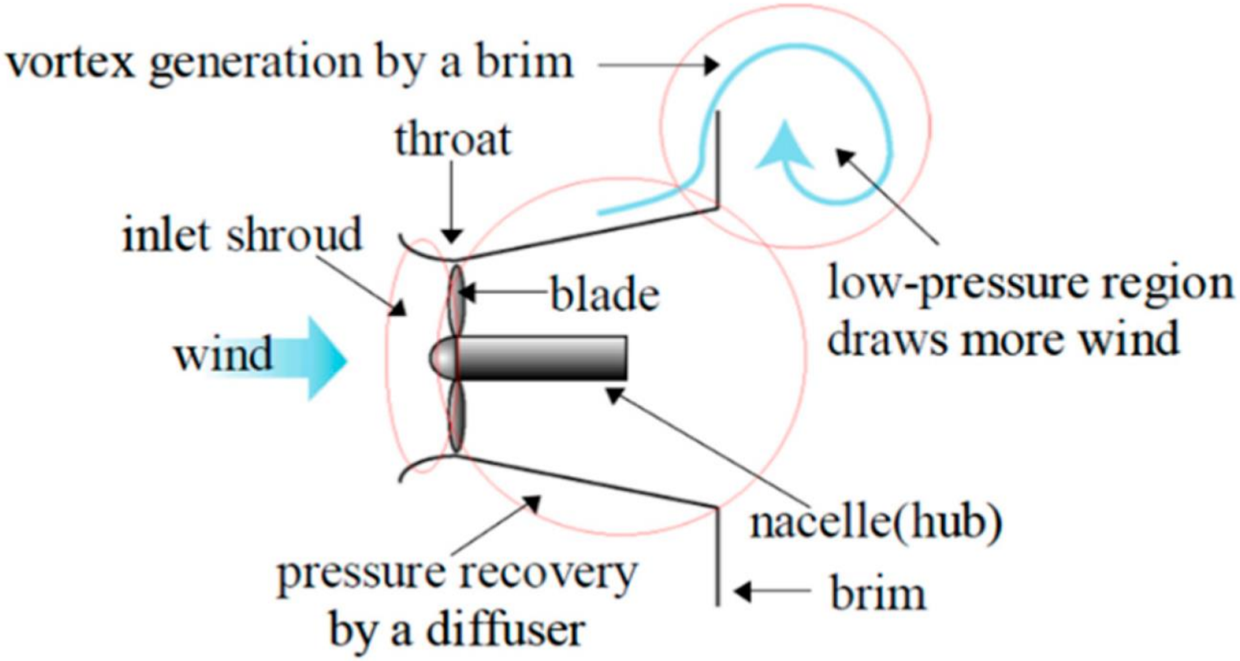


Wind rotor concepts combined with static structures for concentrating wind energy

The basic idea common to all these concepts is to increase the power yield in relation to the rotor-swept area. Basically, this can be achieved by static, i. e. non-rotating structures which produce an acceleration in the flow velocity to the rotor or, in some cases, even generate concentrating vortices (see Figures).

The intention is to achieve a drastic reduction in rotor size whilst at the same time hoping that the additional construction required for " pre-concentrating" the wind energy will not become too expensive.

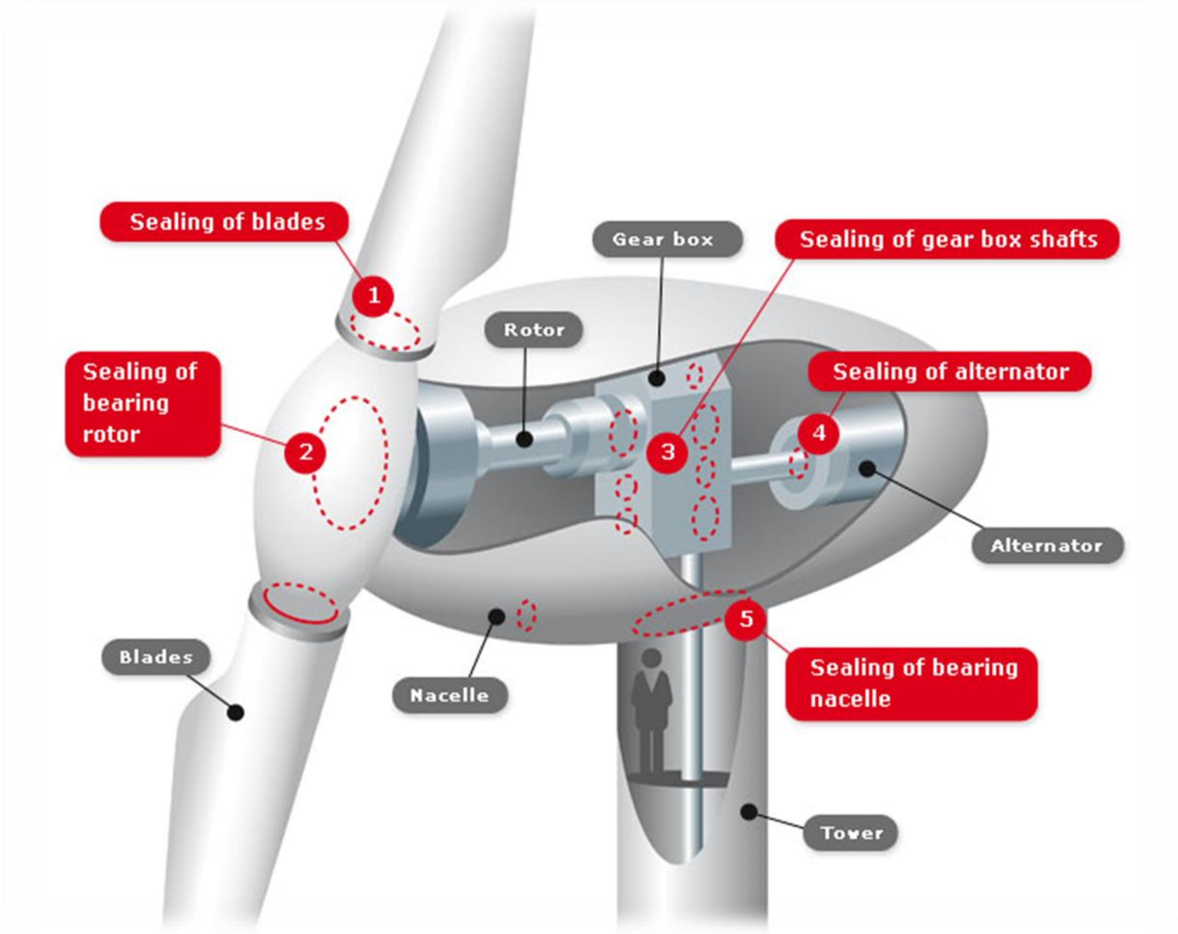
Basic Concepts of Wind Energy Converters : Wind Energy Concentrators



Ducted rotor: The simplest method for increasing rotor efficiency is to enclose it in a duct. The duct prevents narrowing of the flow tube before it reaches the converter, which is unavoidable with a rotor in a free air stream.

Turbine with a diffuser duct: An idea aimed at " capturing more wind" is to mount a funnel in front of the rotor. It is more effective to place the rotor in a duct in the shape of a reversed funnel, a diffuser. This results in an additional circulatory flow the speed components of which in the diffuser have the same direction as the wind stream, thus reinforcing it.

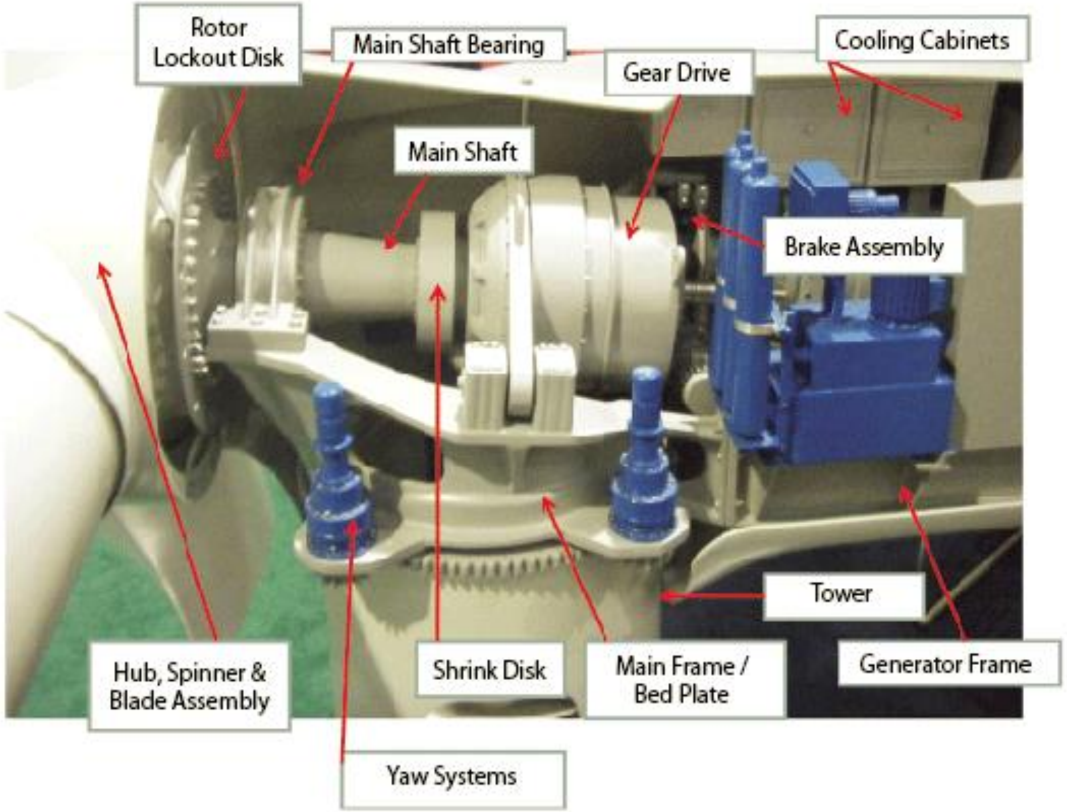
Generator



The **generators** of modern wind turbines used the difference in electrical charge to create a change in voltage, which acts as the driving force behind the subsequent electrical current.

This current is then passed through power lines for distribution, powering the turbine’s associated grid.

Nacelle



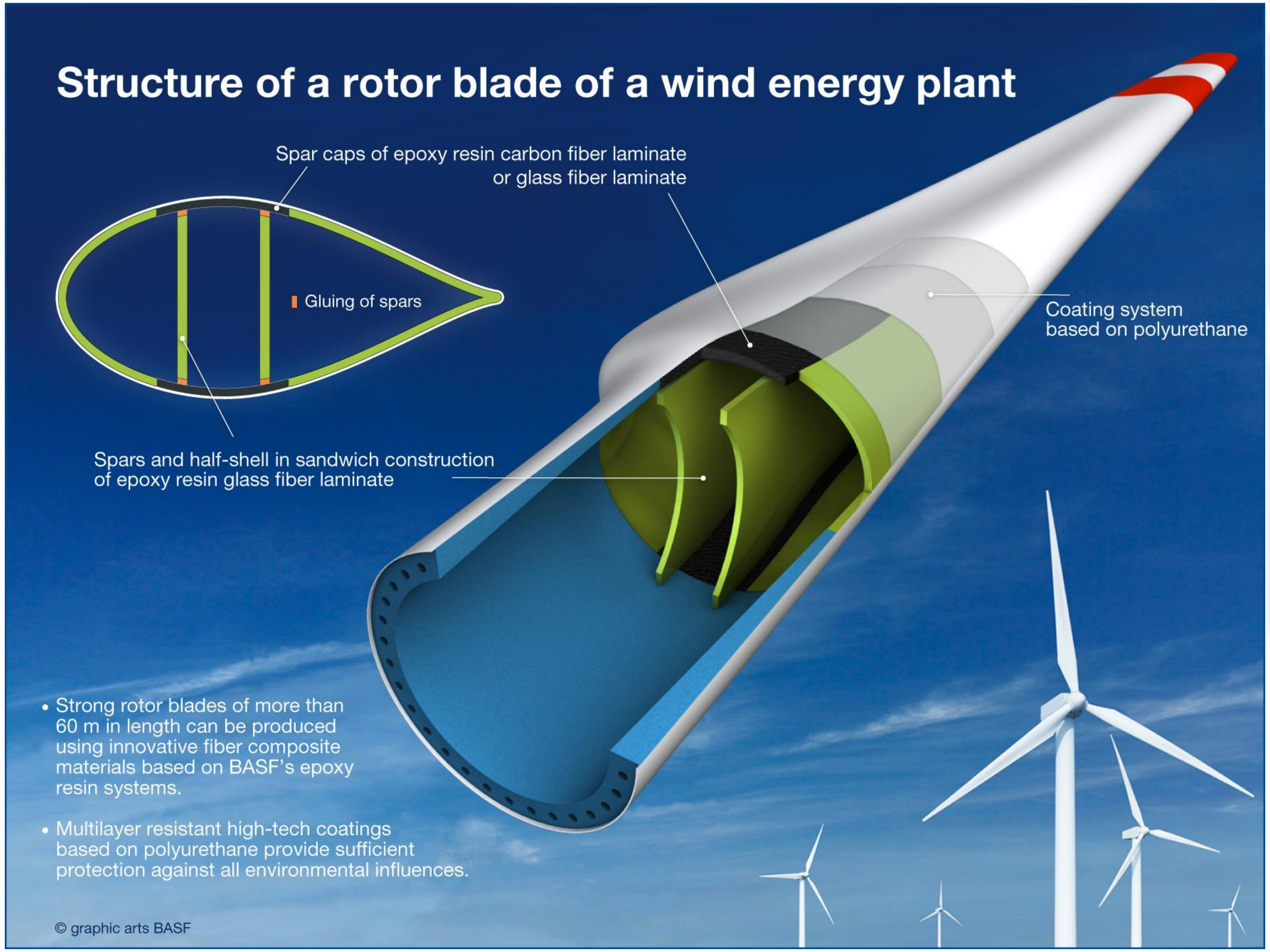
A wind turbine's nacelle houses a multitude of sub-components

The **nacelle** houses a wind turbine's generator, and is mostly commonly manufactured as either gear-driven or direct drive.

Gear-driven: can comprise a case as heavy as 150 tonnes, while the latter comprises a rotor hub which directly drives the generator without the need for a gear train arrangement.

Direct drive: comprises a rotor hub which directly drives the generator without the need for a gear train arrangement.

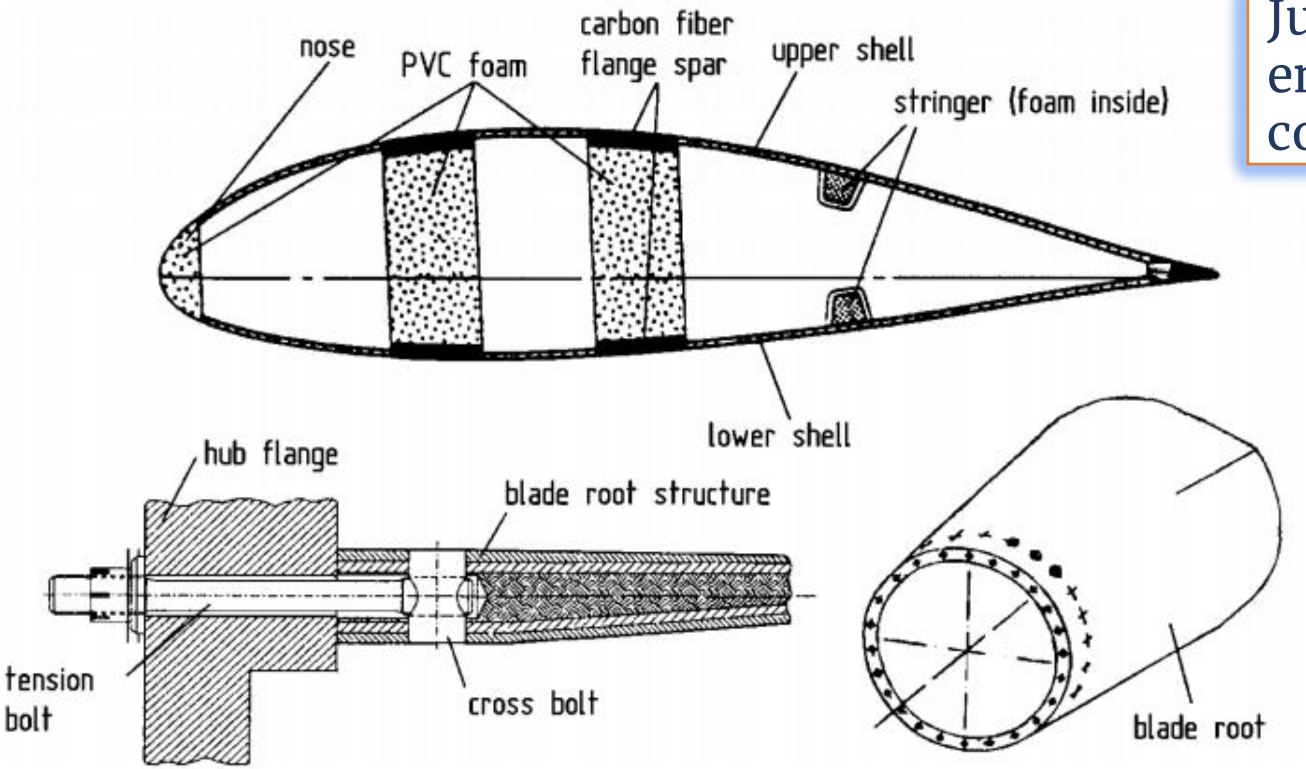
Rotor Blades



Wind turbine blades can reach speeds in excess of 160 miles per hour when in operation and therefore require robust construction.

The component primarily comprises wood, fibreglass, resin and carbon, but can host more than 100 layers of material once complete.

Rotor Blades



Rotor blade of the experimental Aeolus II turbine in mixed glass fibre/carbon fibre construction with crossbolt joint to the rotor hub

Judging from experience gained in aircraft engineering, the following materials are considered as suitable in principle:

- aluminium
- titanium
- steel
- fibre composite material (glass, carbon and aramide fibres)
- wood

Rotor Blades

Rotor blade connection to the hub in the Vestas V-39 rotor blade

Blade Connection to the Rotor Hub

- **Bonded-in lightweight flanges or sleeves** One alternative to the cross-bolt connection is a blade connection with bonded-in aluminium flanges first developed by Vestas. The rotor blades of the larger Vestas turbines have extremely light blade flanges made of high-strength aluminium, which are bonded into the blade root structure (see Fig). In the rotor blades of the Vestas V-39, with a rotor diameter of 39 m, the flange weighs less than 50 kg. The total weight of the rotor blade is approximately 1100 kg.

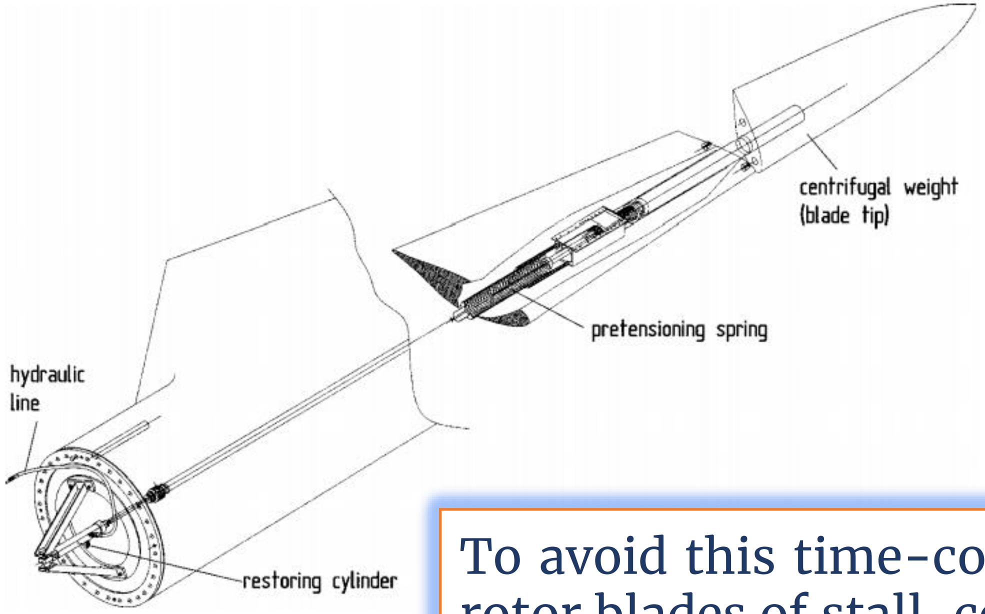
Rotor Blades

Blade Connection to the Rotor Hub - Bonded-in bolts

The simplest solution from a design point of view, and one which saves weight, is to bond the connecting bolts straight into the rotor blade root structure, without further form-fitting elements like the cross bolt.

However, this type of construction is considered to be risky. It may be possible to improve this design in future developments so that it, too, can be used in mass production.

Rotor Blades



Aerodynamic Brakes on Stall-Controlled Rotors

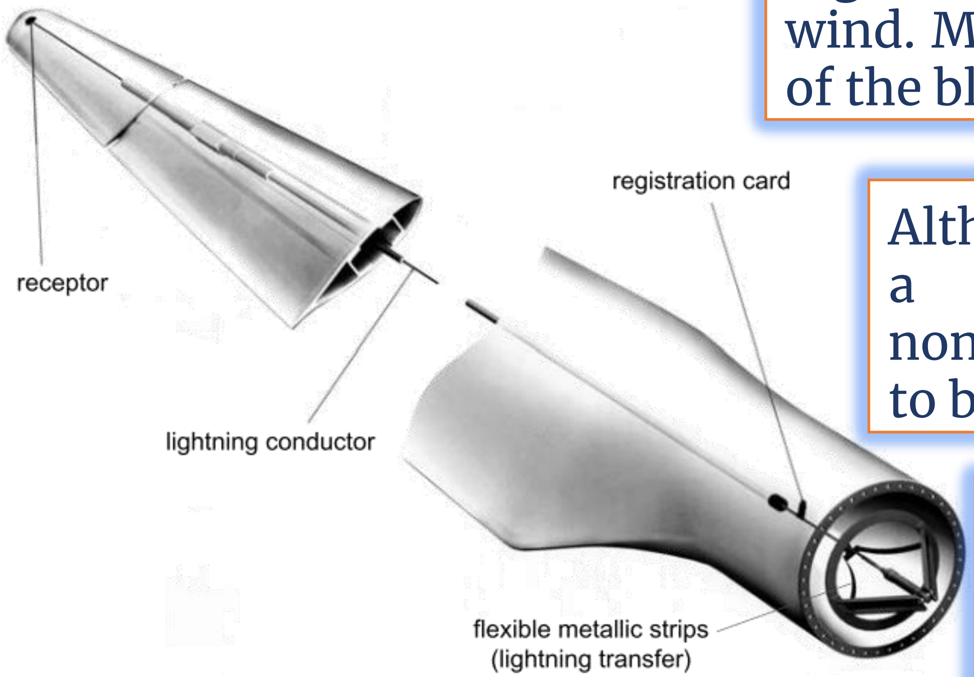
In older wind turbines, this mechanical system worked without any possibility being provided for resetting it. The result was that in the case of a grid outage, an entire wind park was brought to a standstill by the aerodynamic blade tip brakes and then every blade tip had to be reset again manually to its normal position

To avoid this time-consuming restarting of the wind turbines, the more recent rotor blades of stall-controlled systems are equipped with an hydraulic resetting system (see Figure).

However, this makes the structural complexity of rotors with a fixed blade pitch angle as great as that for rotors with blade pitch control and it also considerably increases the weight of the rotor blades.

Rotor Blades

Lightning Protection – Lightning strikes are unavoidable on large wind. Most of the lightning strikes on the rotor blades hit the area of the blade tip, resulting in considerable damage.

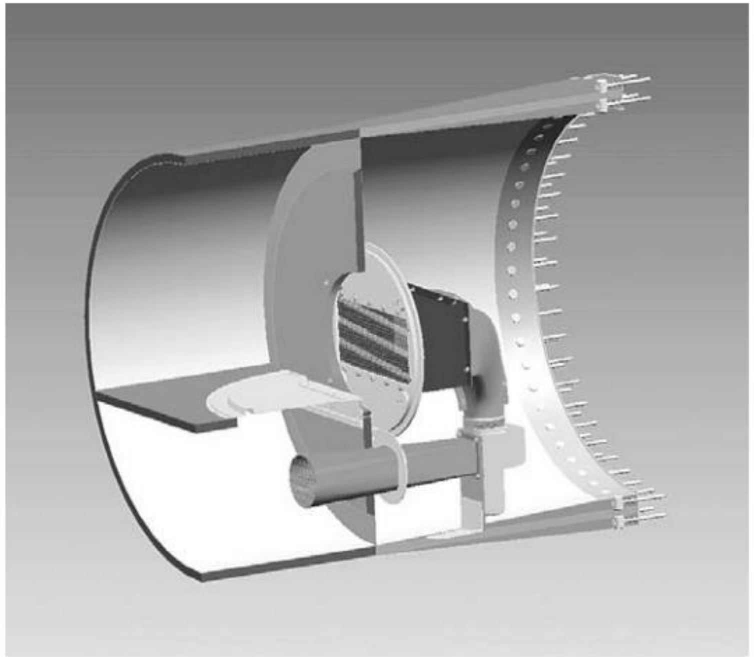


Although it was initially thought that one could dispense with a lightning protection system on rotor blades of nonconductive composite fibre glass material, this was found to be not true in actual operation.

For this reason, the demands for effective lightning protection have become more and more vociferous as more and more wind turbines of increasing size were installed — especially from the insurers.

Today, lightning protection systems are a standard feature with all new rotor blades (see Figure).

Rotor Blades



Rotor blade root section with the de-icing system using hot air

Ice Warning and De-icing

On some sites, there is a risk that ice becomes deposited on the rotor blades under certain weather conditions.

For this reason, the manufacturers of rotor blades offer an optional ice warning system which switches the unit off as a preventative measure during certain weather conditions. A much more complicated task is that of providing the rotor blades with a de-icing system.

An electrical resistance heater developed by some rotor blade manufacturers and also being offered already in some cases (see Figure).

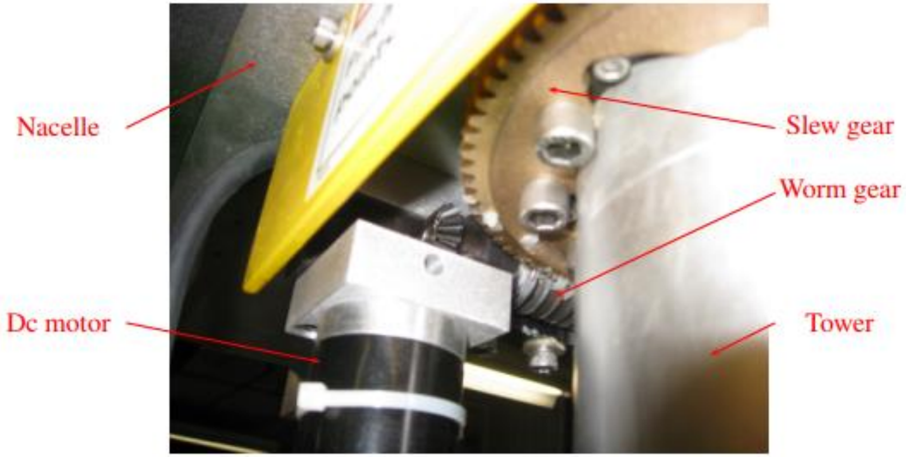
In view of the permanent deformation of the blade structure under the bending stress, the mounting system and the material of the heating elements are subject to particularly high demands. In recent years it has also been attempted to largely prevent the blade surface from icing up by means of a special surface coating.

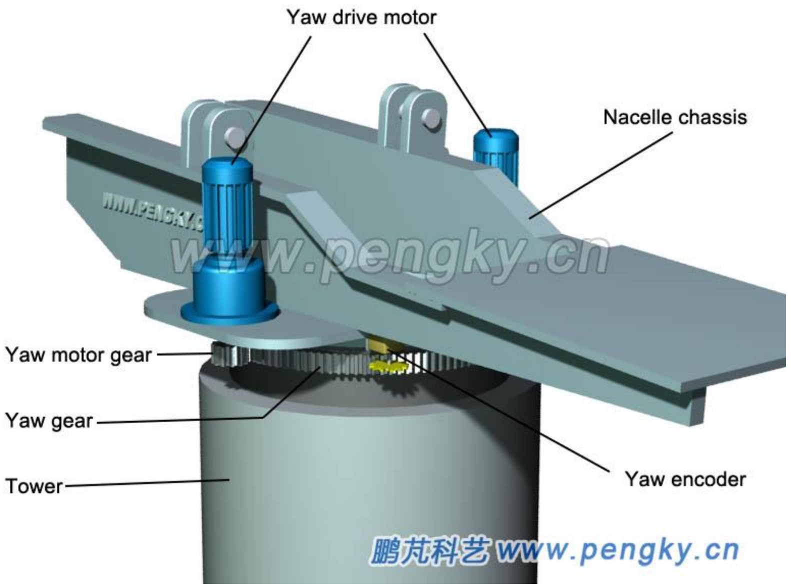
A fully satisfactory de-icing system is not available at present.

Yaw

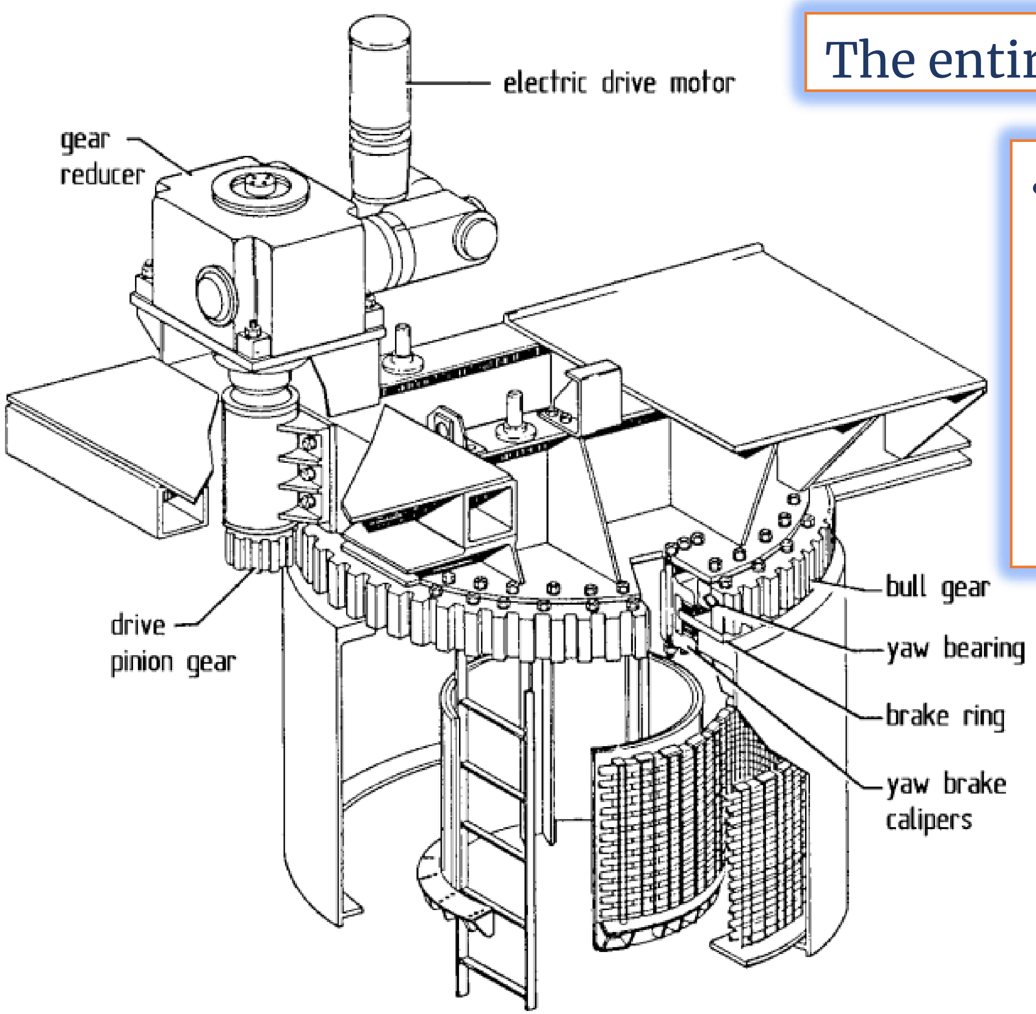
To keep the wind turbine pointed into the wind, signals from a wind vane (or other wind direction measuring device) are monitored to check incoming wind direction

With this information, controller can actuate yaw motors to turn the nacelle as necessary





Yaw – Components



Yaw system with assembly of the Westinghouse WTG-0600 [18], 1985

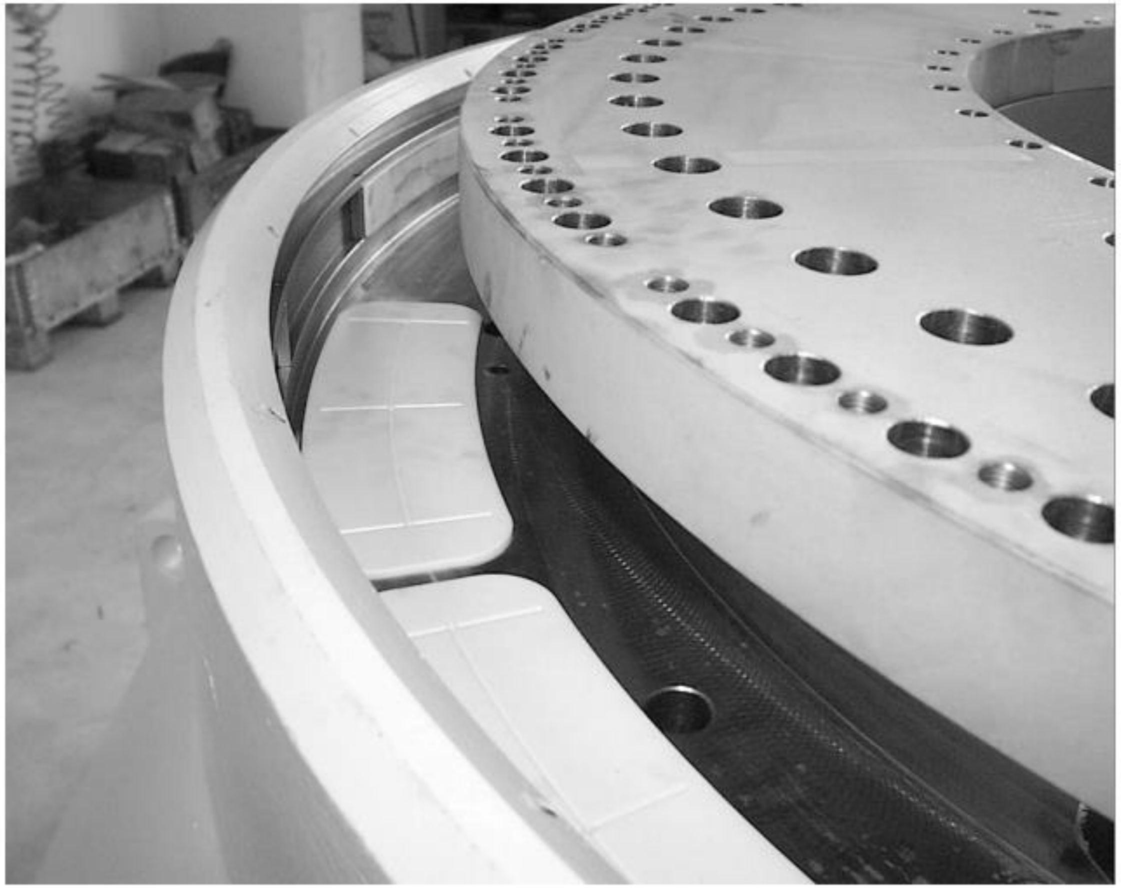
The entire system consists of the following components:

- **Azimuth bearing** – The azimuth or yaw bearing is subject to contradictory requirements. On the one hand, it should ensure easy-running yawing and a long service life and, on the other hand, yaw damping is desirable, even during the yawing, in order to avoid unwanted yawing oscillations. These requirements can be met both by a **conventional roller bearing** and by a **friction bearing**.

The traditional design consists of a large roller bearing, whereas a four-point ball bearing is used as a rule in more recent designs (see Figure).

In some cases, roller bearings with special yaw damping are also used (prestressed bearings).

Yaw – Components



Azimuth friction bearing system of the NEG Micon NM 52

- Azimuth bearing –

The alternative is a friction bearing in which the nacelle moves on sliding elements made of a synthetic material.

This design, initially only used in small-scale turbines, is now also being used successfully in large turbines, e.g. in the Vestas V-66 or NEG Micon NM 52 (see Figure).

The advantage of the friction bearing consists in that no elaborate azimuth brakes and braking rings are required.

Pitch

Wind turbine blades provide lift and drag forces, similar to an airplane.

As air passes around the blades a torque is applied to the main shaft making it accelerate.

Turbulence is created around the blades as they cut through the flowing airmass. As the rotor speed increases, the blades will begin to cut into the turbulent air created by the previous blade, causing it to “stall”.

Stall provides a means of mechanical speed limitation; blades can be designed to stall at specific speeds and rates. More complex turbine designs include individual pitch control, via electric motors or hydraulic cylinders. These systems rely on feedback of blade angle measurements.

Hub entrance

Heat wrap

Accumulator

Cylinder

Pitch system components; a hydraulic system in a harsh environment

Drivetrain

The **drivetrain** consists of all components attached to energy-transmitting shafts.

This includes the **main bearing** and **low-speed shaft**, all gearbox shafts and bearings, and the generator shaft assembly which includes a flexible coupling to allow slight shaft misalignment.

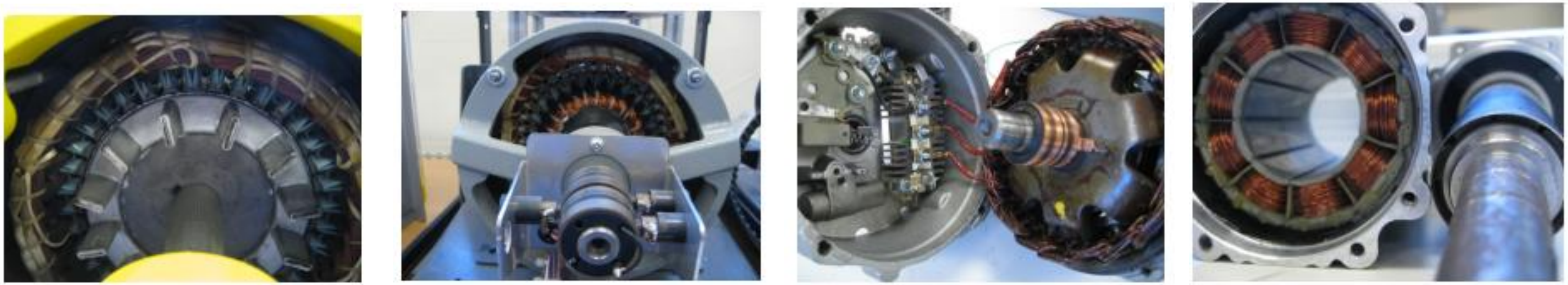
Gearbox increases the speed of the shaft connected to the generator. The generators torque and speed characteristics will influence the choice of gear ratio, so that the desired operating wind speed range aligns with a desired generator operating speed range.

Shaft couplings usually include at least one joint which offers flexibility. Without a flexible shaft coupling, vibrations caused by misalignment are transferred through the rigid coupling and into the connected equipment

Power system interconnection

Wind turbines can be operated as part of an existing power distribution network or in a standalone island power system.

Both require use of **controllers**, **transformers**, **filters**, **relays**, and **other sensors** and **protective devices**



Types of machines used in wind turbines. (a) Type 1 squirrel-cage machine. (b) Type 2 and 3 wound-rotor induction machine. (c) Type 4 external-field synchronous machine. (d) Type 4 permanent magnet machine.

Supervisory control and data acquisition

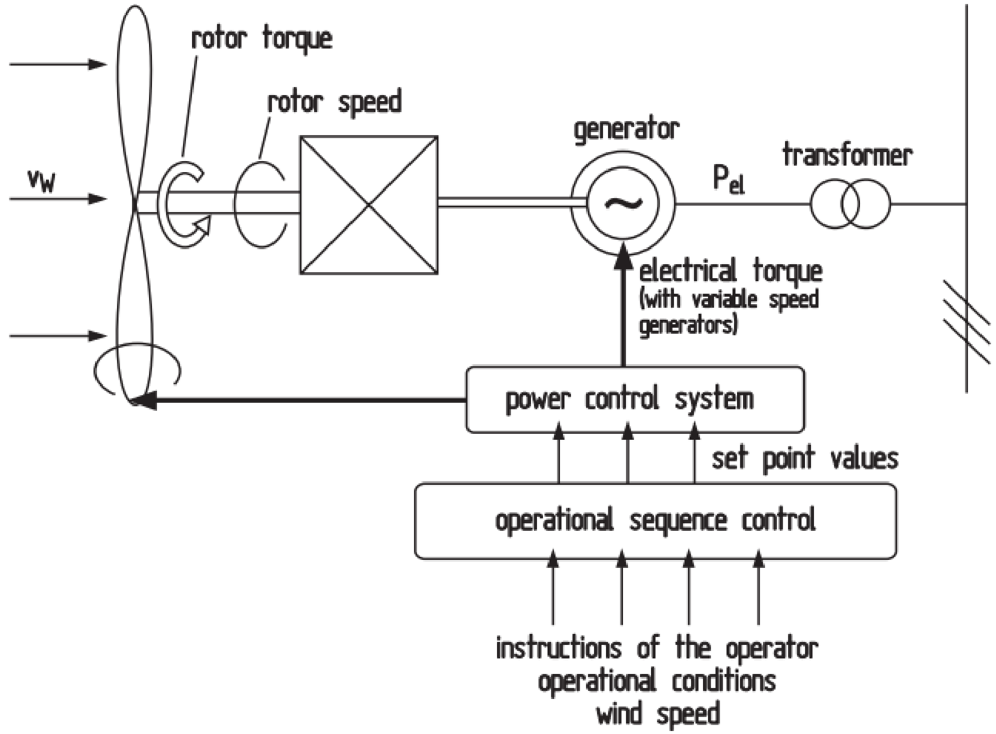
Supervisory control and data acquisition SCADA systems collect information from wind turbines, substations, loads, and system operators, and can control turbine set-points to maintain reliable operation.

When power generation signals are provided by a system operator, such as Mid-Continental Independent Service Operator (MISO), the SCADA system receives those and adjusts set-points of individual turbines. It can also shut down turbines in case of excess energy production and emergency operations.

Interfaces are usually provided to visualize system details and provide remote control the wind turbine.

SCADA interface of the 100 kW wind turbine on the Iowa State University campus.

Supervisory control and data acquisition



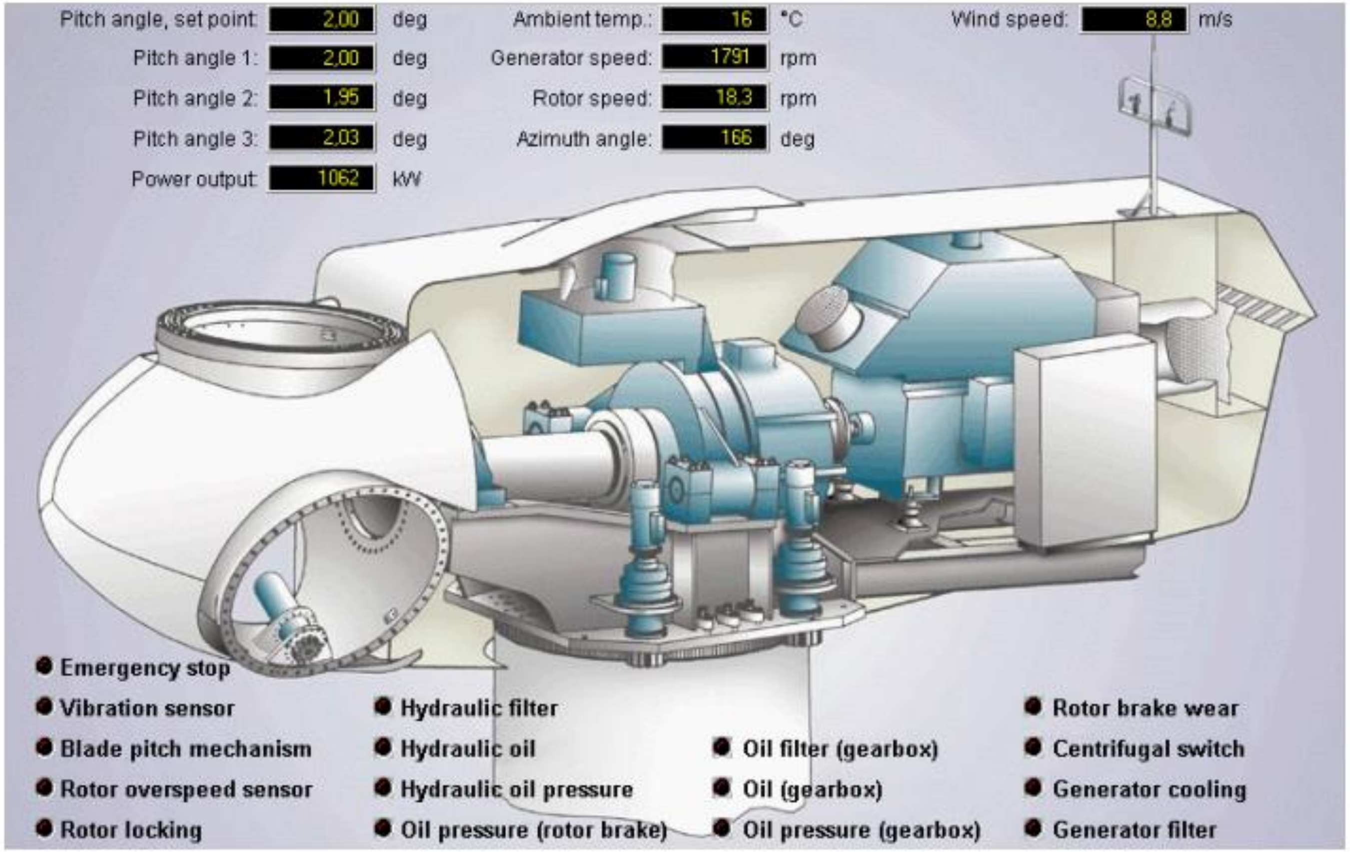
Tasks of the control system and sequence control of a wind turbine

The **control systems and sequence control** of a wind turbine must primarily ensure its fully automatic operation.

Any other approach requiring some manual intervention during normal operation would be entirely unacceptable from an economic standpoint.

Moreover, economical considerations demand from the control systems that maximum efficiency be achieved at every point of operation. This requires **“intelligent” control systems**.

Supervisory control and data acquisition

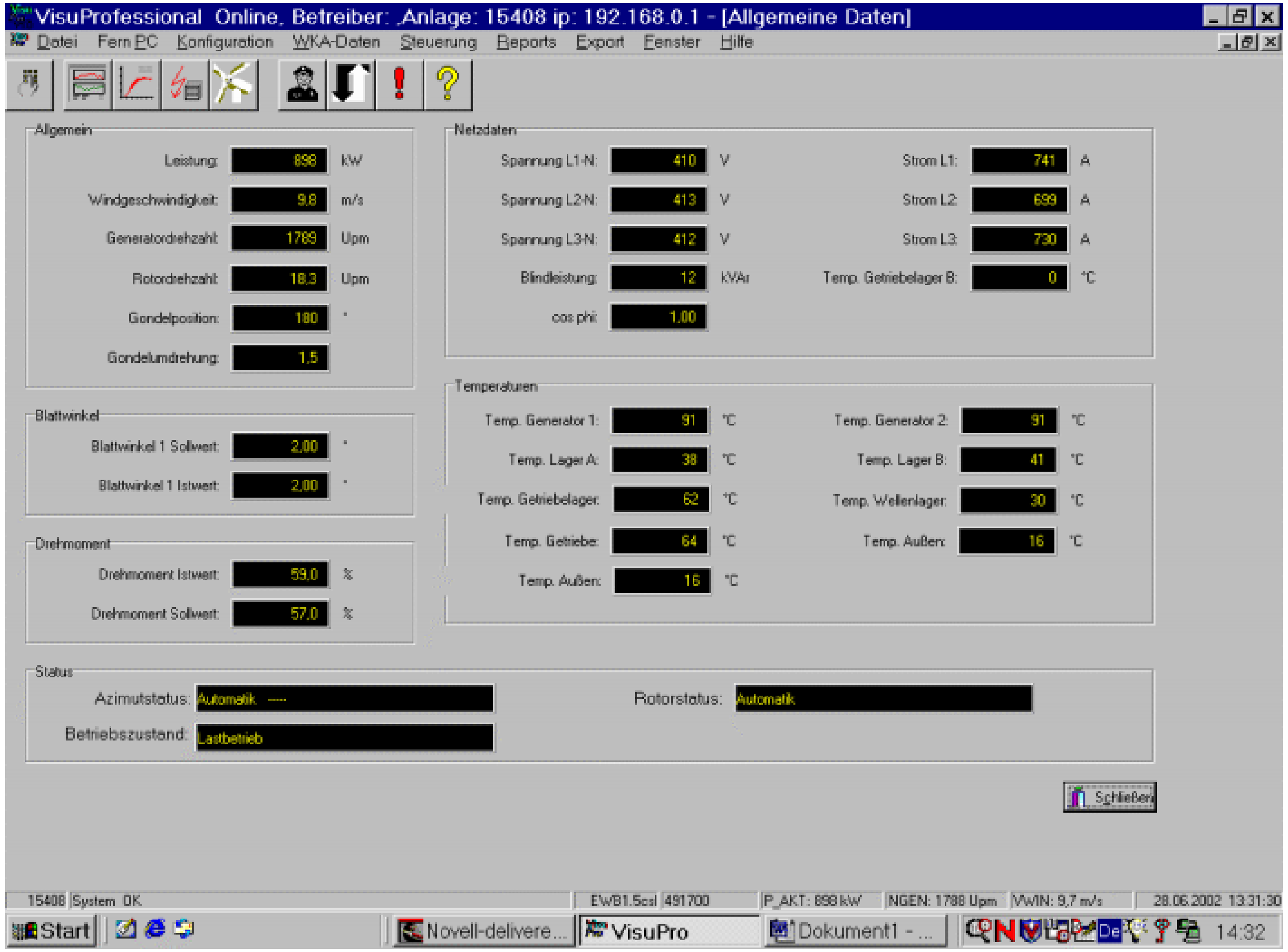


Data acquisition in the nacelle of a GE-1.5S turbine for monitoring its mechanical components

The **technical monitoring** requires an appropriate data acquisition system in the turbine and, if possible, also the acquisition of data from the environment, for example wind and weather information from an external anemometer station or the acquisition of certain

In the wind turbine, the required measurement data are acquired from sensors on the mechanical and electrical components

Supervisory control and data acquisition

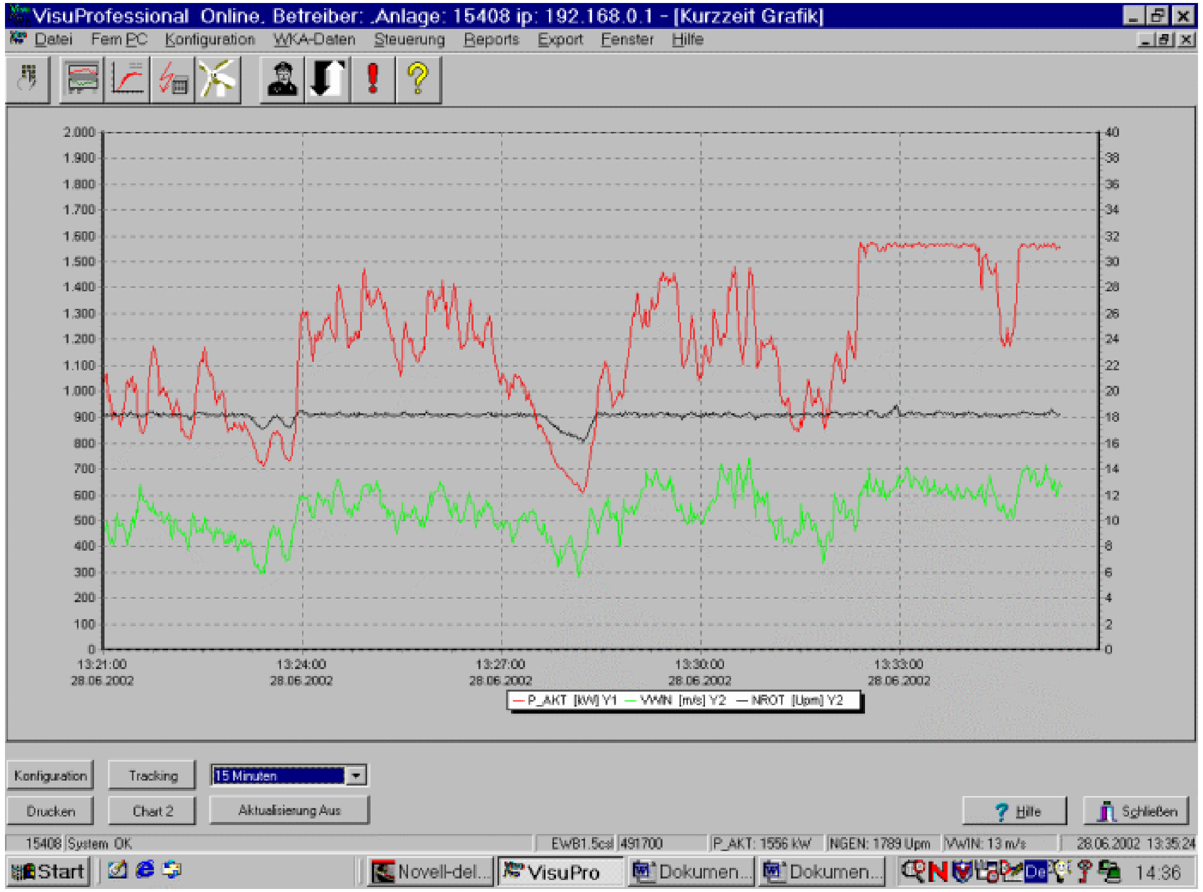


Main remote monitoring menu of a GE-1.5S turbine

The turbine monitoring system commonly has a menu-structure with different levels and options. Besides the wind turbine identification data and general operational information, the main menu shows, for example, the following parameters on the display (see Figure):

– Wind velocity
– Electric power output
– Generator revolutions
– Rotor speed
– Pitch angle
– Voltage
– Frequency
– Current intensity

Supervisory control and data acquisition

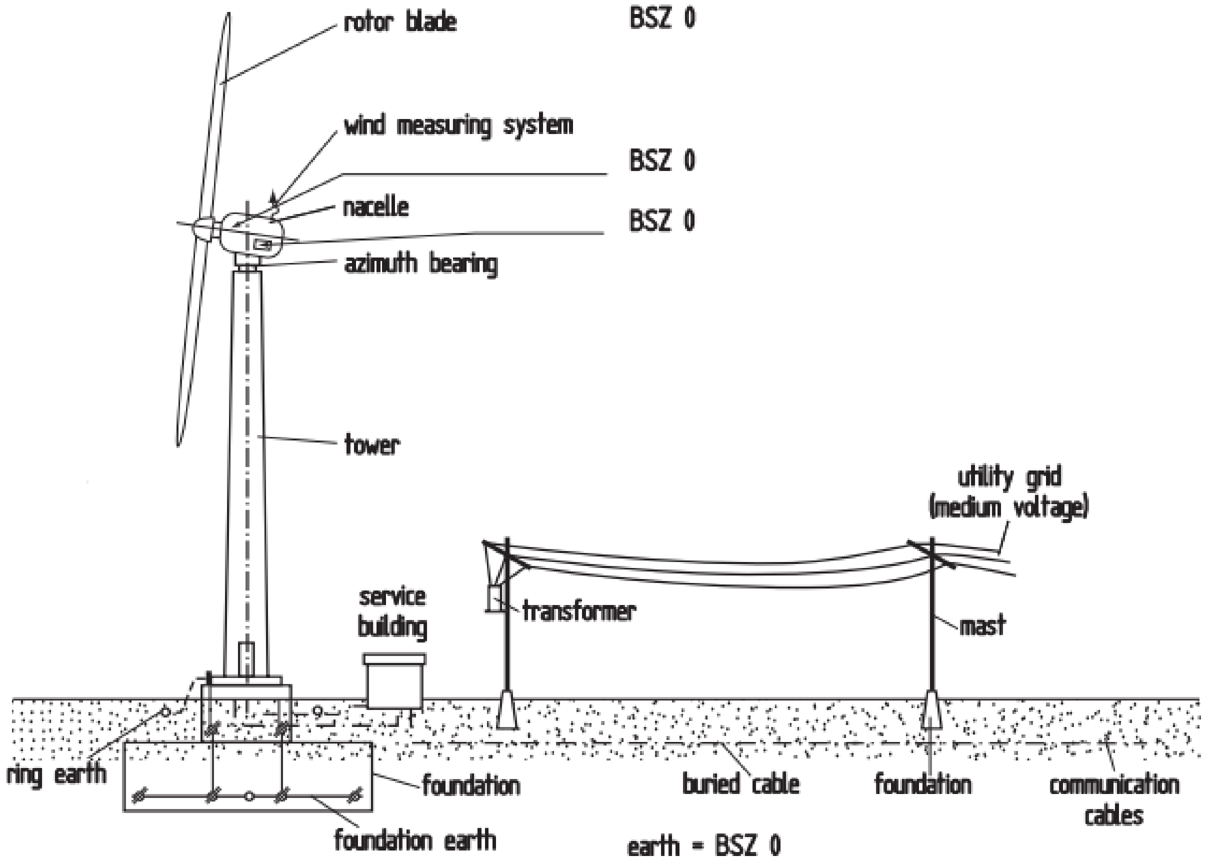


Short-time graph (15 minutes) of wind velocity, rotor speed and electrical power output of a TW-1.5S turbine

Apart from this instantaneous information relating to the operating conditions, the **monitoring parameters** provide the possibility of calling up and/or printing out long-term data evaluations in a statistical or graphical form.

For example power and availability statistics of the current operating year, or also as a " short-time graph" of the variation of wind speed, rotor speed and electrical power over the period of some minutes (see Figure).

Other futures



Lightning protection system and earthing of a wind turbine

Lightning stroke
A reliable protection against lightning is an important feature for a wind turbine (see Figure).

In level terrain, high, slender structures perfectly attract lightning strikes.

Other futures

Lightning protection system and earthing of a wind turbine

De-icing systems -
The protective measures against the hazard of flying chunks of ice simply consist of an ice warning system which automatically switches off the turbine if ice accretion is to be expected due to the prevailing weather conditions.

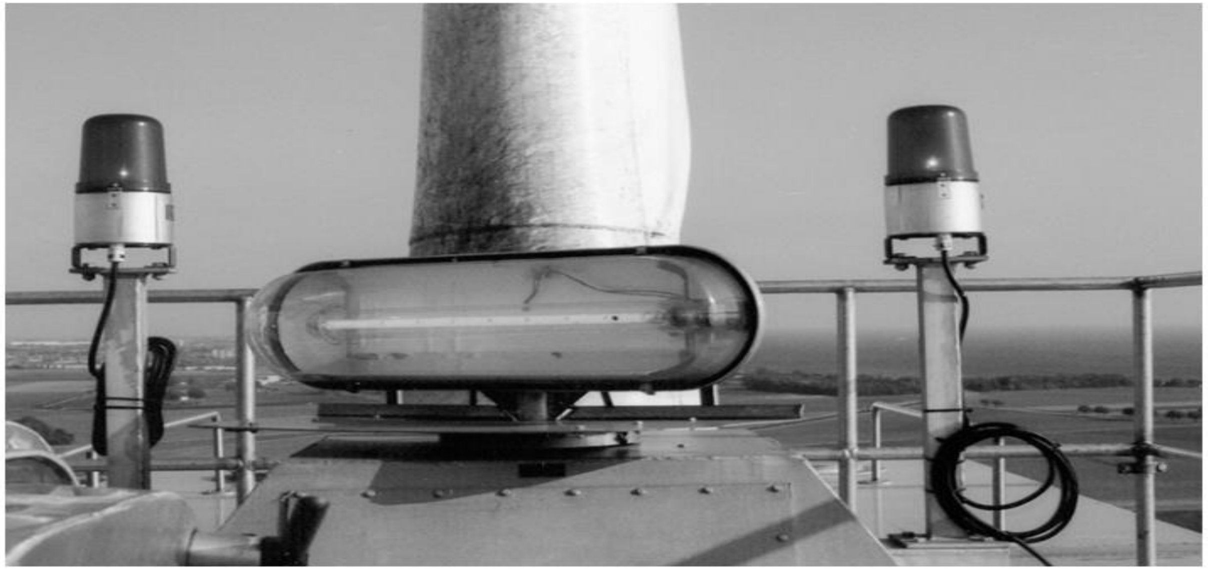
Such systems are being offered by the turbine manufacturers as supplementary equipment.

Other futures

Daytime markings on the rotor blades of a Dewind D-6 turbine

Air traffic

Large turbines, like all large buildings projecting above the skyline of their surroundings, require warning markers for air traffic.



Safety lights (night-time markers) on the WTS-3 in Maglarp with omnidirectional beacons or also rotating flashing lights (Sweden)

Thank you for your attention