ANKARA UNIVERSITY
DEPARTMENT OF ENERGY ENGINEERING

WIND POWER SYSTEMS

INSTRUCTOR
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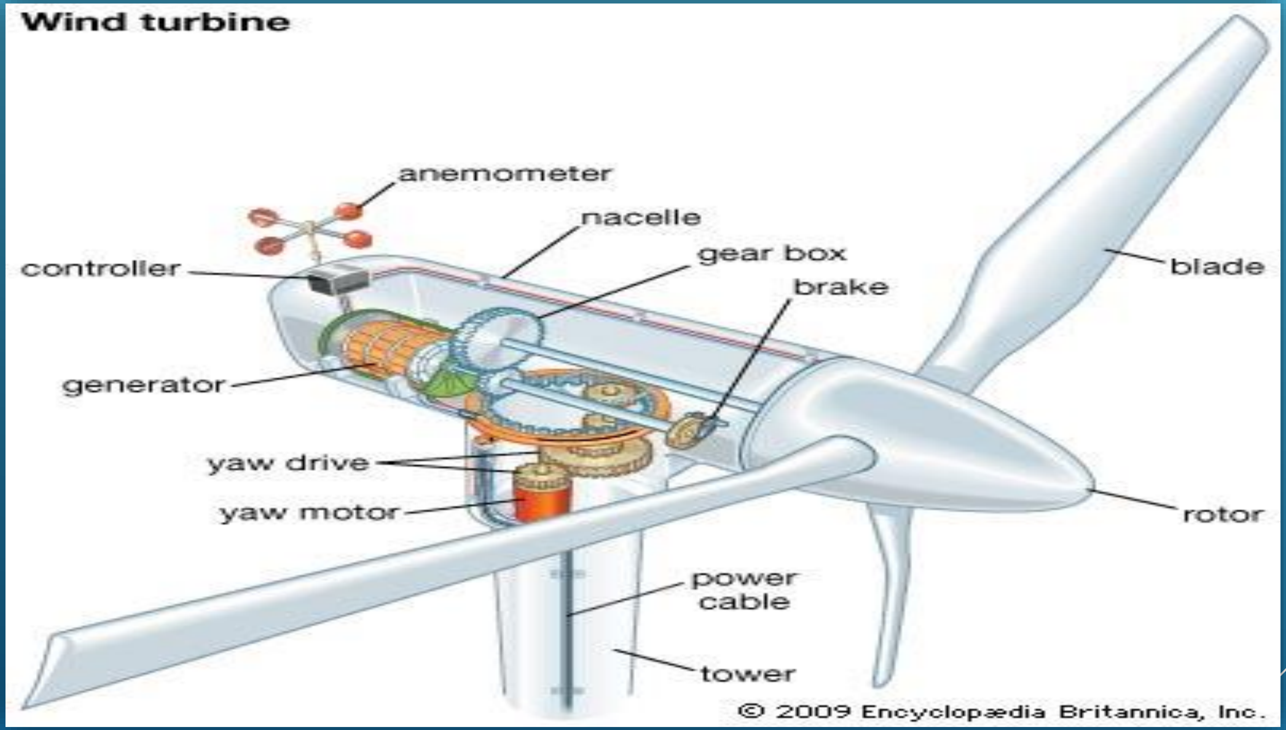
CONTENTS

SYSTEM COMPONENTS

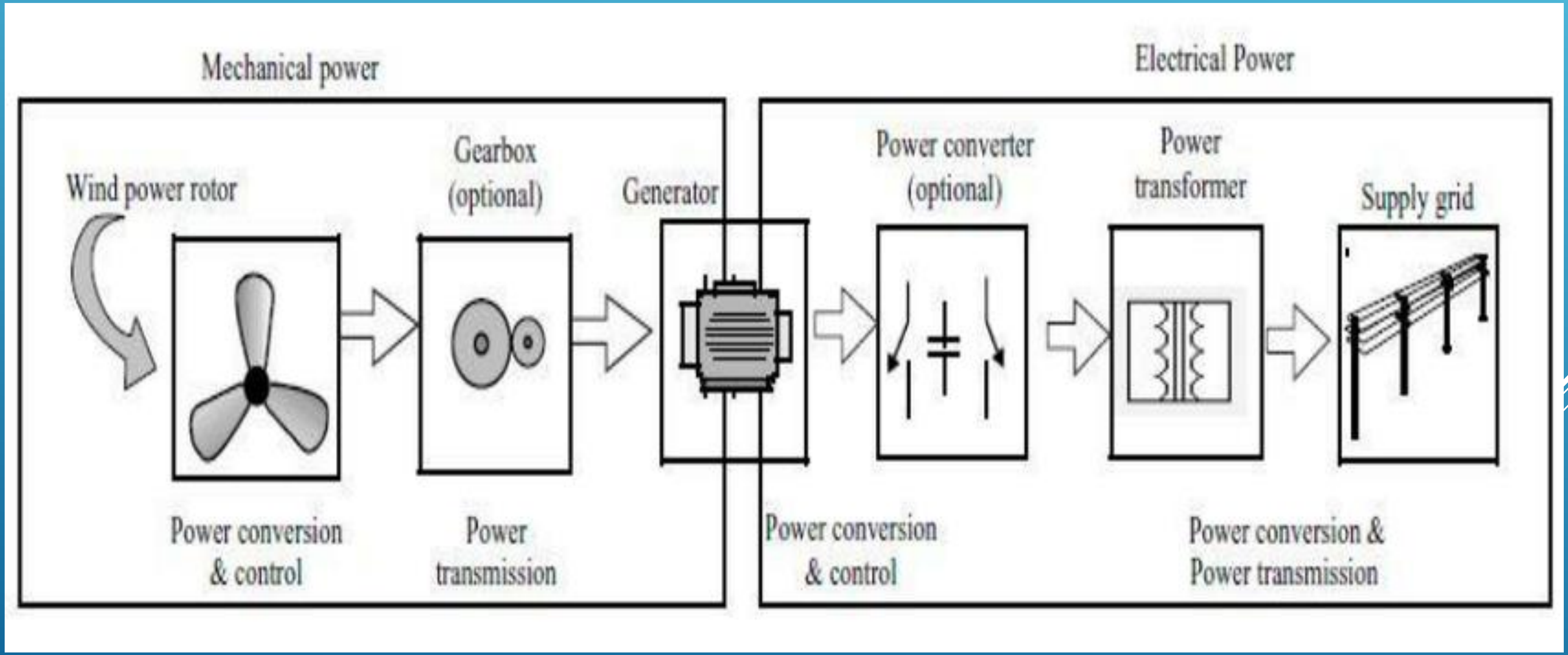
The total system consists of the wind turbine and load. A typical wind turbine consists of the rotor (blades and hub), speed increaser (gearbox), conversion system, controls, and tower.

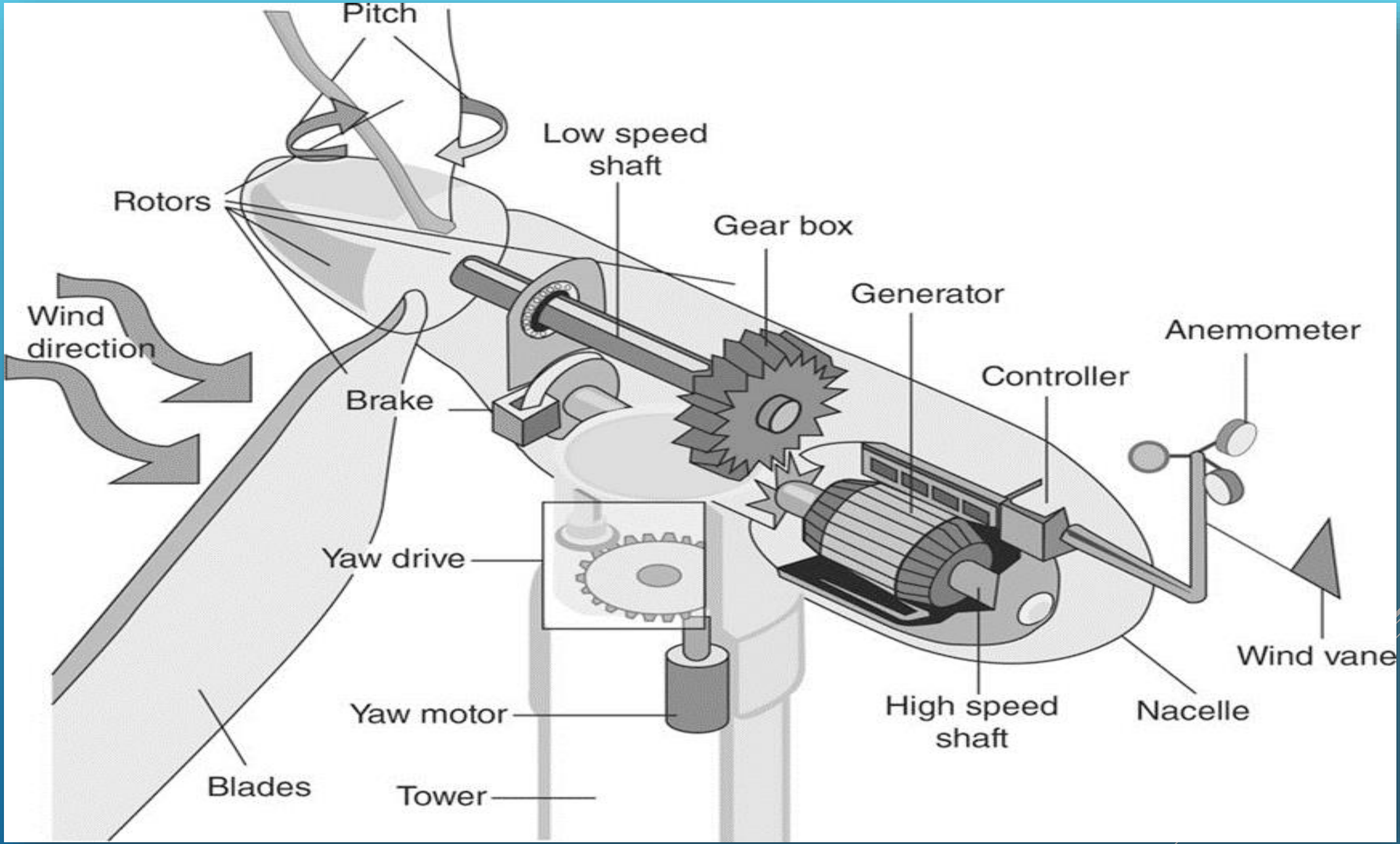
The nacelle is the covering or enclosure. The output of the rotor, rotational kinetic energy, can be converted to electrical, mechanical, or thermal energy. Generally, it is electrical energy, so the conversion system is a generator.



Electric motors are used to rotate, change the pitch of the blades. All blades must have the same pitch for all operational conditions.

Most direct current (DC) generators and permanent magnet alternators on small wind turbines do not have a speed increaser. One type of large wind turbine has no gearbox, which means it has very large generators.

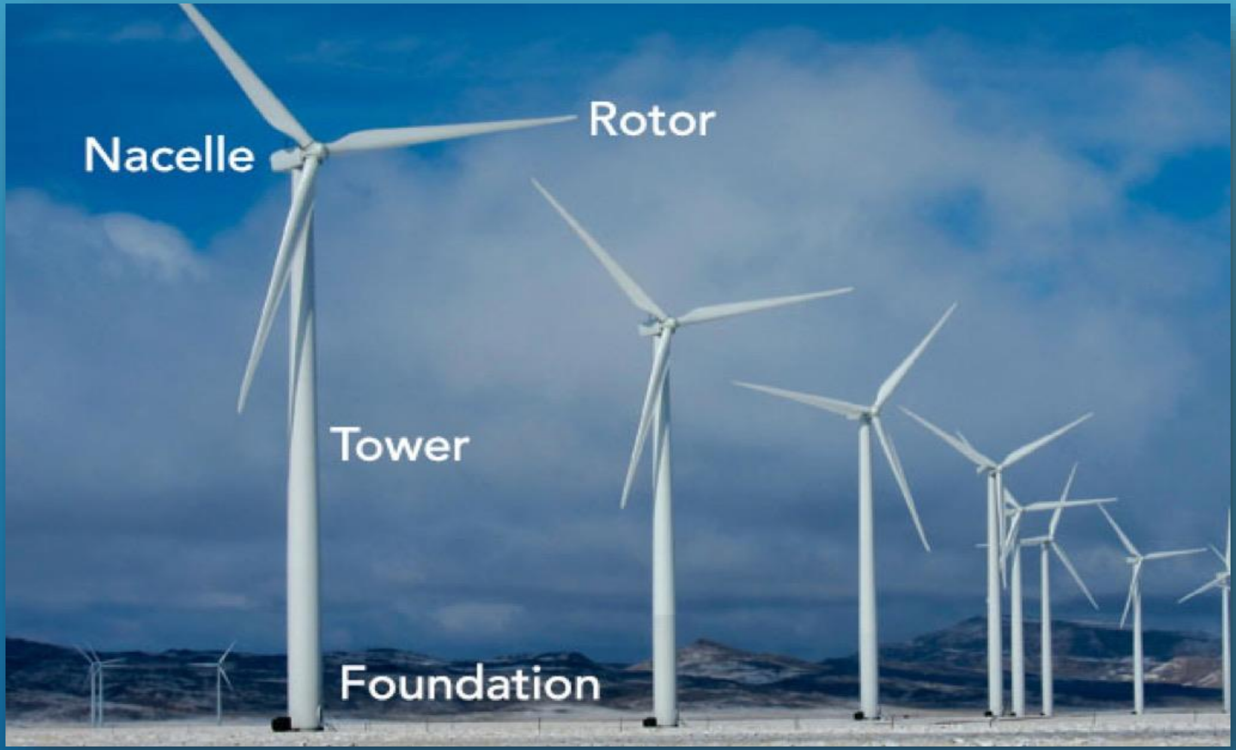




Principal components of most wind energy conversion systems

TOWER

The tower of a wind turbine serves to elevate the main part of the machine up into the air. For a horizontal axis machine the tower must be at least high enough to keep the blade tips from touching the ground as they rotate. In practice, towers are usually much higher than that. Winds are nearly always much stronger as elevation above ground increases, and they are less turbulent.



The vast majority of wind turbine towers are constructed from steel. Concrete towers are a perfectly practicable alternative but, except at the smaller sizes, they require the transfer of a substantial element of work from the factory to the turbine

Lattice Tower

Guyed Pole Tower

Concrete Tower

Tubular Steel Towers

TURBİNE

Wind turbines for generating electricity are known and are being deployed in increasing numbers to provide a sustainable electricity supply.The maximum power which a wind türbine can generate is proportional to the swept area of its blades.

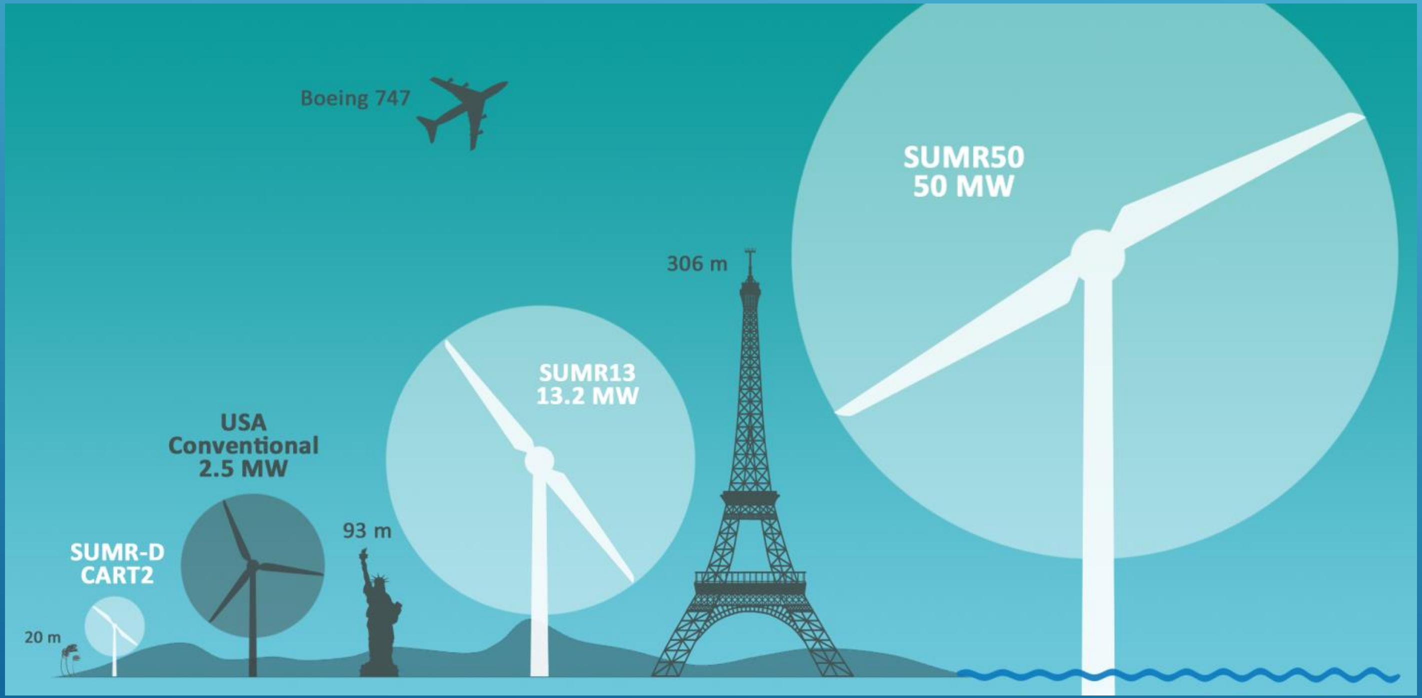
There is desire to increase the size of wind türbines so as to increase the maximum power.

Small Wind Turbines

Local electrical grids may not be able to handle the large electrical output from a large turbine, so smaller turbines may be more suitable.

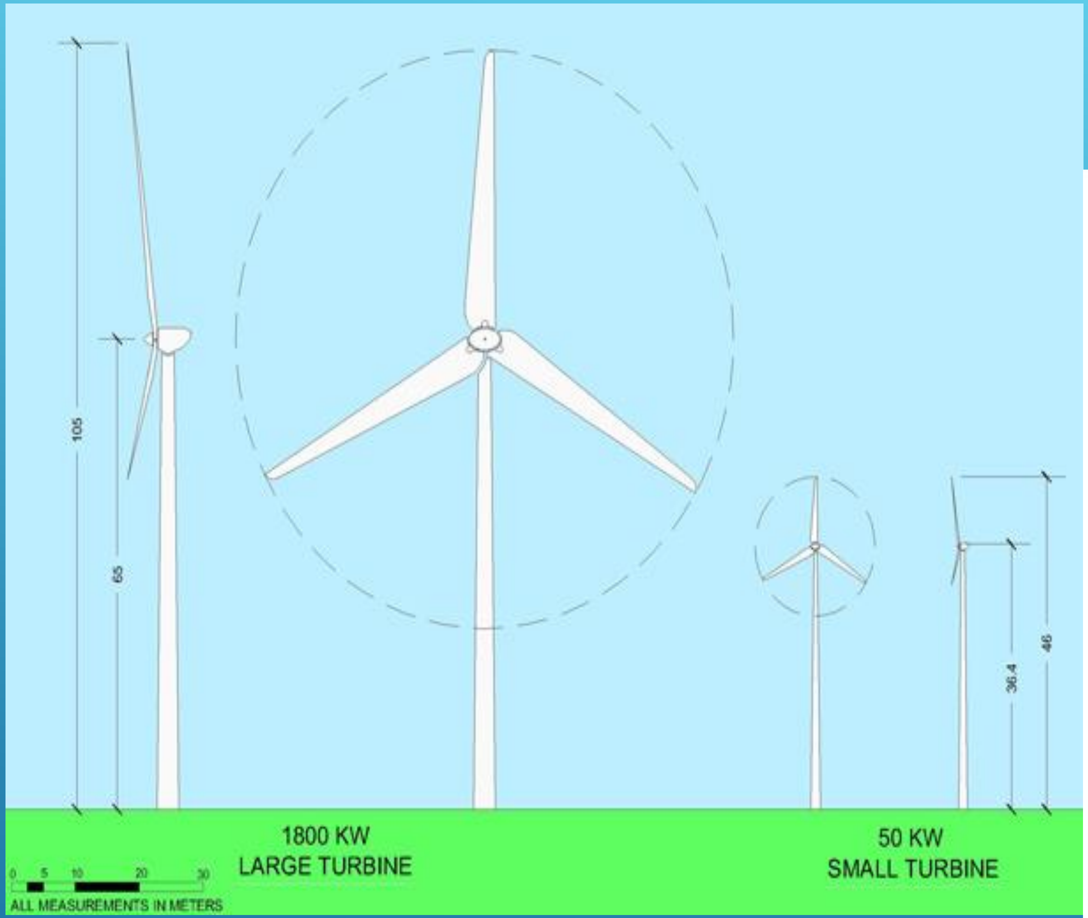
Large Wind Turbines

Able to deliver electricity at lower cost than smaller turbines, because foundation costs, planning costs, etc. are independent of size.



In areas where it is difficult to find sites, one large turbine on a tall tower uses the wind extremely efficiently.

Well-suited for offshore wind plants.



Sizes and applications

Photo from Bergey Windpower Co. Inc., NREL 02102

Small

(≤100 kW)

- Homes
- Farms
- Remote applications (water pumping, telecom sites, icemaking)

Photo from Tjaden Farms, NREL 13764

Mid-scale

(100-1,000 kW)

- Village power
- Hybrid systems
- Distributed power

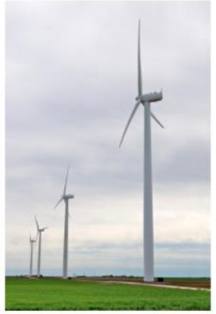


Photo from Native Energy Inc., NREL 17593

Large, land-based

(1-3+ MW)

- Utility-scale wind farms
- Large distributed power

Photo from HC Sorensen, NREL 17855

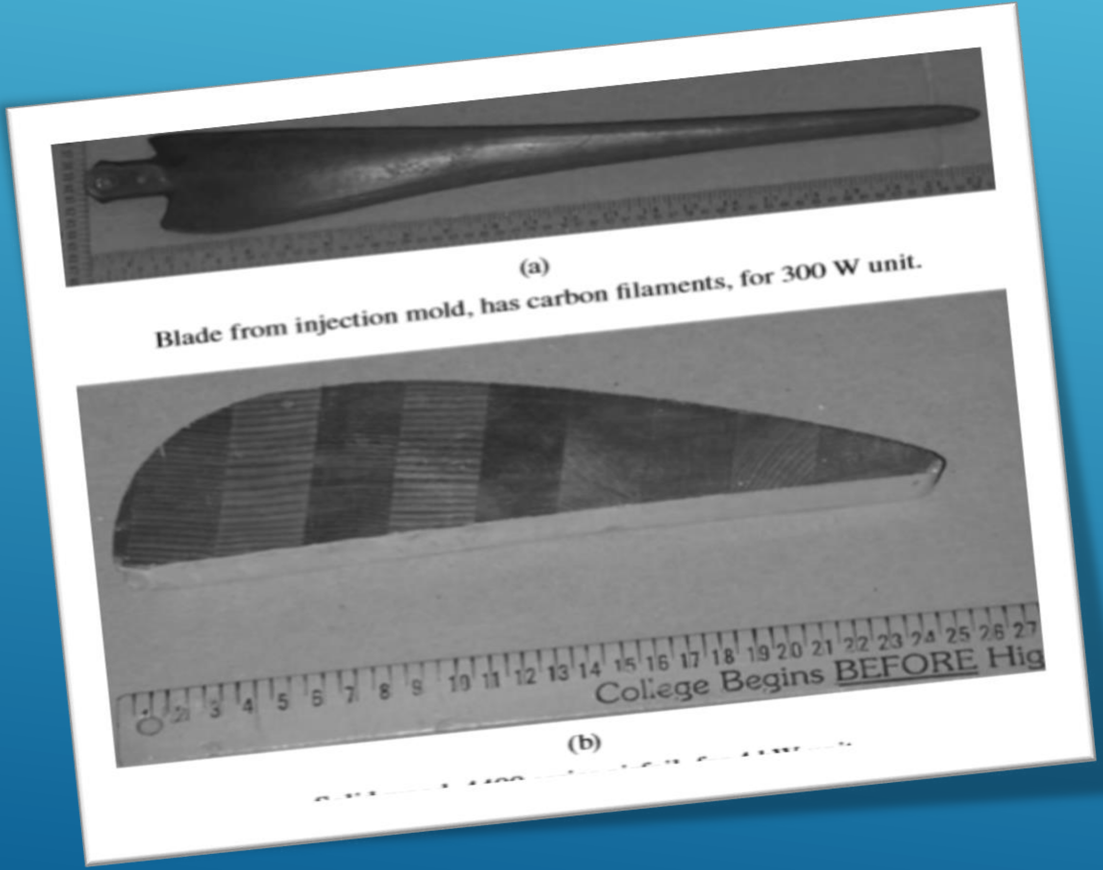
Large, offshore

(3-7 MW)

- Utility-scale wind farms, shallow coastal waters
- No U.S. installations

BLADES

For years, small wind turbines blades were made of wood, carved from a single piece or from a wood block glued together from several pieces. The material properties of wood are good: strength, flexibility, and resistance to fatigue. Machines could carve up to four blades from a master blade. However, for large blades, solid wood was not acceptable, as the weight became too large.



Wind turbine blades have been made from a number of materials: aluminum cover, fabric cover, or metal cover on rib and spar (like an airplane wing); a sail wing, which is fabric attached to a leading edge spar; laminated wood composite (shell); fiberglass-reinforced plastics (FRPs), also carbon fibers.

Form Of Blade Structure

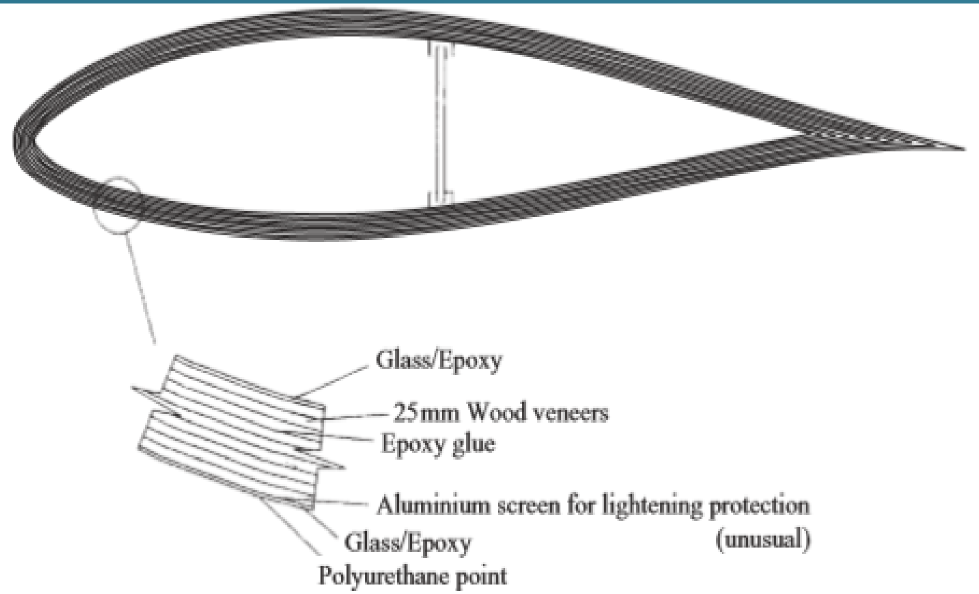


Figure 7.1 Wood/Epoxy Blade Construction Utilizing Full Blade Shell (Reproduced from Corbet (1991) by permission of the DT1 Renewable Energy R&D Programme)

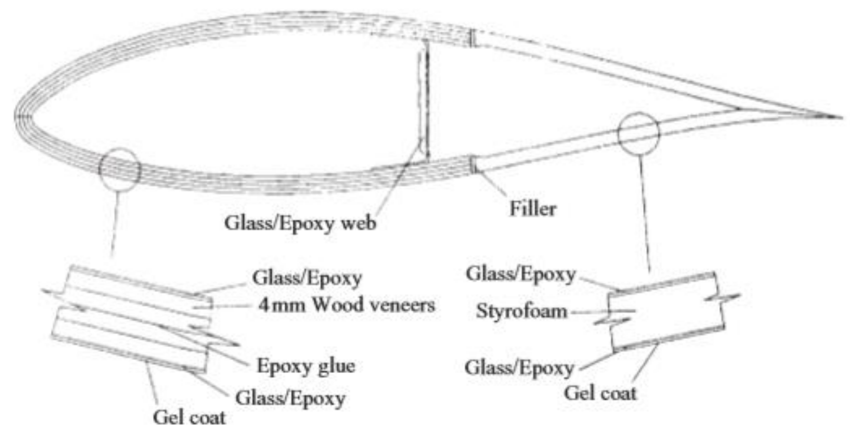


Figure 7.2 Wood/Epoxy Blade Construction Utilizing Forward Half of Blade Shell (Reproduced from Corbet (1991) by permission of the DT1 Renewable Energy R&D Programme)

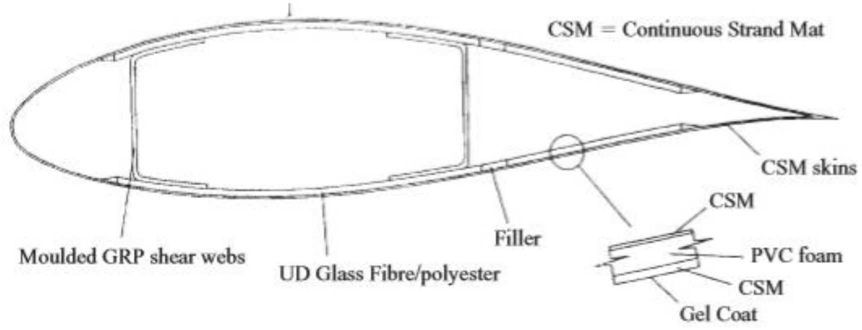
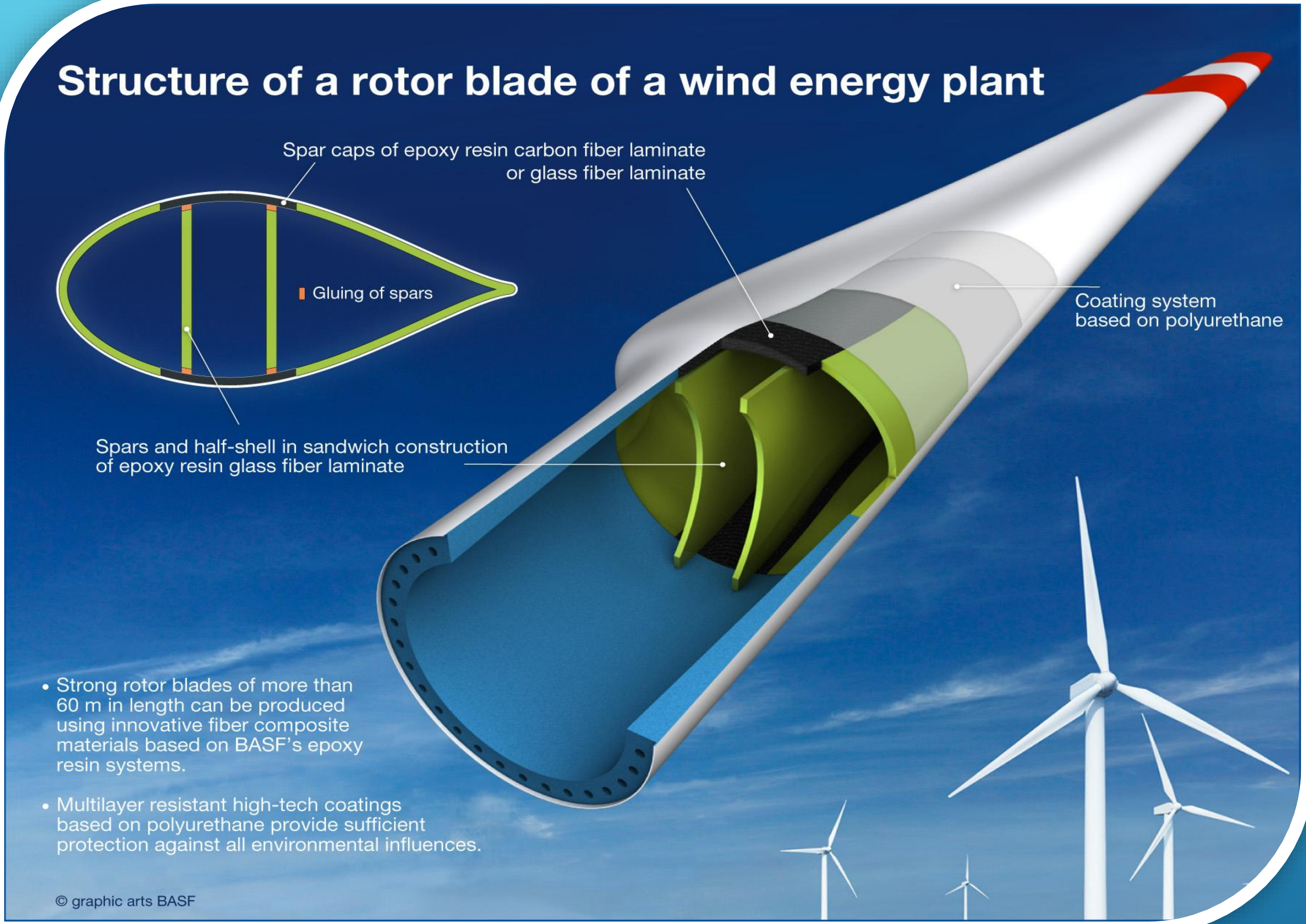
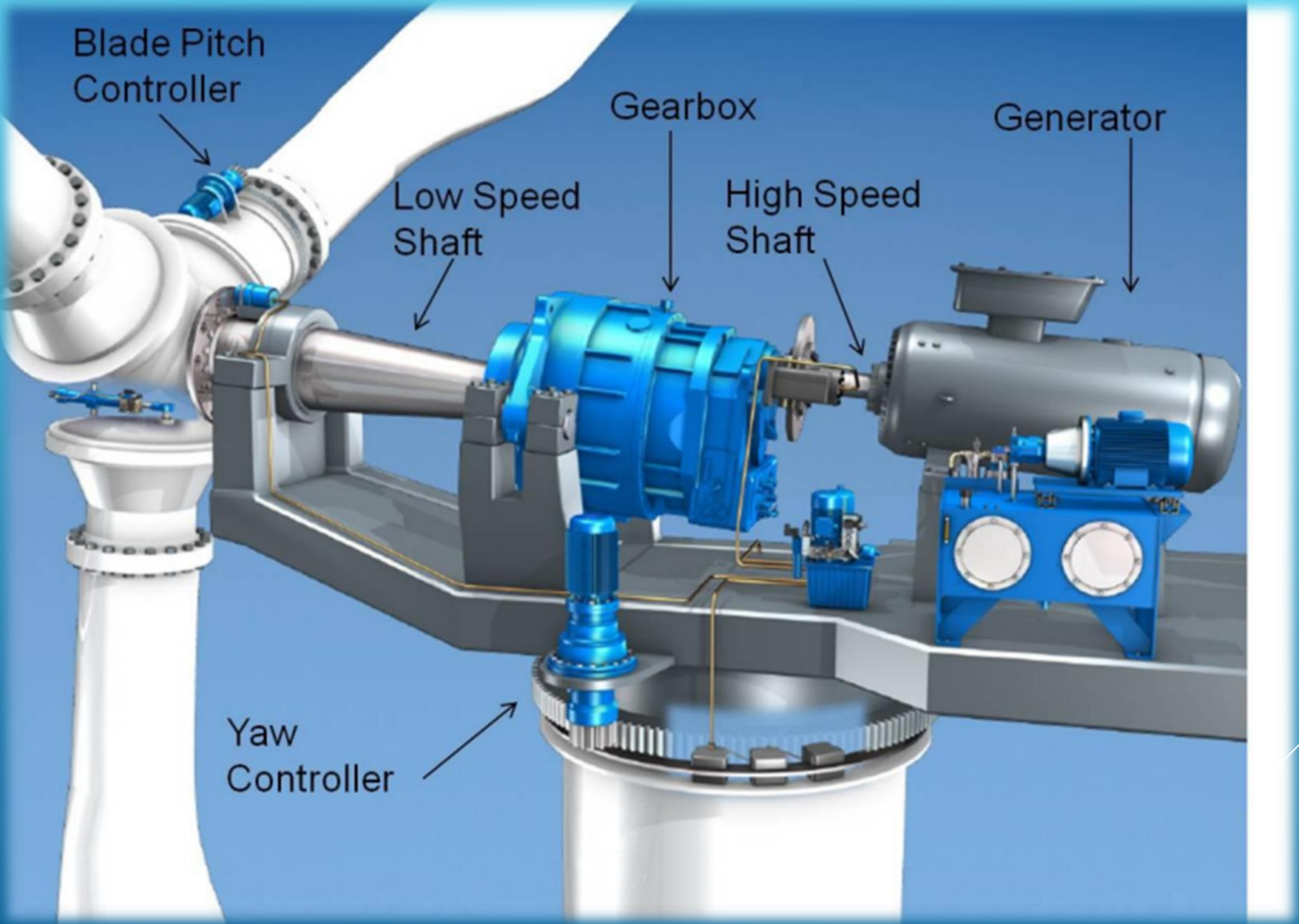


Figure 7.3 Glass-fibre Blade Construction Using Blade Skins in Forward Portion of Blade Cross Section and Linking Shear Webs. (Reproduced from Corbet (1991), by permission of the DT1 Renewable Energy, R&D Programme)

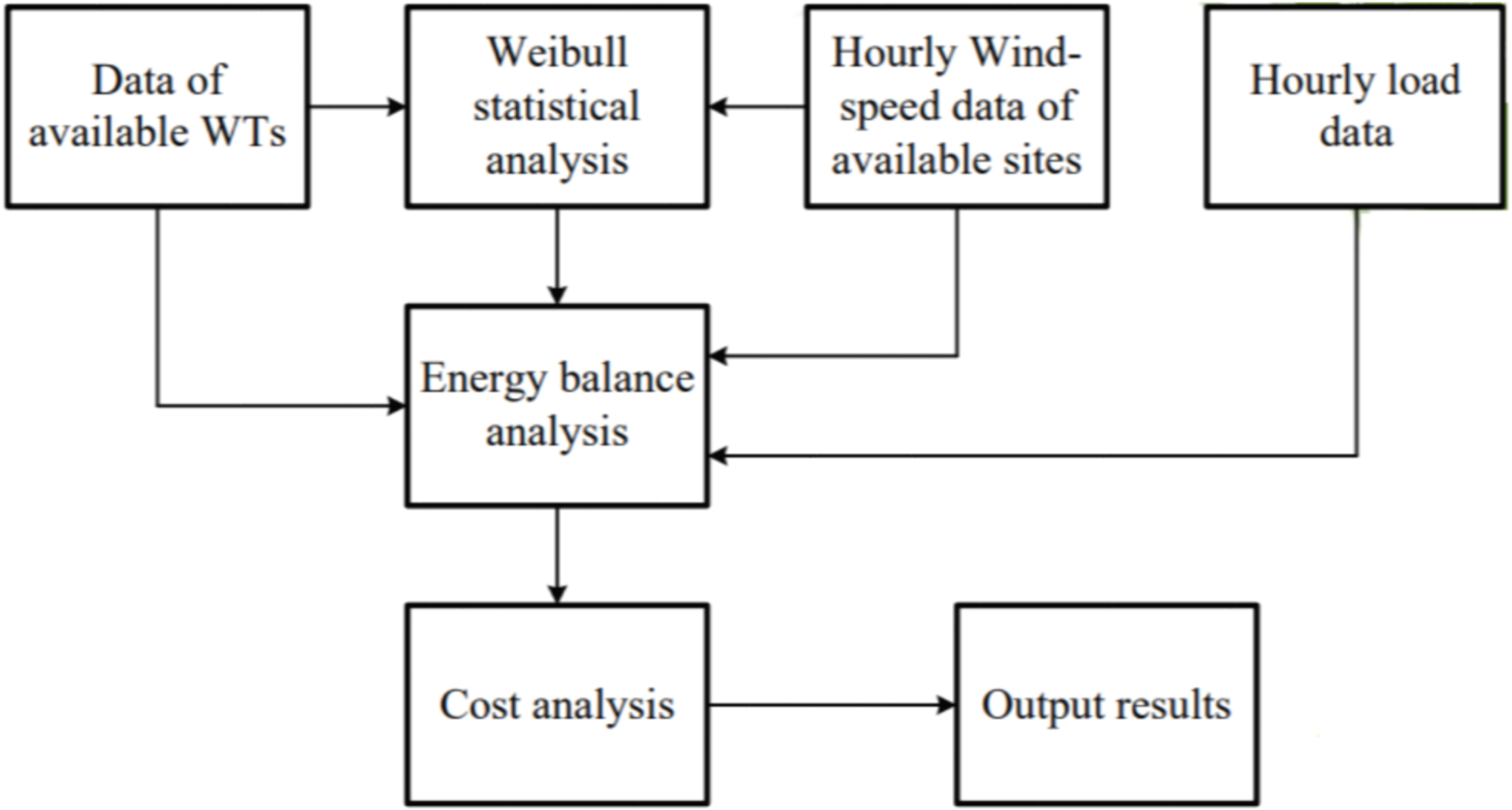

Structure of a rotor blade of a wind energy plant
Spar caps of epoxy resin carbon fiber laminate or glass fiber laminate
Gluing of spars
Coating system based on polyurethane
Spars and half-shell in sandwich construction of epoxy resin glass fiber laminate
• Strong rotor blades of more than 60 m in length can be produced using innovative fiber composite materials based on BASF's epoxy resin systems.
• Multilayer resistant high-tech coatings based on polyurethane provide sufficient protection against all environmental influences.
© graphic arts BASF

SYSTEM DESİGN FEATURES

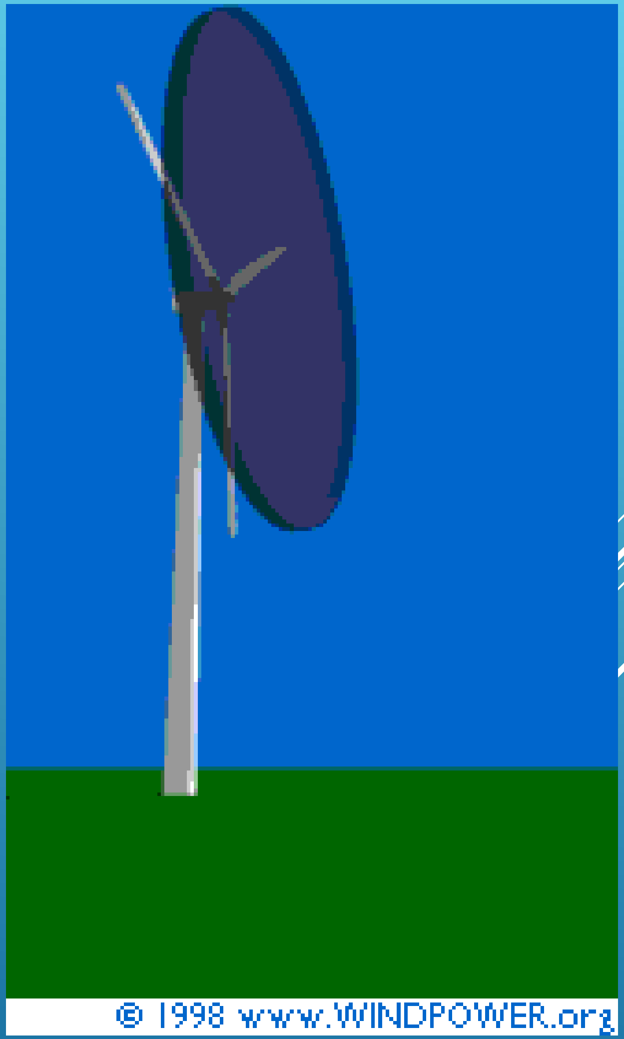
Wind turbine design involves a great many consideration. The process of designing a wind turbine involves the conceptual assembling of a large number of mechanical and electrical components into a machine which can convert the varying power in the wind into a useful form.


Blade Pitch
Controller
Gearbox
Generator
Low Speed
Shaft
High Speed
Shaft
Yaw
Controller

Design of Wind Energy System



- Winds are influenced by the ground surface at altitudes up to 100 meters.
- Wind is slowed by the surface roughness and obstacles.
- When dealing with wind energy, we are concerned with surface winds.
- A wind turbine obtains its power input by converting the force of the wind into a torque (turning force) acting on the rotor blades.
- The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed.
- The kinetic energy of a moving body is proportional to its mass (or weight). The kinetic energy in the wind thus depends on the density of the air, its mass per unit of volume.



Design Procedure

There are a number of approaches that can be taken towards wind turbine design, and there are many issues that must be considered. This section outlines the steps in one approach. The following sections provide more details on those steps. The key design steps include the following:

1) *Determine application*
2) *Review previous experience*
3) *Select topology*
4) *Preliminary loads estimate*
5) *Develop tentative design*
6) *Predict performance*
7) *Evaluate design*
8) *Estimate costs and cost of energy*
9) *Refine design*
10) *Build prototype*
11) *Test prototype*
12) *Design production machine*

The first step in designing a wind turbine is to determine the application. Wind turbines for producing bulk power for supply to large utility networks, for example, will have a different design than will turbines intended for operation in remote communities.

The application will be a major factor in choosing the size of the turbine, the type of generator it has, the method of control, and how it is to be installed and operated. For example, wind turbines for utility power will tend to be as large as practical. At the present time, such turbines have power ratings in the range of 500 to 1500 kW, with rotor diameters in the range of 38 m (125 ft) to 61 m (200 ft). Such machines are often installed in clusters or wind farms, and may be able to utilize fairly developed infrastructure for installation, operation and maintenance.

TOPOLOGY

There are a wide variety of possible overall layouts or 'topologies' for a wind turbine. Most of these relate to the rotor.

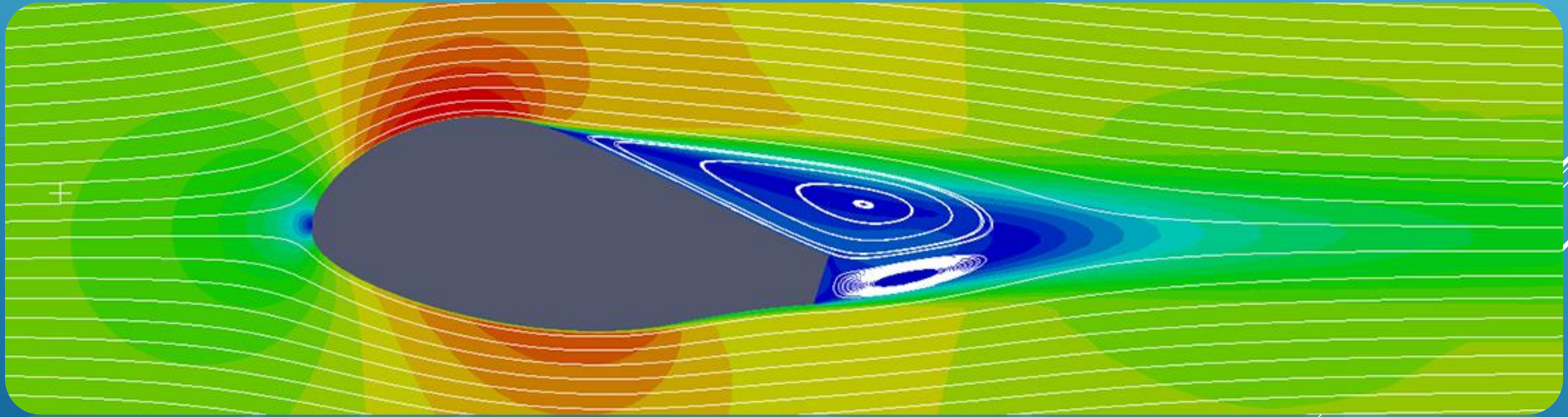
The most important choices are listed below:

- Rotor axis orientation: horizontal or vertical
- Power control: stall, variable pitch, controllable aerodynamic surfaces and yaw control
- Rotor position: upwind of tower or downwind of tower
- Yaw control: driven yaw, free yaw or fixed yaw
- Rotor speed: constant or variable
- Design tip speed ratio and solidity
- Type of hub: rigid, teetering, hinged blades or gimballed
- Number of blades

Early in the design process it is necessary to make a preliminary estimate of the loads that the turbine must be able to withstand

Aerodynamic Design

The aerodynamic design encompasses the selection of aerofoil family and optimization of the chord and twist distributions. The variation of thickness to chord ratio along the blade also has to be considered, but this ratio is usually set at the minimum value permitted by structural design considerations, as this minimizes drag losses.



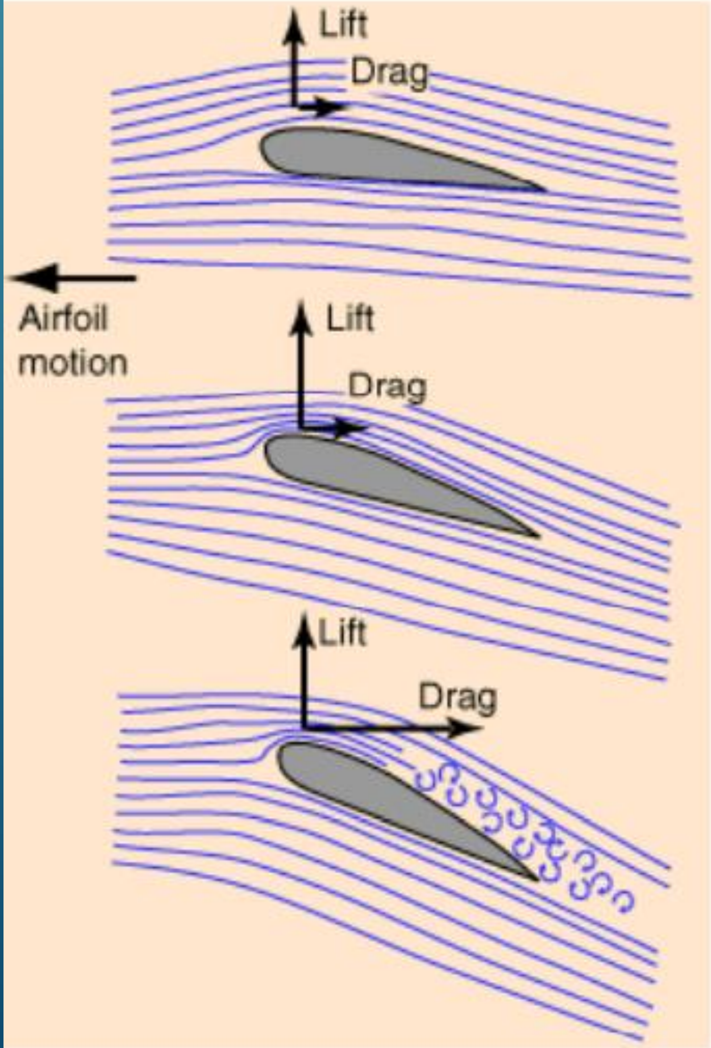
The moving blades of the wind turbine convert part of the power in the wind to rotational power

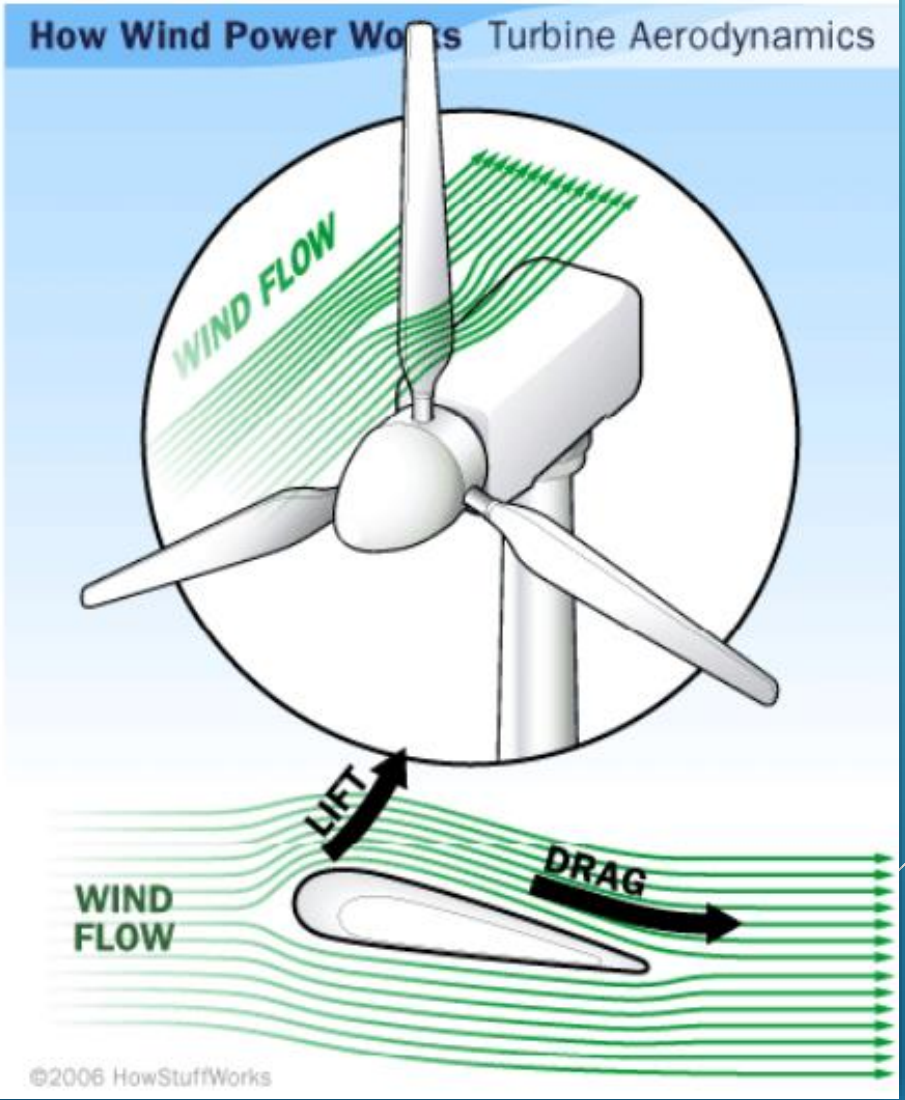
$$P = T . w$$ *(Torque)*

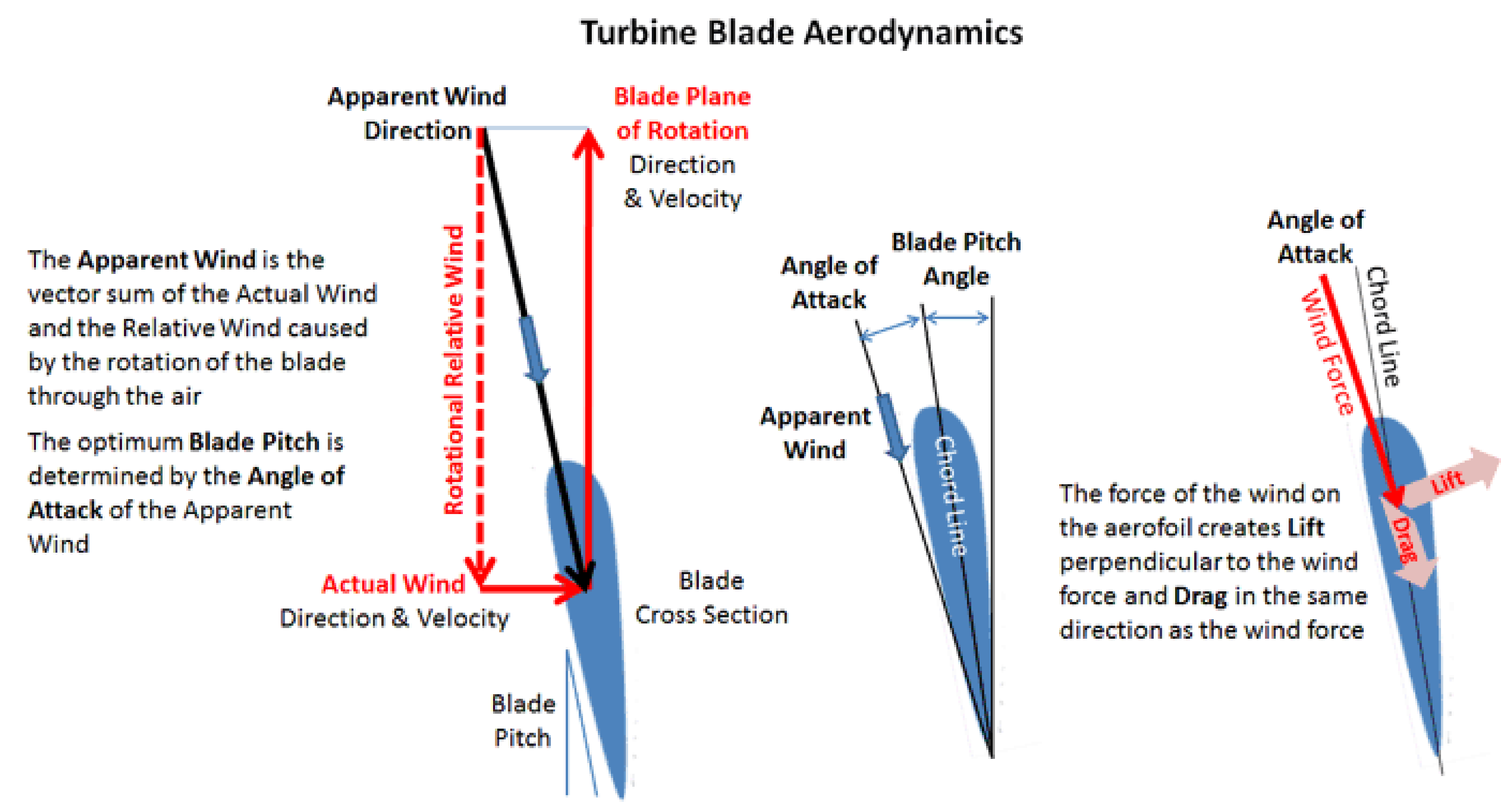
$$v = w . r$$ *(Linear velocity of the tip of the blade)*

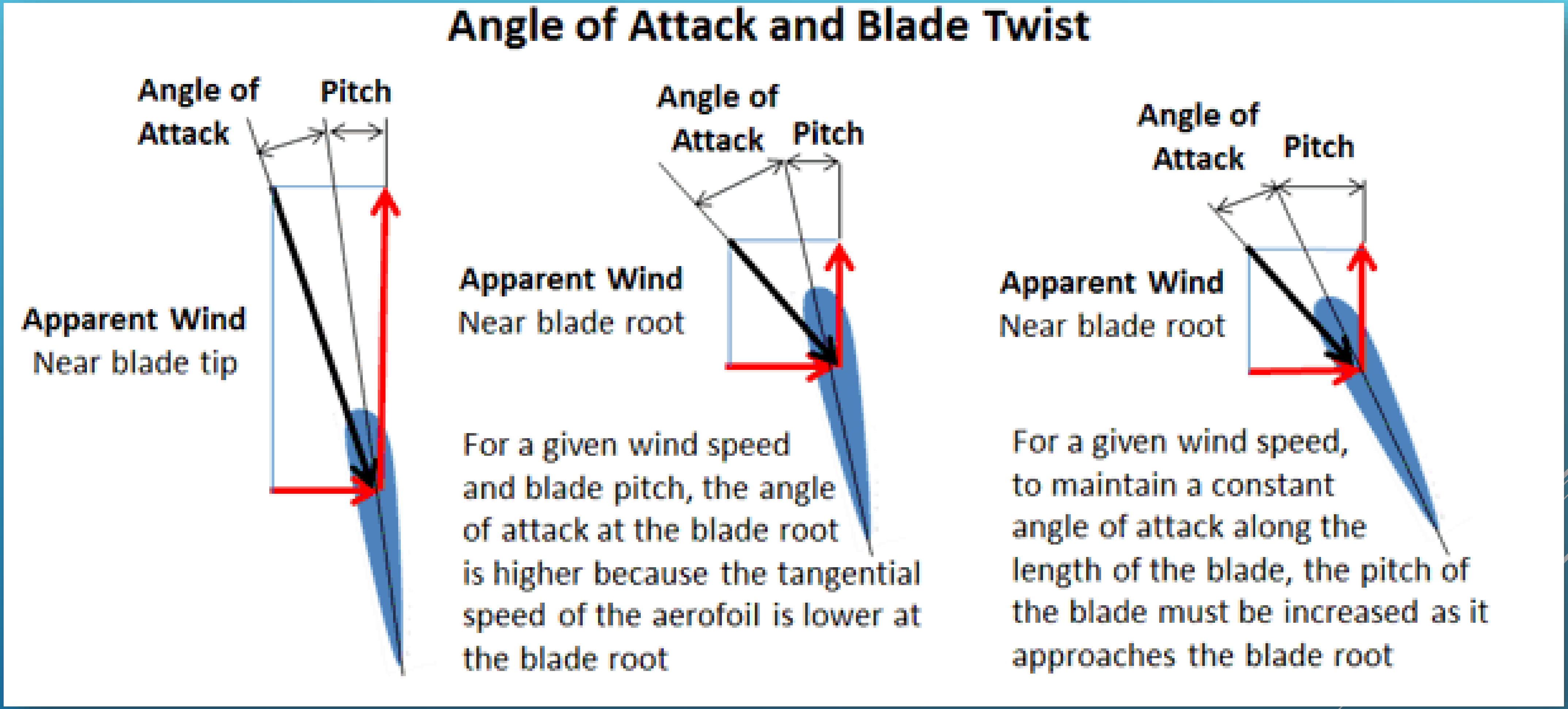
where T is the torque (N–m) and w (rad/s) is the angular velocity. The same power can be transferred with a large T and small w, or a small T and large -w . The torque–w characteristics of the rotor should be matched to the torque- w characteristics of the load

Lift and Drag Forces





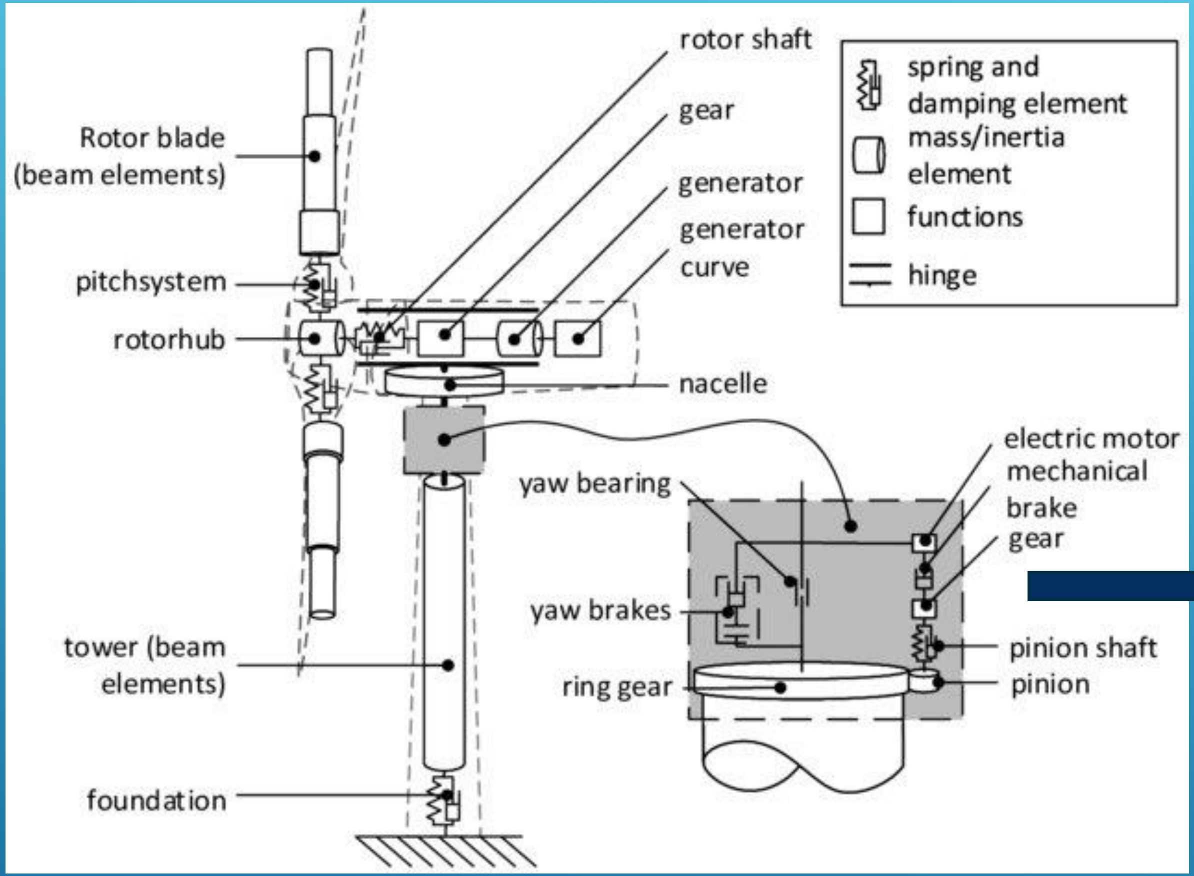

Turbine Blade Aerodynamics
Apparent Wind Direction
Blade Plane of Rotation Direction & Velocity
The Apparent Wind is the vector sum of the Actual Wind and the Relative Wind caused by the rotation of the blade through the air
The optimum Blade Pitch is determined by the Angle of Attack of the Apparent Wind
Rotational Relative Wind
Actual Wind Direction & Velocity
Blade Cross Section
Blade Pitch
Angle of Attack
Blade Pitch Angle
Apparent Wind
Chord Line
Angle of Attack
Wind Force
Chord Line
Lift
Drag
The force of the wind on the aerofoil creates Lift perpendicular to the wind force and Drag in the same direction as the wind force

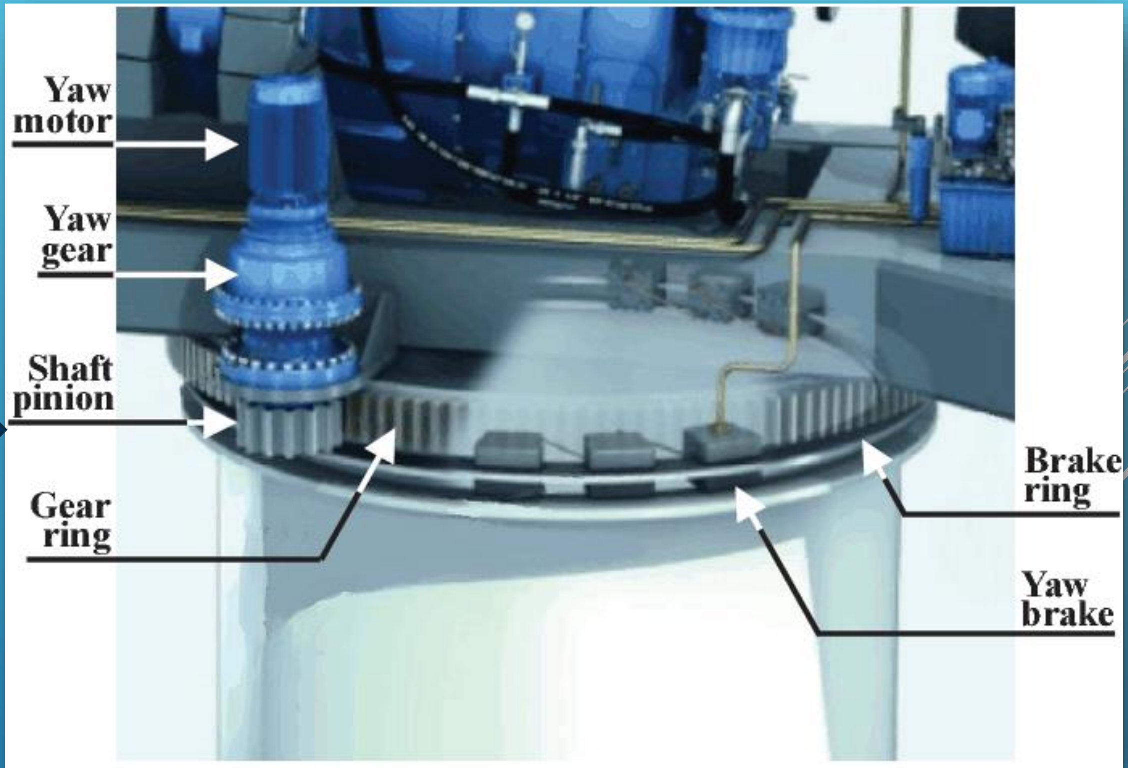

Angle of Attack and Blade Twist
Angle of Attack
Pitch
Apparent Wind
Near blade tip
Angle of Attack
Pitch
Apparent Wind
Near blade root
For a given wind speed and blade pitch, the angle of attack at the blade root is higher because the tangential speed of the aerofoil is lower at the blade root
Angle of Attack
Pitch
Apparent Wind
Near blade root
For a given wind speed, to maintain a constant angle of attack along the length of the blade, the pitch of the blade must be increased as it approaches the blade root

Blade Number

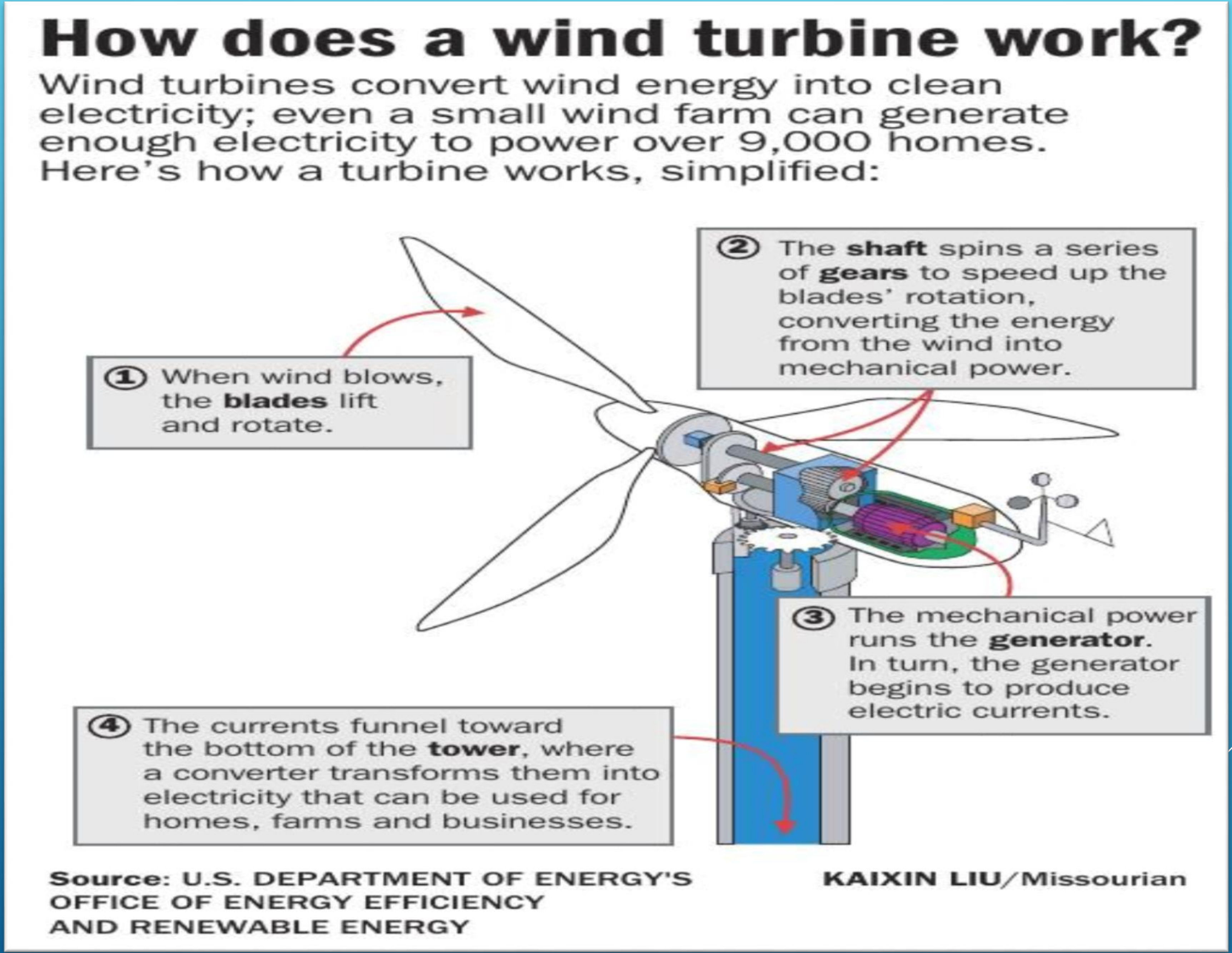
The number of rotor blades a wind turbine design has is generally determined by the aerodynamic efficiency and cost. The ideal wind turbine would have many thin rotor blades but most horizontal axis wind turbine generators have only one, two or three rotor blades. Increasing the number of rotor blades above three gives only a small increase in rotor efficiency but increases its cost, so more than three blades are usually not required.

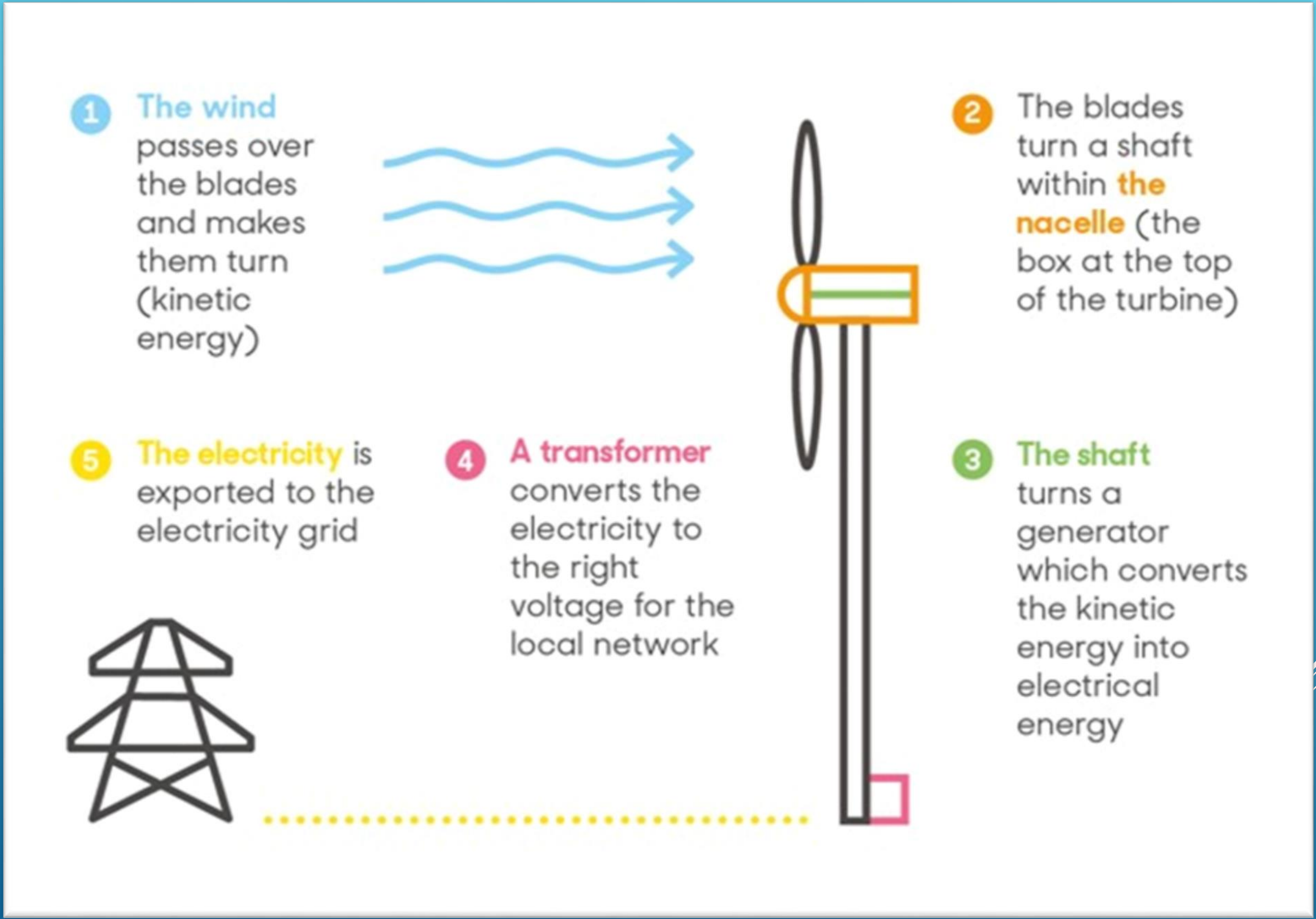
YAW SYSTEM

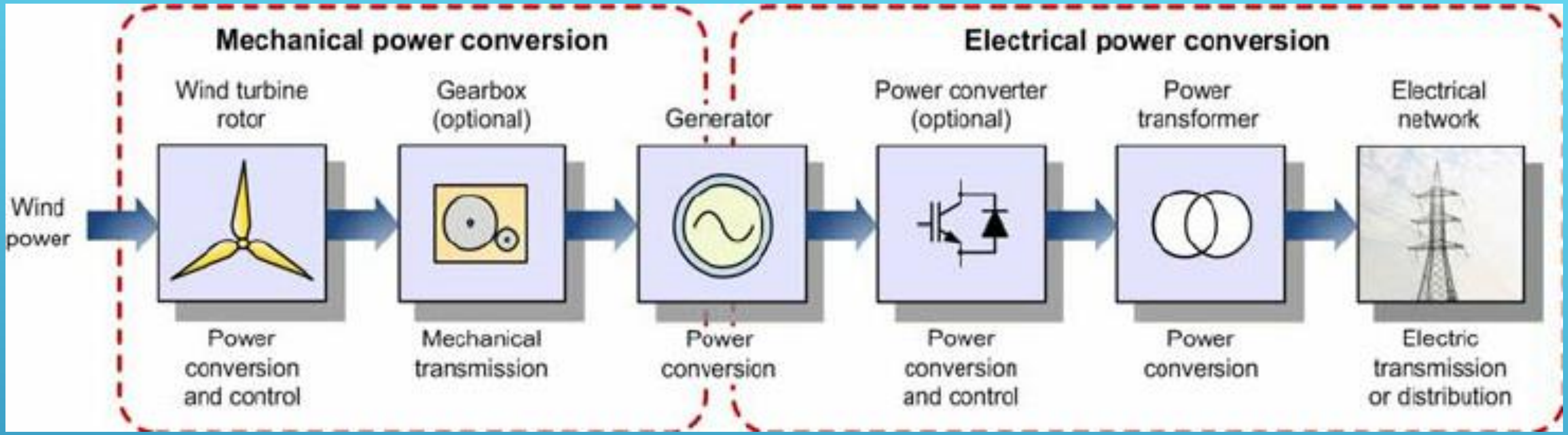


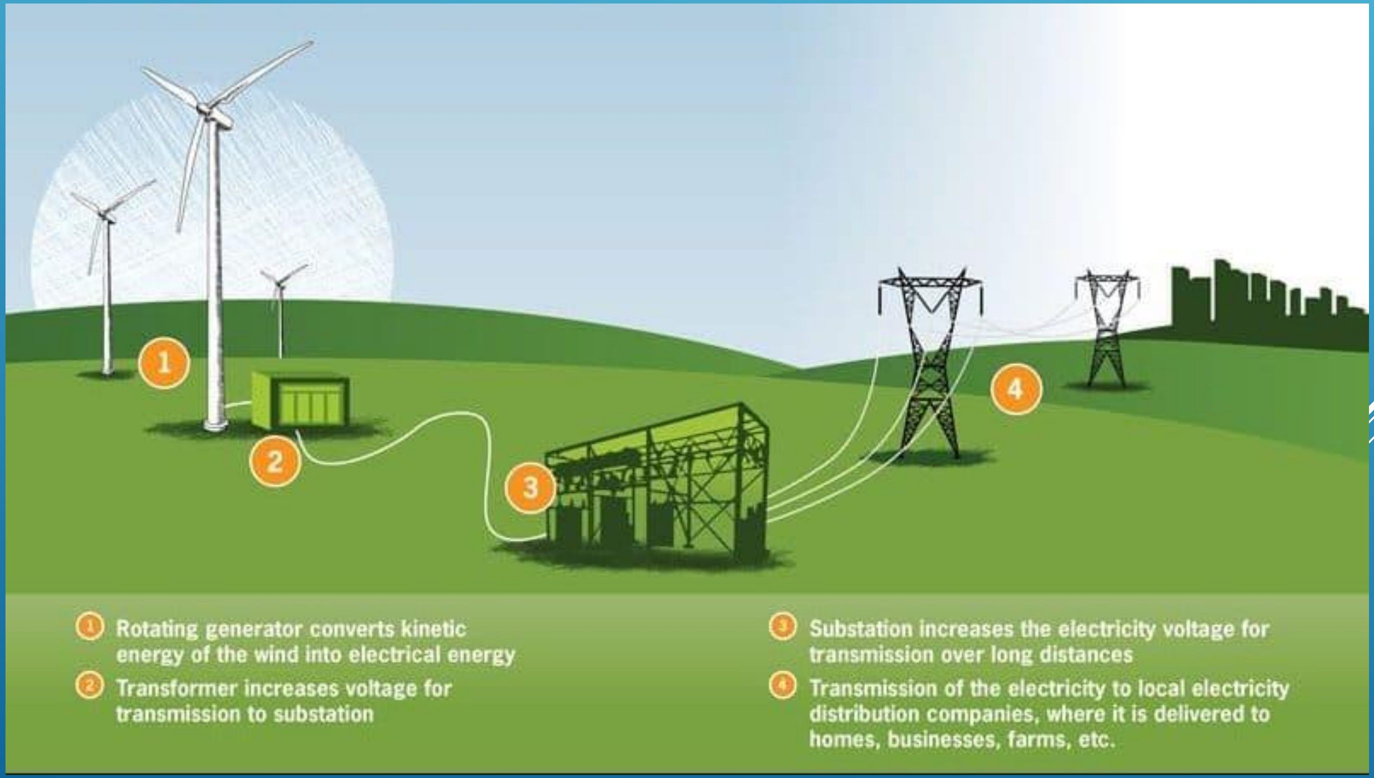


The yaw drive is the name given to the mechanism used to rotate the nacelle with respect to the tower on its slewing bearing, in order to keep the turbine facing into the wind and to unwind the power and other cables when they become excessively twisted.


How does a wind turbine work?
Wind turbines convert wind energy into clean electricity; even a small wind farm can generate enough electricity to power over 9,000 homes. Here's how a turbine works, simplified:
① When wind blows, the blades lift and rotate.
② The shaft spins a series of gears to speed up the blades' rotation, converting the energy from the wind into mechanical power.
③ The mechanical power runs the generator. In turn, the generator begins to produce electric currents.
④ The currents funnel toward the bottom of the tower, where a converter transforms them into electricity that can be used for homes, farms and businesses.
Source: U.S. DEPARTMENT OF ENERGY'S OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY
KAIXIN LIU/Missourian


1 The wind passes over the blades and makes them turn (kinetic energy)
2 The blades turn a shaft within the nacelle (the box at the top of the turbine)
3 The shaft turns a generator which converts the kinetic energy into electrical energy
4 A transformer converts the electricity to the right voltage for the local network
5 The electricity is exported to the electricity grid


Mechanical power conversion
Electrical power conversion
Wind turbine rotor
Gearbox (optional)
Generator
Power converter (optional)
Power transformer
Electrical network
Wind power
Power conversion and control
Mechanical transmission
Power conversion
Power conversion and control
Power conversion
Electric transmission or distribution


1
2
3
4
1 Rotating generator converts kinetic energy of the wind into electrical energy
2 Transformer increases voltage for transmission to substation
3 Substation increases the electricity voltage for transmission over long distances
4 Transmission of the electricity to local electricity distribution companies, where it is delivered to homes, businesses, farms, etc.

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