WIND ENERGY CONVERSION

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NON- CONVENTIONAL ENERGY
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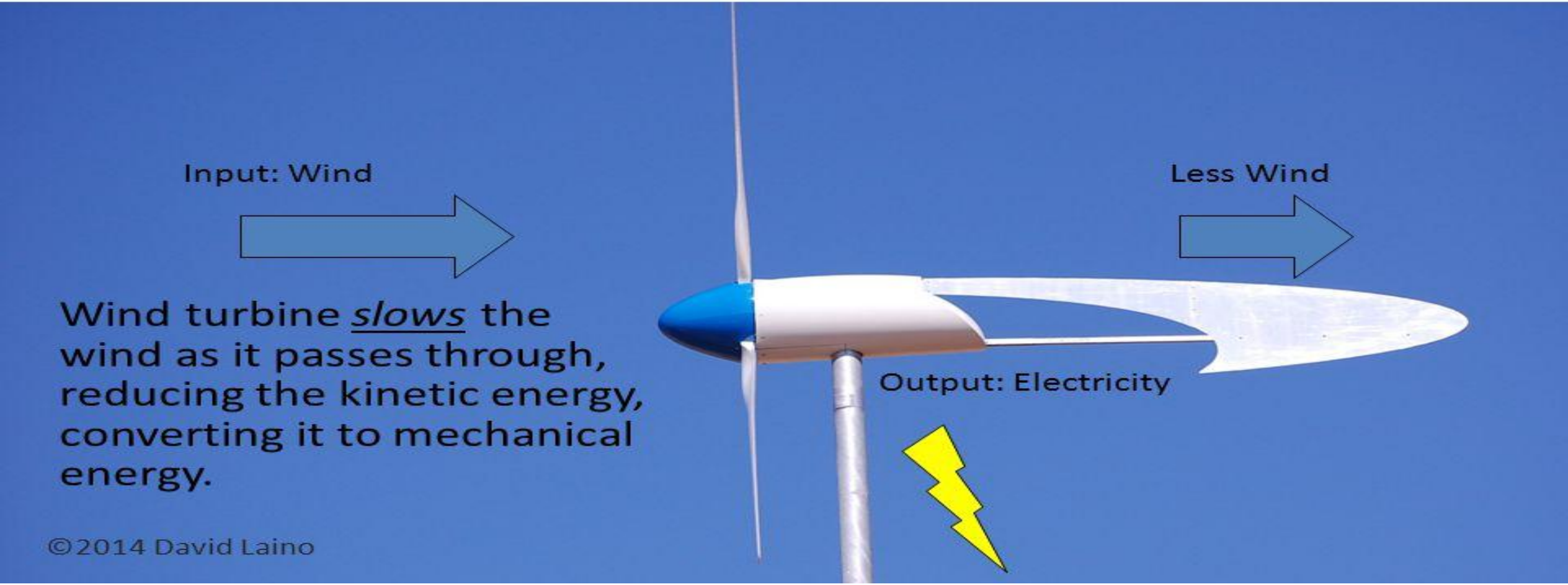
Lesson: What a wind turbine does

Convert the kinetic energy of the moving air into electrical energy



WIND ENERGY - PRINCIPLES

- Wind turbines are mounted on a tower to capture the most energy.
- At 100 feet (30 meters) or more aboveground, they can take advantage of the faster and less turbulent wind.
- Turbines catch the wind's energy with their propeller-like blades.
- Usually, two or three blades are mounted on a shaft to form a rotor.
- Wind turbines convert the kinetic energy in the wind into mechanical power.

Grid Connection

- We have seen in the previous section the generation of electrical power by the flow of water through turbines.
- The generated electrical power could be dc or ac depending on the type of generator.
- After the power is generated, it needs to be transmitted and distributed to consumers by connecting it to the grid.

Lift & Drag Forces

- The ***Lift Force*** is perpendicular to the direction of motion. We want to make this force BIG.

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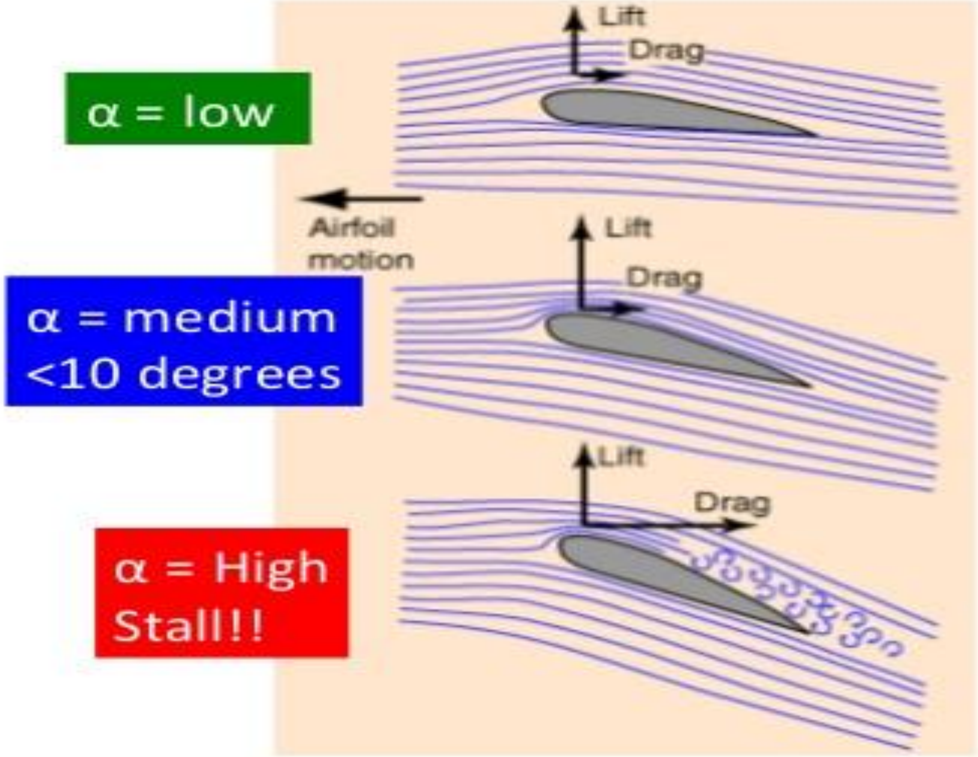
- The ***Drag Force*** is parallel to the direction of motion. We want to make this force small.



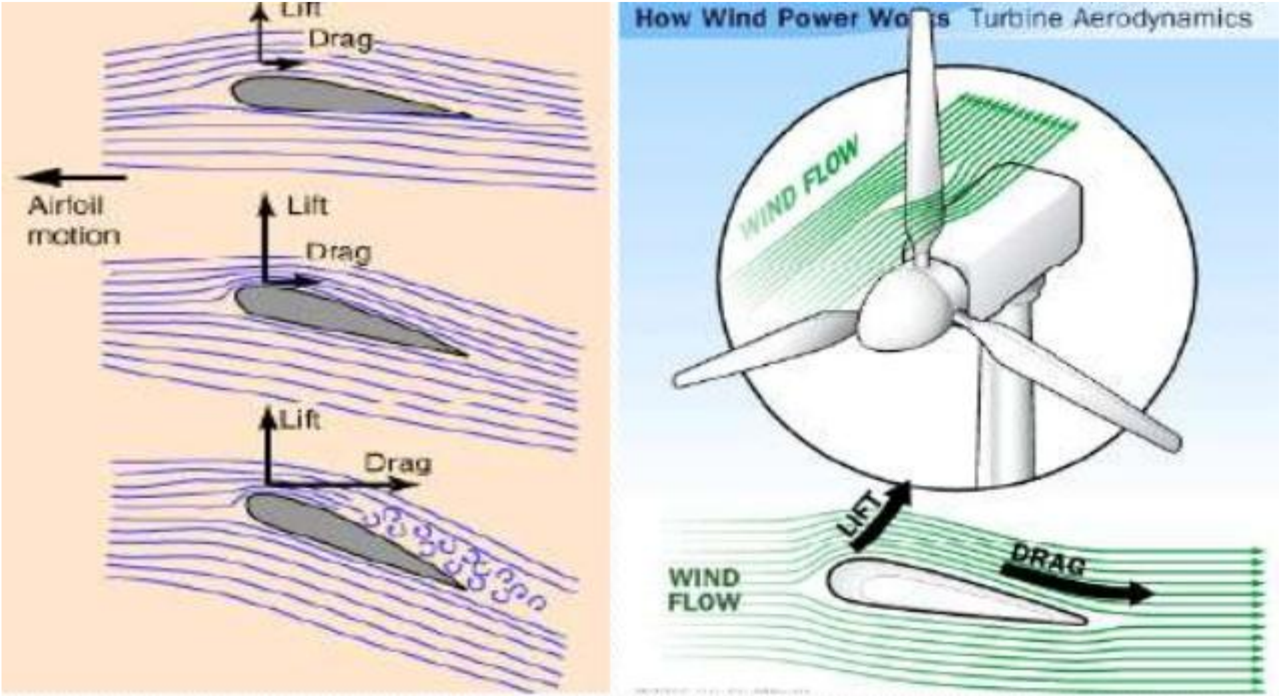
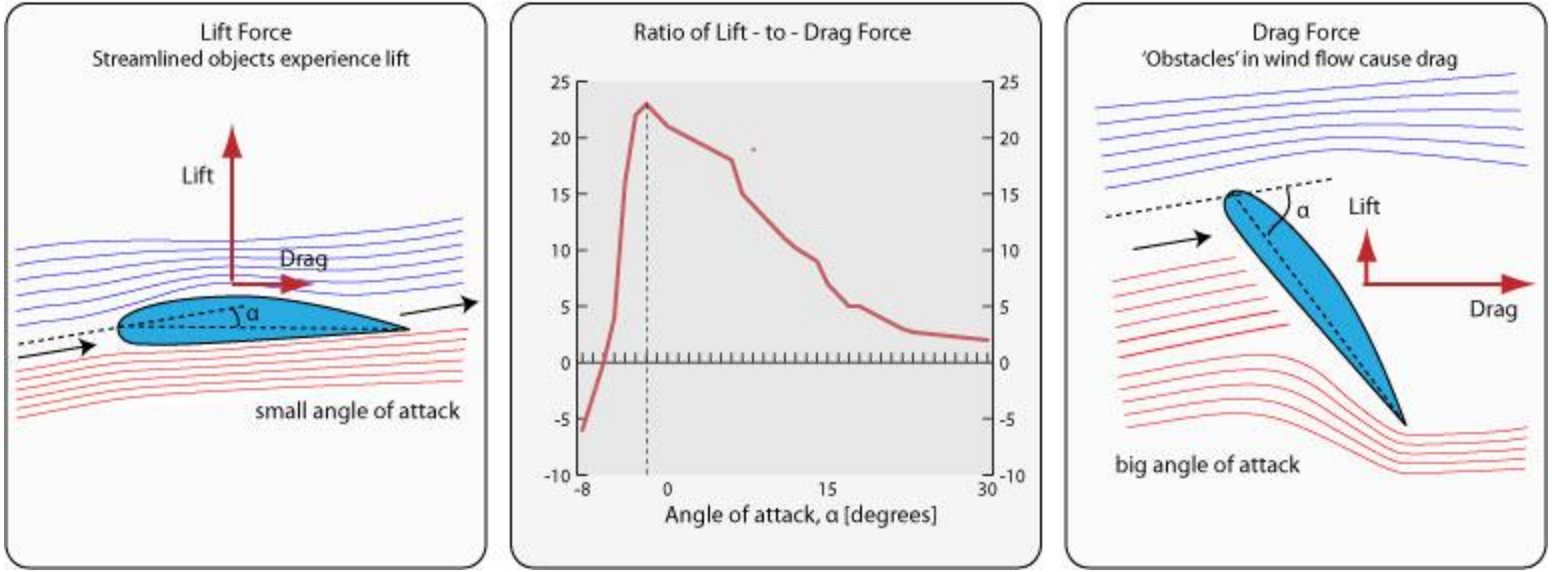
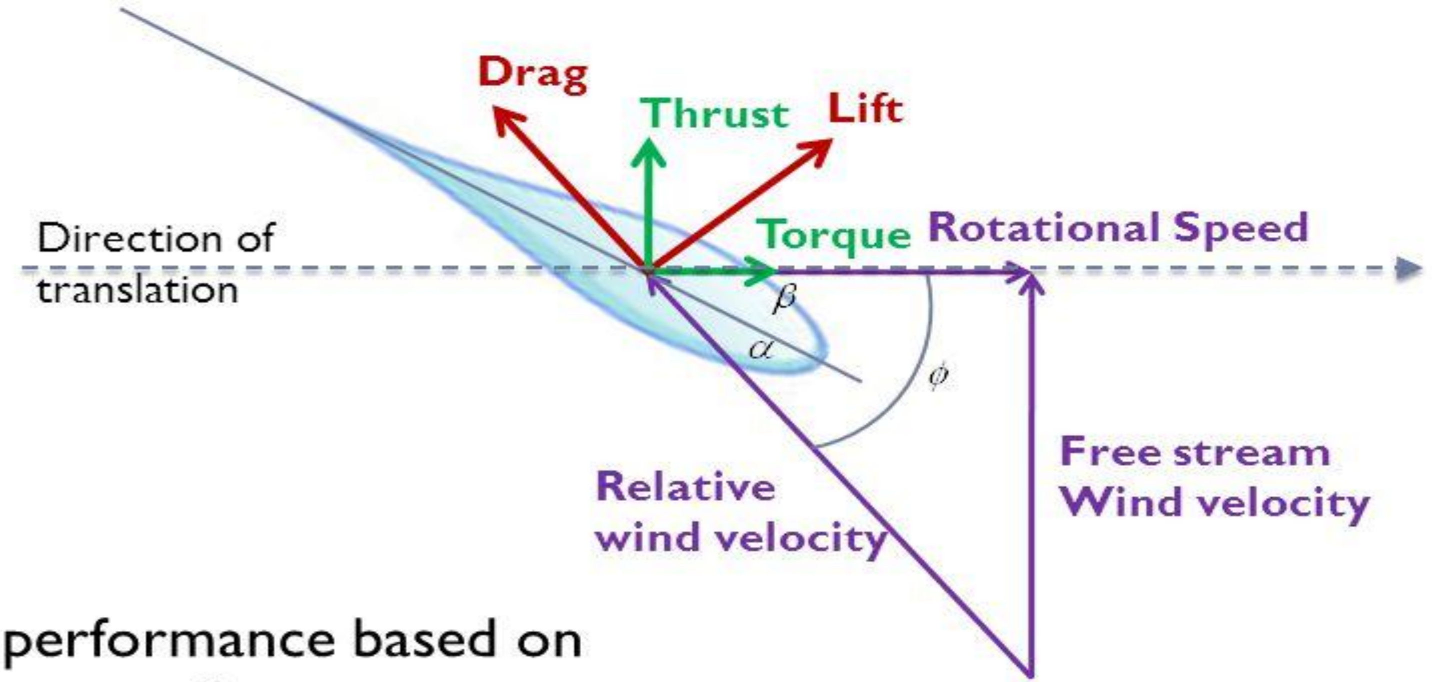


Figure 7:combined effect of lift and drag force on turbine blade [3]


Lift Force
Streamlined objects experience lift
Lift
Drag
α
small angle of attack
Ratio of Lift - to - Drag Force
25
20
15
10
5
0
-5
-10
-8
0
15
30
Angle of attack, α [degrees]
Drag Force
'Obstacles' in wind flow cause drag
α
Lift
Drag
big angle of attack

DRAG TYPE	LIFT TYPE
Low speed turbines	High speed turbines
Rotor shaft torque is comparatively high.	Rotor shaft torque is comparatively low.
Greater blade area is required	Aerofoil type blades are required to minimize the effect of drag forces
Blades are fabricated using curved plates	Blades are having high thickness to chord ratio to produce high lift

Performance parameters



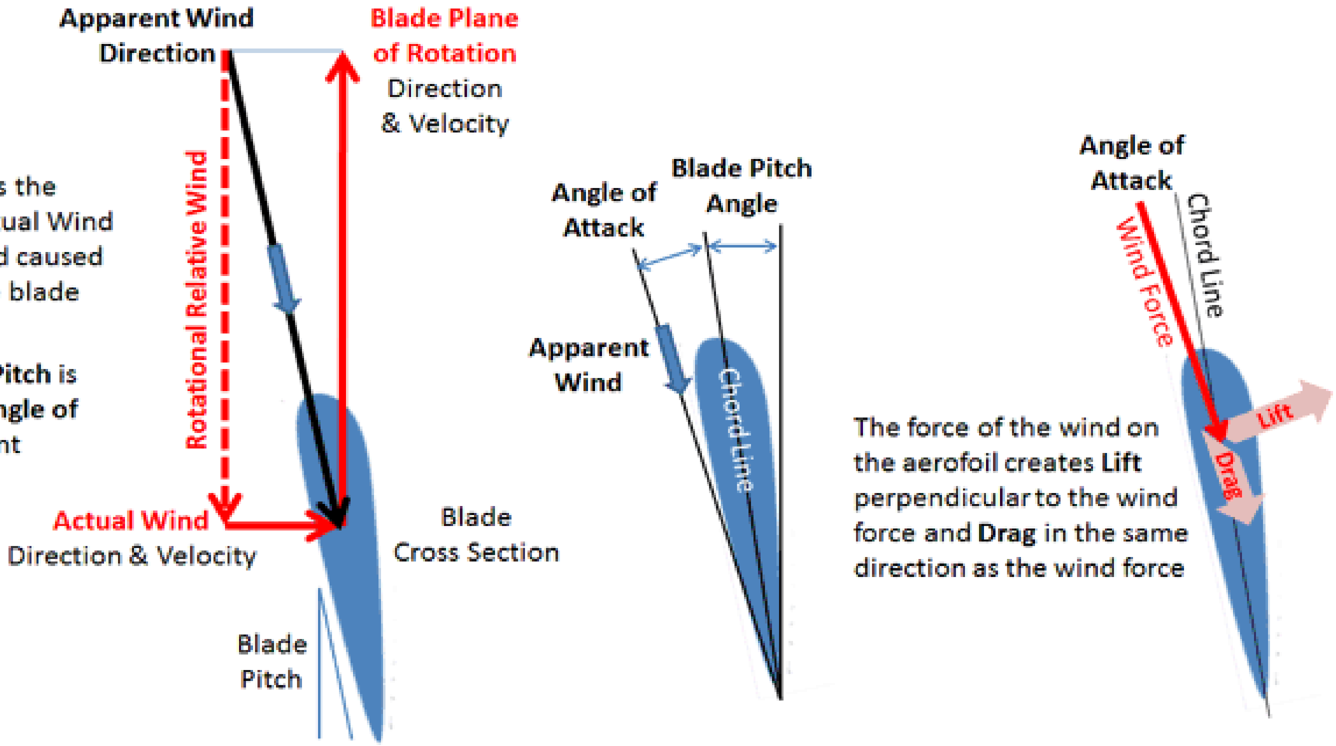
Wind turbine performance based on

- lift and drag coefficients
- Pitch angle, β - angle btwn chord line and plane of rotation
- Angle of attack, α - angle btwn blade and relative wind, which

Turbine Blade Aerodynamics

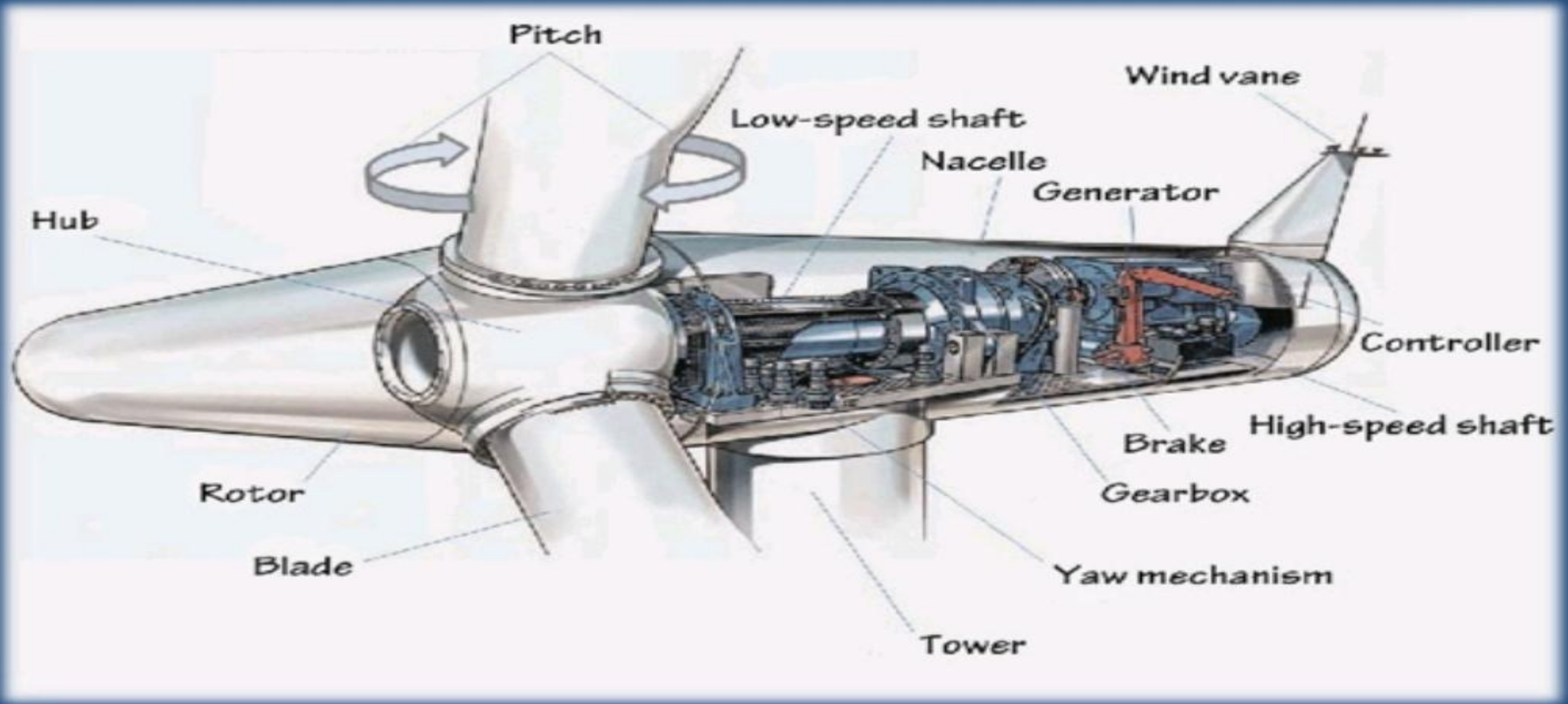
The **Apparent Wind** is the vector sum of the Actual Wind and the Relative Wind caused by the rotation of the blade through the air

The optimum **Blade Pitch** is determined by the **Angle of Attack** of the Apparent Wind



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

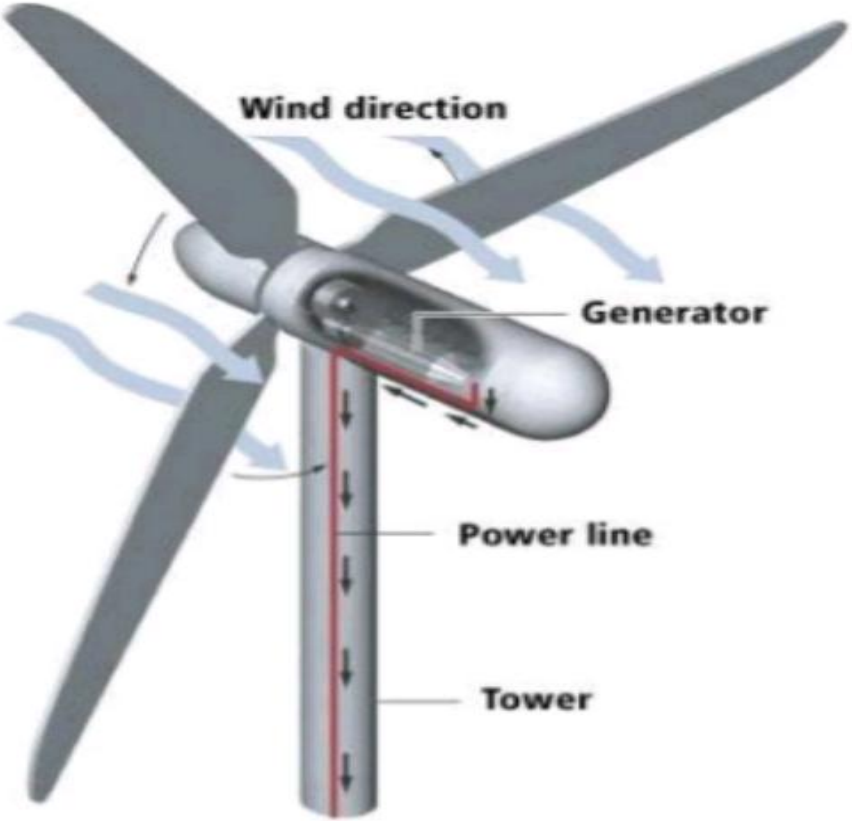
PARTS OF WIND TURBINE



- Electricity generation is the most important application of wind energy today. The
- major components of a commercial wind turbine are:
- 1. Tower
- 2. Rotor
- 3. High speed and low speed shafts
- 4. Gear box
- 5. Generator
- 6. Sensors and yaw drive
- 7. Power regulation and controlling units
- 8. Safety systems

TURNING WIND INTO ELECTRICITY

Wind power is the fastest-growing energy source in the world. Turbines powered by wind are mounted on towers 100 or more feet above the ground, where the wind is faster and less turbulent.



HOW IT WORKS

1. When the blades start moving, they spin a shaft that leads to a generator.
2. The generator consists of a conductor, such as a coiled wire, that is surrounded by magnets.
3. The rotating shaft turns the magnets around the conductor and generates an electrical current.
4. Sensors cause the top of the turbine to rotate to face into the wind and the blades change their angle to best catch the wind. The blades are flexible and stop spinning if wind is too strong.

Source: U.S. Department of Energy

SEATTLE P-I

Wind Energy Conversion

Wind energy conversion systems convert wind energy into electrical energy, which is then fed into electrical grid.

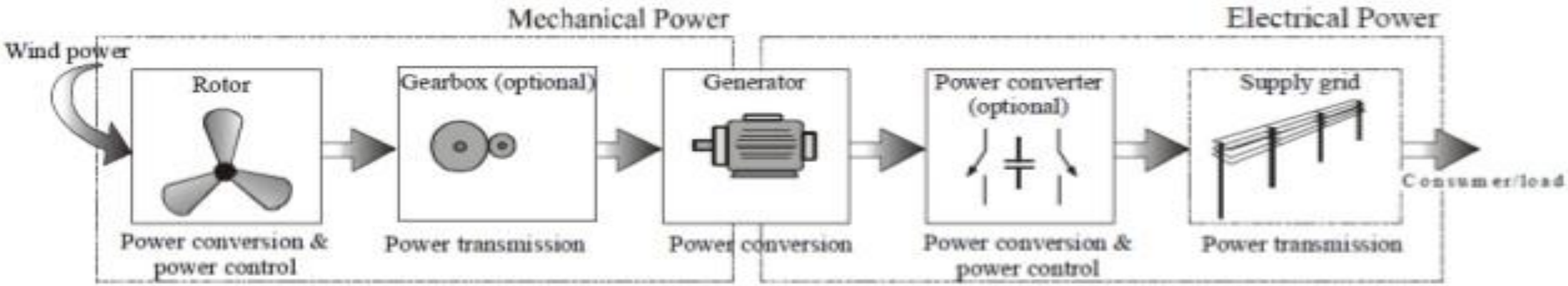
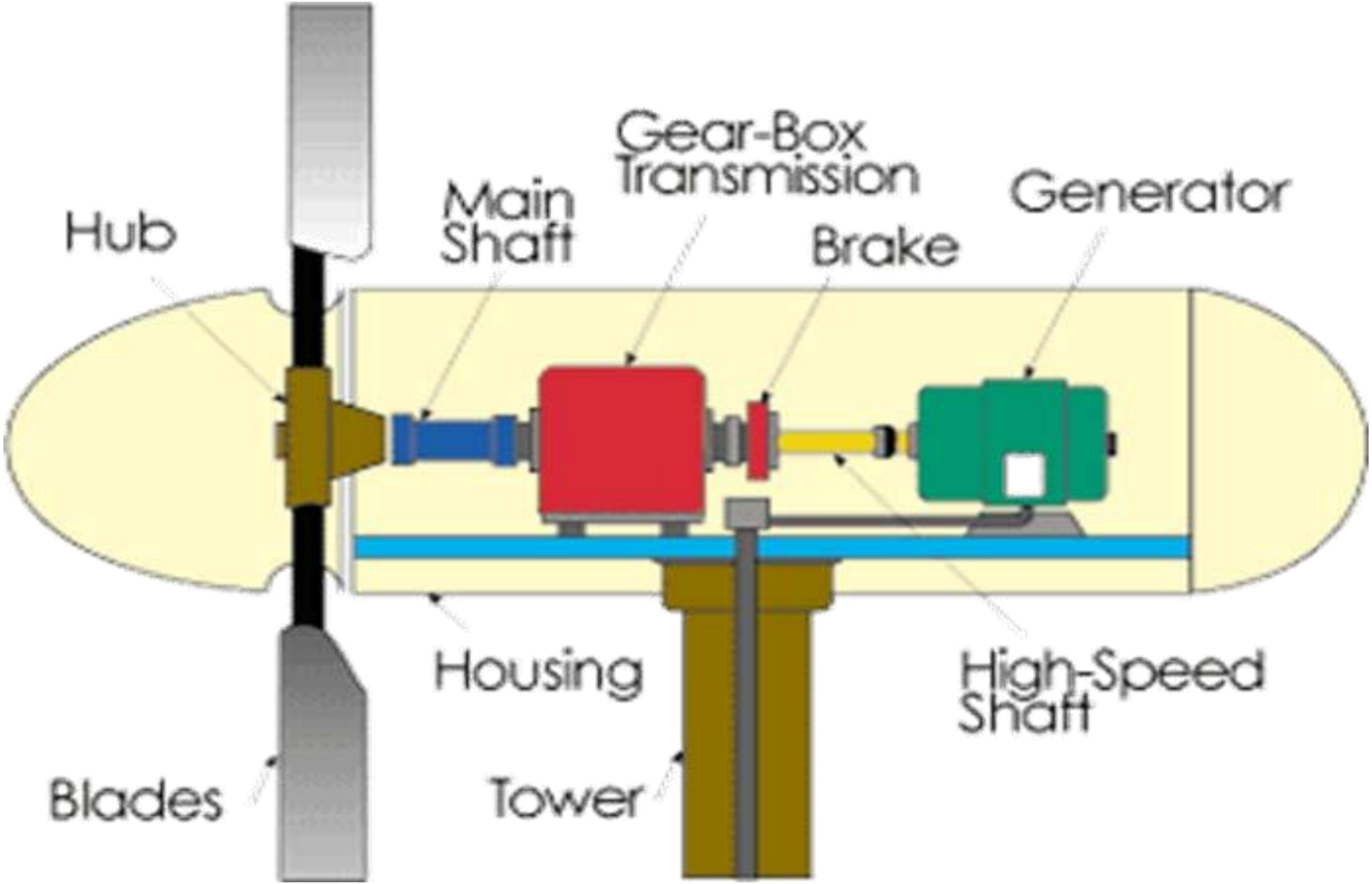


Fig. 4. Converting wind power to electrical power in a wind turbine

- The turbine rotor, gear box and generator are the main three components for energy conversion.
- Rotor converts wind energy to mechanical energy.
- Gear box is used to adapt to the rotor speed to generator speed.
- Generator with the variable speed wind turbine along with electronic inverter absorbs mechanical power and convert to electrical energy.
- The power converter can not only transfer the power from a wind generator, but also improve the stability and safety of the system.


Gear-Box
Transmission
Main
Shaft
Generator
Hub
Brake
Housing
High-Speed
Shaft
Blades
Tower

Rotor:

- The portion of the wind turbine that collects energy from the wind is called the rotor.
- The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades.
- The blades are attached to the hub, which in turn is attached to the main shaft.

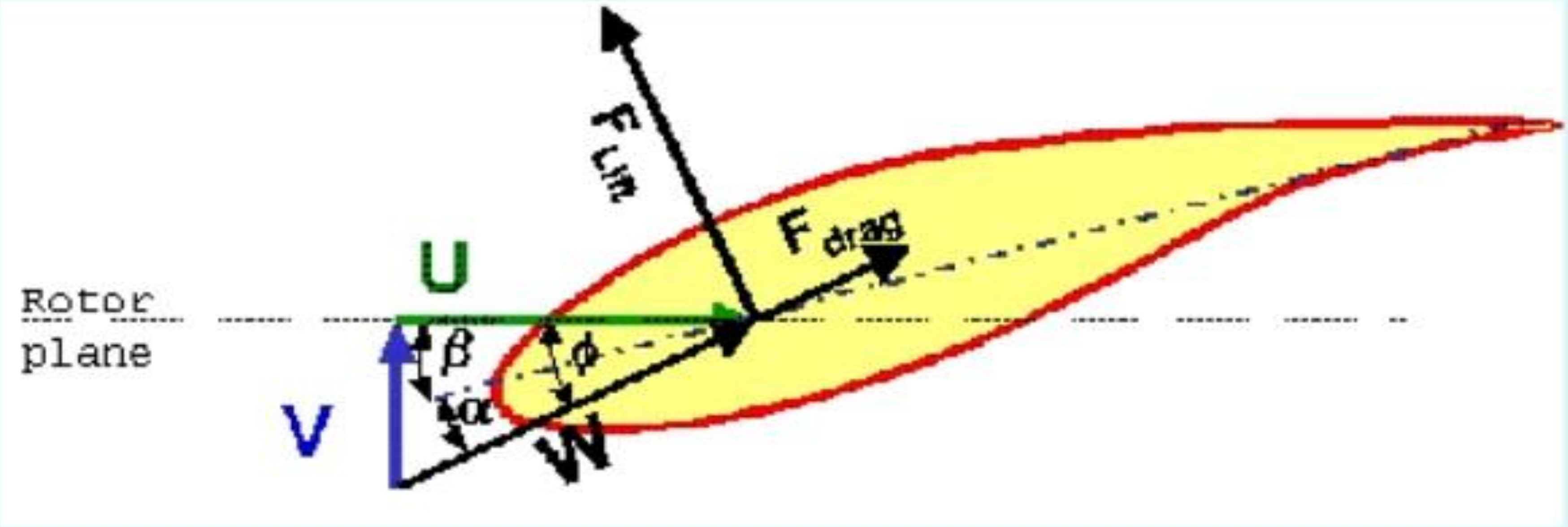
Drag Design:

- Blade designs operate on either the principle of drag or lift.
- For the drag design, the wind literally pushes the blades out of the way.
- Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities.

Lift Design:

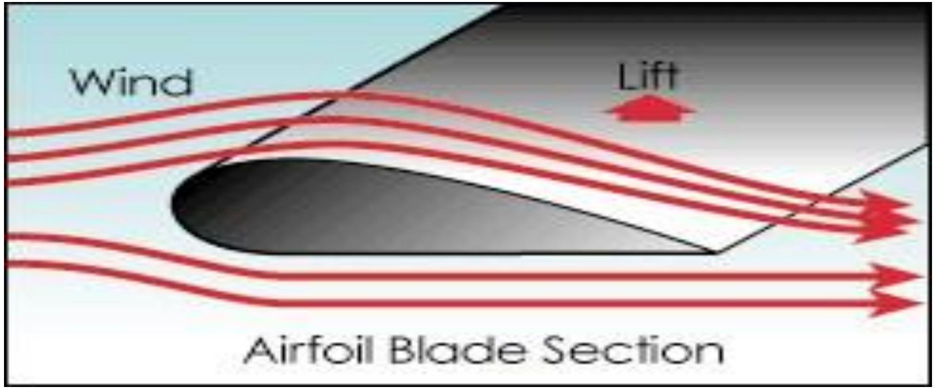
- The lift blade design employs the same principle that enables airplanes, kites and birds to fly.
- The blade is essentially an airfoil, or wing.
- When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces.
- The pressure at the lower surface is greater and thus acts to "lift" the blade.
- When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion.
- Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation

Blade



Many Different Rotors...

Following figure gives an idea about the drag and lift principle



- **Tip Speed Ratio:**
- The tip-speed is the ratio of the rotational speed of the blade to the wind speed.
- The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed.

- Electricity generation requires high rotational speeds.
- Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1.
- Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.
- The number of blades that make up a rotor and the total area they cover affect wind turbine performance.
- For a lift-type rotor to function effectively, the wind must flow smoothly over the blades.
- To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it.
- It is because of this requirement that most wind turbines have only two or three blades on their rotors.

Generator:

- The generator is what converts the turning motion of a wind turbine's blades into electricity.
- Inside this component, coils of wire are rotated in a magnetic field to produce electricity.
- Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings.
- The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.
- It is important to select the right type of generator to match intended use.

- Most home and office appliances operate on 240 volt, 50 cycles AC.
- Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC.
- Storage systems using batteries store DC and usually are configured at voltages of between 12 volts and 120 volts.
- Generators that produce AC are generally equipped with features to produce the correct voltage of 240 V and constant frequency 50 cycles of electricity, even when the wind speed is fluctuating.
- DC generators are normally used in battery charging applications and for operating DC appliances and machinery.
- They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Transmission:

- The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed.
- Generators typically require rpm's of 1,200 to 1,800.
- As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production.
- Some DC-type wind turbines do not use transmissions.
- Instead, they have a direct link between the rotor and generator.
- These are known as direct drive systems.
- Without a transmission, wind turbine complexity and maintenance requirements are reduced.

But a much larger generator is required to deliver the same power output as the AC-type wind turbines.

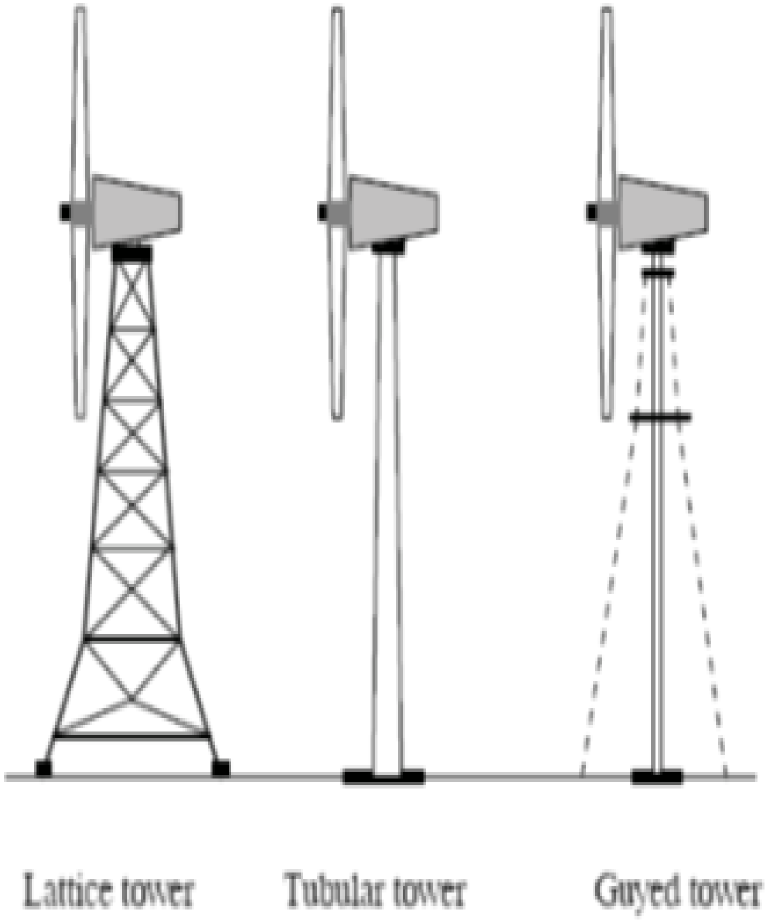
Induction generators

- Most of the wind turbines are equipped with induction generators.
- They are simple and rugged in construction and offer impressive efficiency under varying operating conditions.
- Induction machines are relatively inexpensive and require minimum maintenance and care.
- Characteristics of these generators like the over speed capability make them suitable for wind turbine application.
- As the rotor speed of these generators is not synchronized, they are also called asynchronous generators.
- Induction machines can operate both in motor and generator modes.

Tower:

- The tower on which a wind turbine is mounted is not just a support structure.
- It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations.
- Maximum tower height is optional in most cases, except where zoning restrictions apply.
- The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use.
- Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds.

- Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.
- Towers for small wind systems are generally "guyed" designs.
- This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect.
- These towers cost less than freestanding towers, but require more land area to anchor the guy wires.
- the major types of towers used in modern turbines are: lattice tower, tubular steel tower and guyed tower
- the lattice towers are fabricated with steel bars joined together to form the structure as shown in the fig:
- .



- Lattice towers consume only half of the material that is required for a similar tubular tower.
- Tubular towers are fabricated by joining tubular sections of 10 to 20 m length. Circular cross-section ,can offer optimum bending resistance in all directions
- Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt-up towers

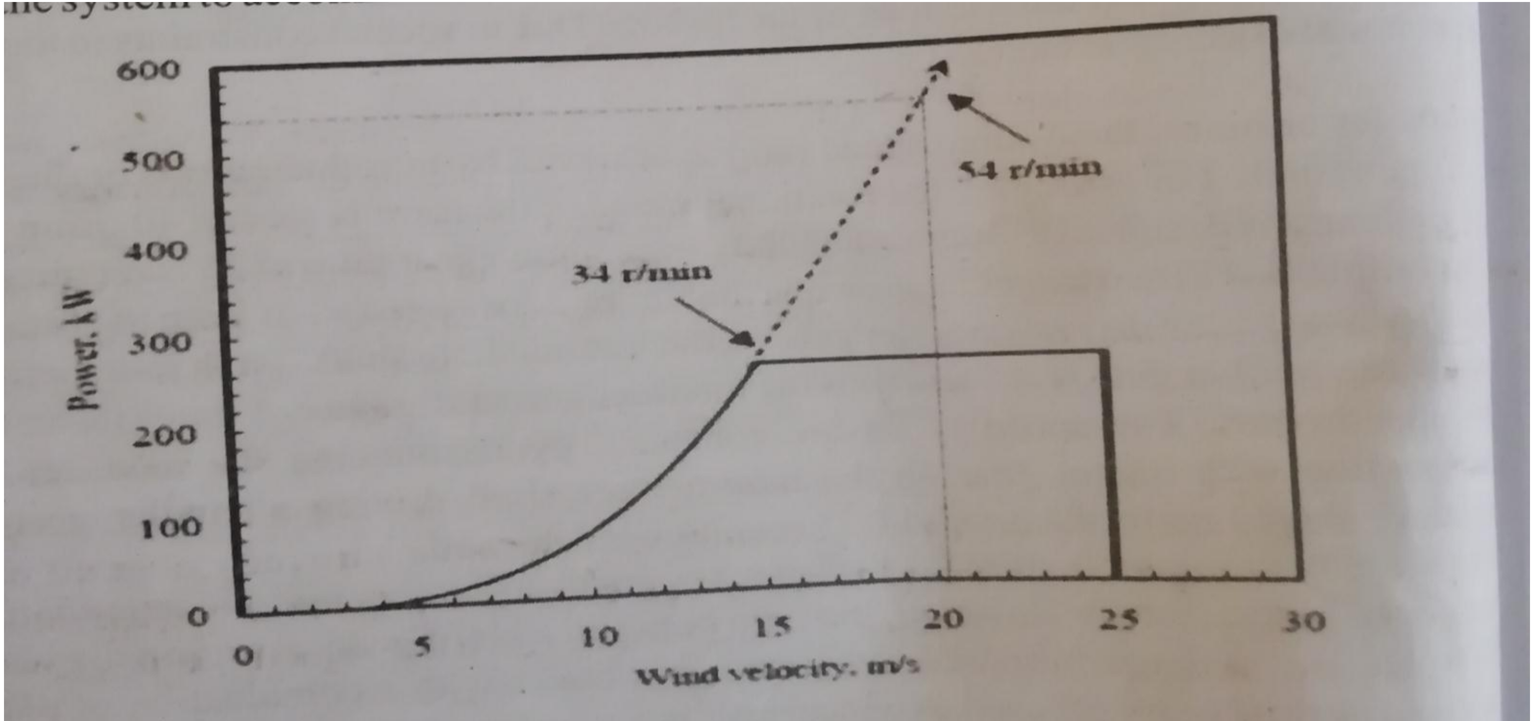
Gear box

- Gear box is an important component in the power trains of a wind turbine.
- Speed of a typical wind turbine rotor may be 30 to 50 r/min whereas, the optimum speed of generator may be around 1000 to1500 r/min.
- Hence, gear trains are to be introduced in the transmission line to manipulate the speed according to the requirement of the generator.
- An ideal gear system should be designed to work smoothly and quietly–even under adverse climatic and loading conditions–throughout the life span of the turbine. Due to special constraints in the nacelle, the size is also a critical factor.
- In smaller turbines, the desired speed ratio is achieved by introducing two or three staged gearing system
- If higher gear ratios are required, a further set of gears on another intermediate shaft can be introduced in the system

- However, the ratio between a set of gears are normally restricted to 1:6.
- Hence, in bigger turbines, integrated gear boxes with a combination of planetary gears and normal gears are used.
- A typical gear box may have primary stage planetary gears combined with a secondary two staged spur gears to raise the speed to the desired level.
- By introducing the planet gears, the gear box size can be considerably reduced. Moreover, planet gears can reliably transfer heavy loads.

Power regulation

Power curve of a typical wind turbine is shown in Fig



Power curve of a typical wind turbine

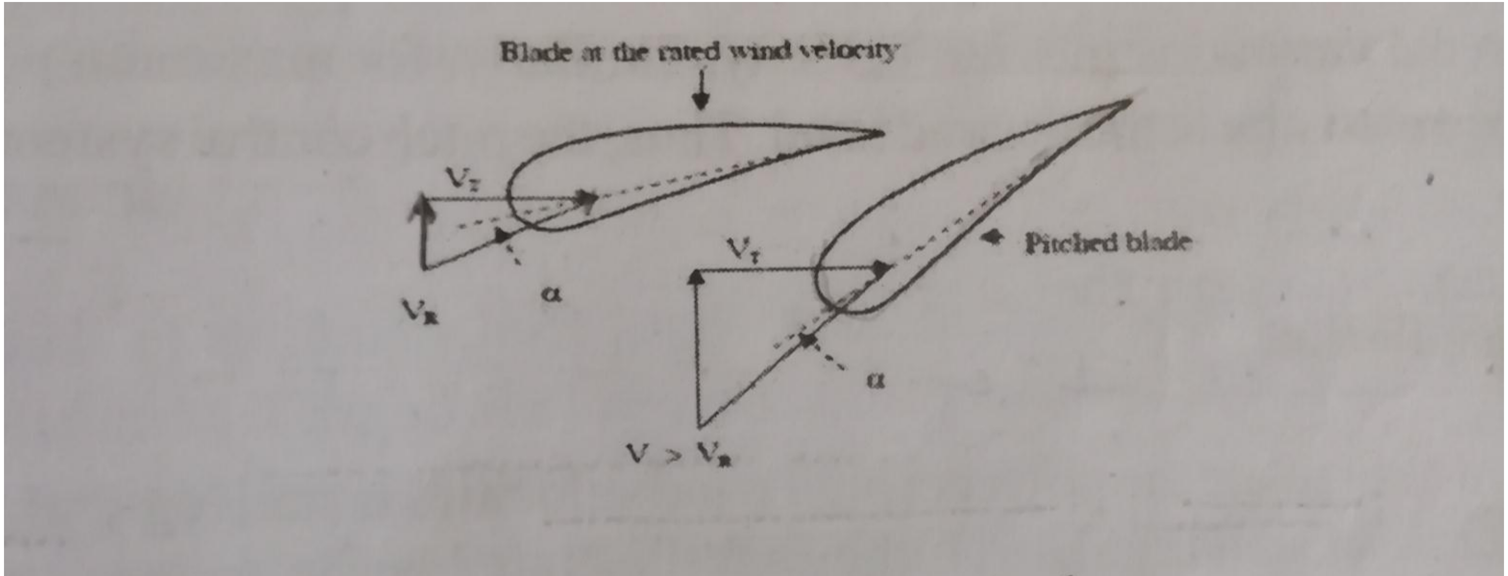
- The turbine starts generating power as the wind speeds crosses its cut-in velocity of 3.5 m/s. The power increases with the wind speed up to the rated wind velocity of 15 m/s, at which it generates its rated power of 250 kW. Between the rated velocity and cut-out velocity (25 m/s), the system generates the same rated power of 250 kW, irrespective of the increase in wind velocity. At wind velocities higher than the cut-off limit, the turbine is not allowed to produce any power due to safety reasons.

  Power generated by the turbine is regulated to its rated level between the rated and cut-out wind speeds. If not regulated, the power would have been increased with wind speed as indicated by the dotted lines as in the figure.

Speed of the rotor also increases with the wind velocity

- Speed of the rotor also increases with the wind velocity.
- In the above example, the rotor speed increases from 34 r/min to 54 r/min, while the velocity changes from 15 m/s to 20 m/s.
- With further increase in velocity, the rotor may further speed up, finally reaching the run-away situation. It should also be noted that this increase in speed occurs in a short span of time, resulting in rapid acceleration.
- Hence it is vital that the power of the turbine should be regulated at constant level, at velocities higher than the rated wind speed.
- The common methods to regulate the power are pitch control, stall control, active stall control and yaw control.

wind turbine blades offer its maximum aerodynamic performance at a given angle of attack. The angle of attack of a given blade profile changes with the wind velocity and rotor speed. Principle of pitch control is illustrated in Fig



Principle of pitch control

- **VR is the rated wind velocity, VT is** the velocity of the blades due to its rotation and α is the angle of attack.
- In a pitch controlled wind turbine, the electronic sensors constantly monitors the variations in power produced by the system. The output power is checked several times in a second. According to the variations in power output, the pitch control mechanism is activated to adjust the blade pitch at the desired angle as described below.
- Between the cut-in and rated wind speeds, the turbine is made to operate at its maximum efficiency by adjusting the blade pitch to the optimum angle of attack.
- As the wind velocity exceeds VR, the control mechanism change the blade pitch resulting in changes in the angle of attack as shown in the figure.

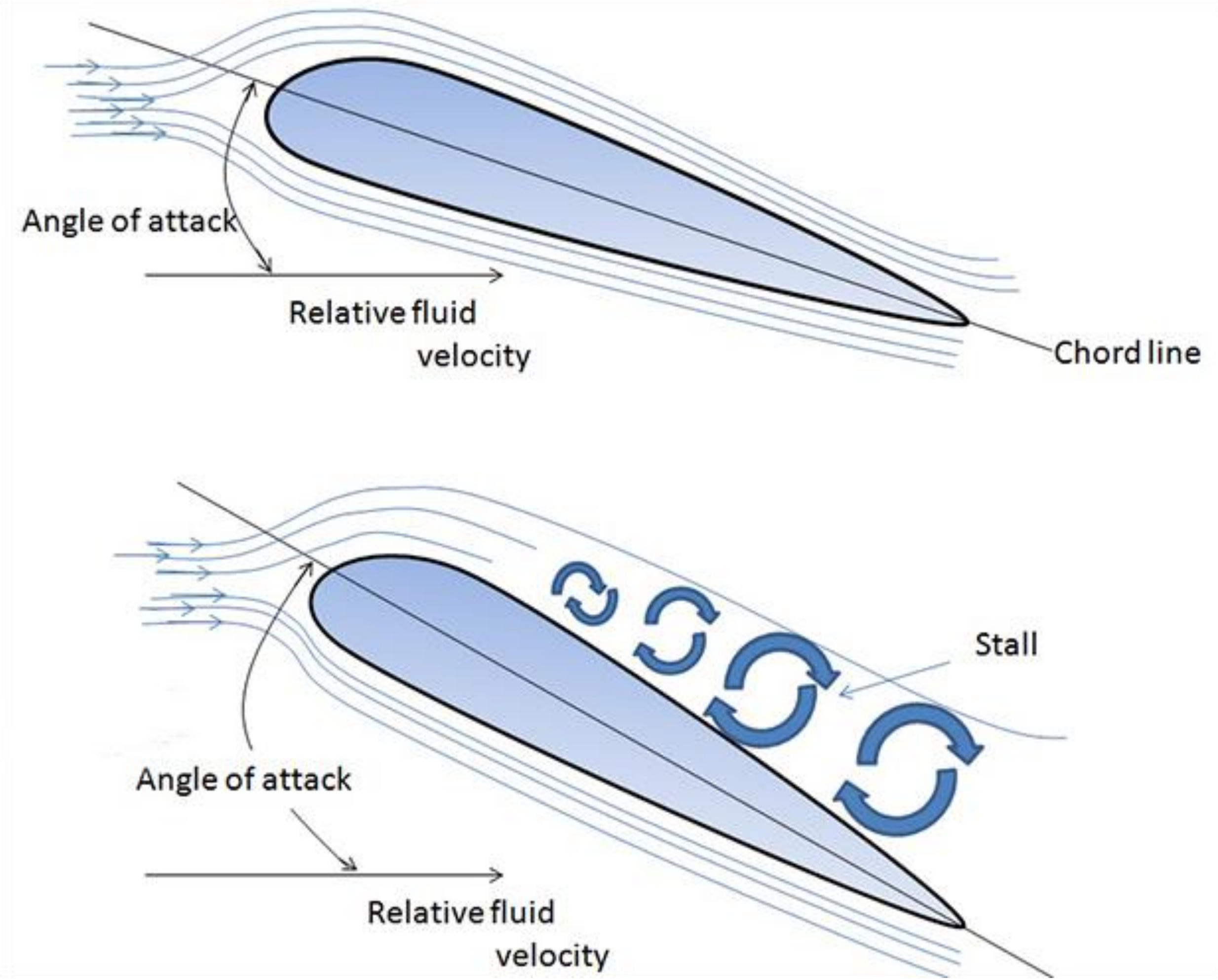
- From Fig. we can see that, any changes in the angle of attack from its optimum level would in turn reduce the efficiency of the rotor.
- Thus, at wind speeds higher than VR, we are shedding the excessive rotor power by spoiling the aerodynamic efficiency of the blades.
- Once the velocity comes down to the rated value or below, the blades are pitched back to its optimum position.
- In a pitch controlled turbine, the blades are to be turned about their longitudinal axis by the pitch control mechanism in tune with the variations in wind speed.
- The pitch control mechanisms are driven by a combination of hydraulic and mechanical devices.
- In order to avoid sudden acceleration or deceleration of the rotor, the pitch control system should respond fast to the variations in wind velocity.
- Similarly, for maximum performance, the pitching should exactly be at the desired level. Thus, the pitch control system should be very sensitive

Stall regulation

- Another method to regulate the power at high wind velocities is stall regulation.
- The basic principle of stall regulated turbines is illustrated in Fig

In these turbines, profile of the blades is designed in such a way that when the wind velocity exceeds beyond the rated limit, the angle of attack increases as shown in the figure. With this increase in angle of attack, air flow on the upper side of the blade.

- ceases to stick on the blade. Instead, the flow starts whirling in an irregular vortex, causing turbulence.
- This kills the lift force on the blades, finally leading to blade stall. Thus, the excess power generated at high wind is regulated.


Angle of attack
Relative fluid velocity
Chord line
Stall
Angle of attack
Relative fluid velocity

Pitch controlled turbines can capture the power more effectively in moderate winds as the blades can be set to its optimum angle of attack by pitching. However, moving components are to be introduced in the blade itself for adjusting its angle, which is a drawback of these systems. Similarly, the control unit should have high sensitivity towards wind fluctuations which makes them costlier.

On the other hand, stall controlled blades do not require any control system or pitching mechanism. However, the blades are to be aerodynamically twisted along its longitudinal axis. Design and manufacturing of such blades demand sophistication.

Structural dynamics of the system should be carefully analyzed before the design to avoid any possible problems like the stall induced vibrations. Power curve of a typical stall controlled turbine is shown in Fig Performance of these turbines at higher wind speeds is not impressive as the power falls below the rated level. In spite of these limitations, many wind power plants are still installed with stall controlled

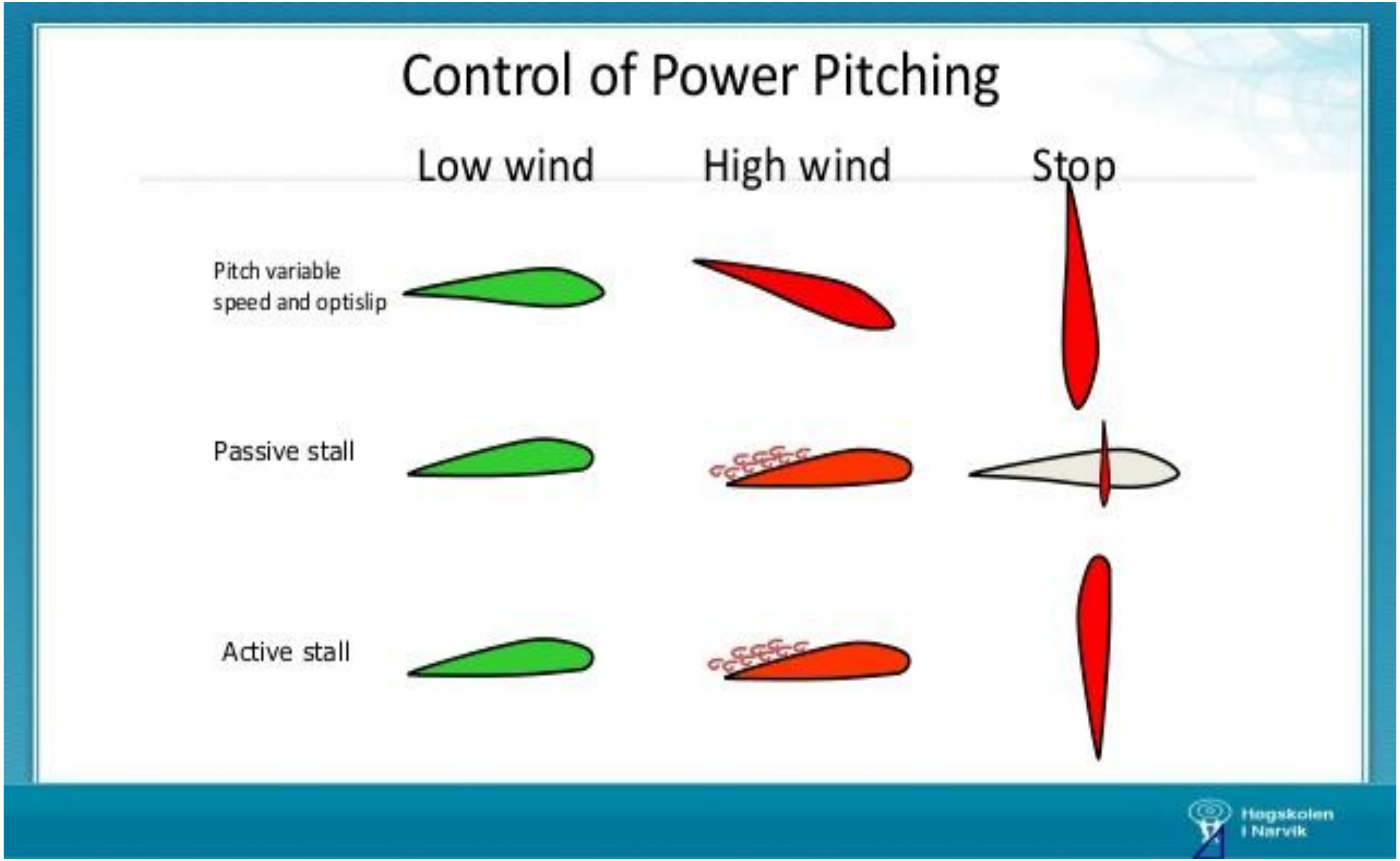
Safety breaks During the periods of extremely high winds, wind turbines should be completely stopped for its safety. Similarly, if the power line fails or the generator is disconnected due to some reason or the other, the wind turbine would rapidly accelerate. This leads the turbine to run-away condition within a few seconds

- ✓ As the rotor accelerates rapidly, the safety brakes should have rapid reactive response to prevent the run-away condition.
- ✓ Two types of brakes are commonly used with wind turbines. They are aerodynamic brakes and mechanical brakes.
- ✓ In order to ensure the safety, wind turbines usually have two braking systems, one functioning as the primary brake and the other as a backup option which comes into action if the primary system fails.

Aerodynamic brakes are the primary system in most of the wind turbines.
Aerodynamic braking in pitch and stall controlled turbines are different. In pitch and active stall controlled systems, the entire blade is turned 90o along its longitudinal axis, there by hindering the driving lift force. Thus the rotor would stop after making a few more rotations.

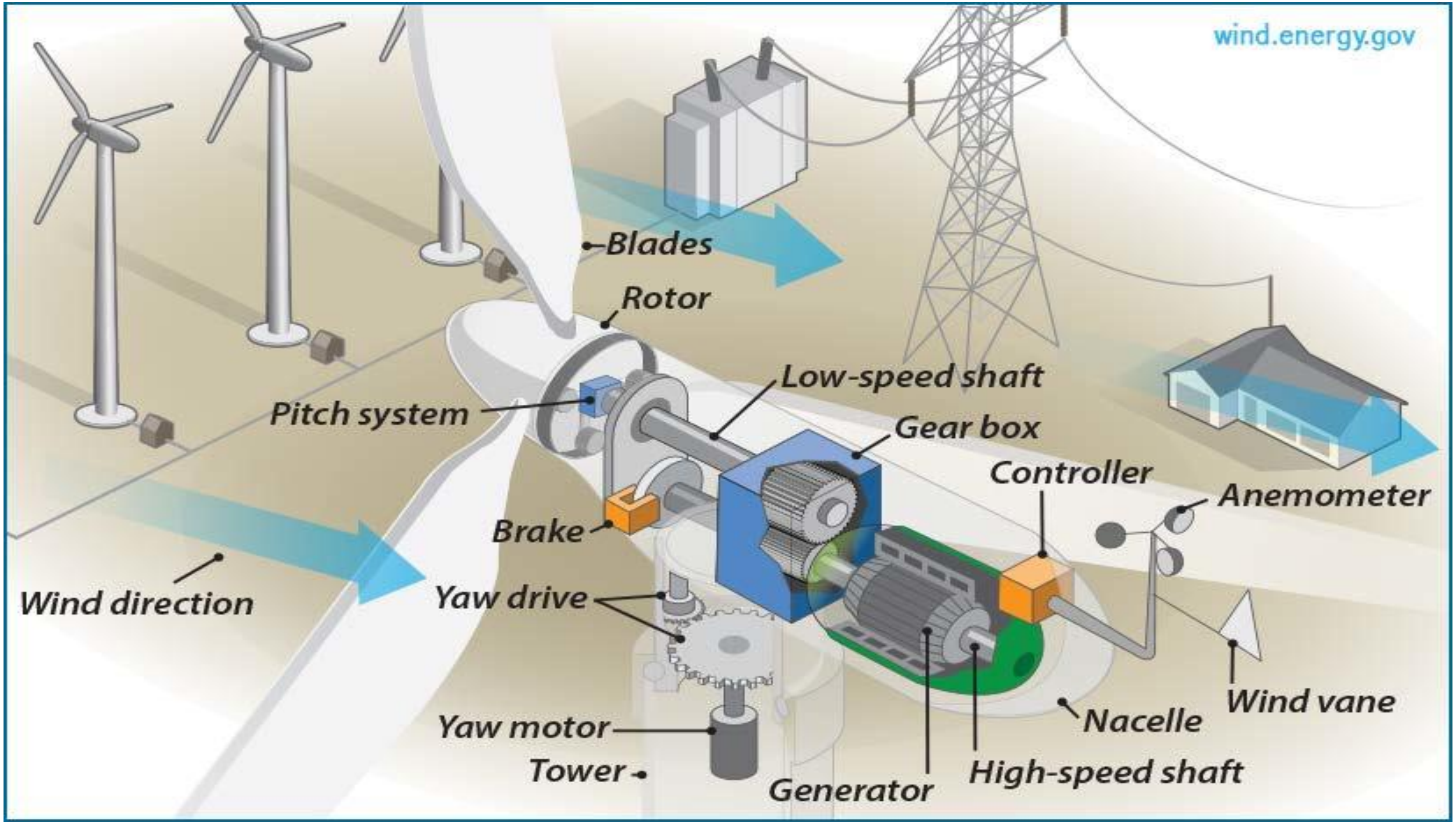
In contrast, it is the tip of the blade which is moved in stall controlled turbines.
Position of the blade tip, relative to the blade, can be changed using a shaft and bearing assembly fixed inside the main body of the blades.

In addition to the aerodynamic braking, a mechanical brake is also provided with the turbine as a back up system. These brakes are applied to bring the rotor to 'full stop' position in stall controlled turbines. They are also useful to lock the rotor during the turbine maintenance.


Control of Power Pitching
Low wind
High wind
Stop
Pitch variable speed and optislip
Passive stall
Active stall
Høgskolen i Narvik

Wind turbines: Components

Blades	Most turbines have three blades. The turning of the blades generate electricity
Hub	Centre of the rotor to which the rotor blades are attached
Rotor	Blades and hub referred together
Low-speed shaft	Turned by the rotor at about 30 to 60 rotations per minute (rpm)
Gears	Connects low-speed shaft to high-speed shaft and increases rotational speeds from about 30 to 60 rpm to about 1000 to 1800 rpm (the rotational speed required by most generators to produce electricity)
Generator	Produces electricity
High-speed shaft	Drives generator
Controller	Starts up and shuts off the machine
Anemometer	Measures wind speed and transmits wind speed data to controller
Wind vane	Measures wind direction and communicates with yaw drive to orient the turbine
Yaw drive	Keeps rotor facing into the wind as wind direction changes
Yaw motor	Powers yaw drive
Nacelle	Contains gear box, low- and high-speed shafts, generator, controller, and brake
Tower	Made from tubular steel, concrete, or steel lattice. Taller towers generate more power
Pitch	Blades are turned, or pitched, to control the rotor speed
Brake	Stops rotor in emergencies


wind.energy.gov
Blades
Rotor
Low-speed shaft
Pitch system
Gear box
Controller
Anemometer
Brake
Wind direction
Yaw drive
Yaw motor
Tower
Generator
High-speed shaft
Nacelle
Wind vane