Energy and Environment Science

Unit – 3 : Wind Energy Syllabus:

Class 2

i. Types of wind turbines

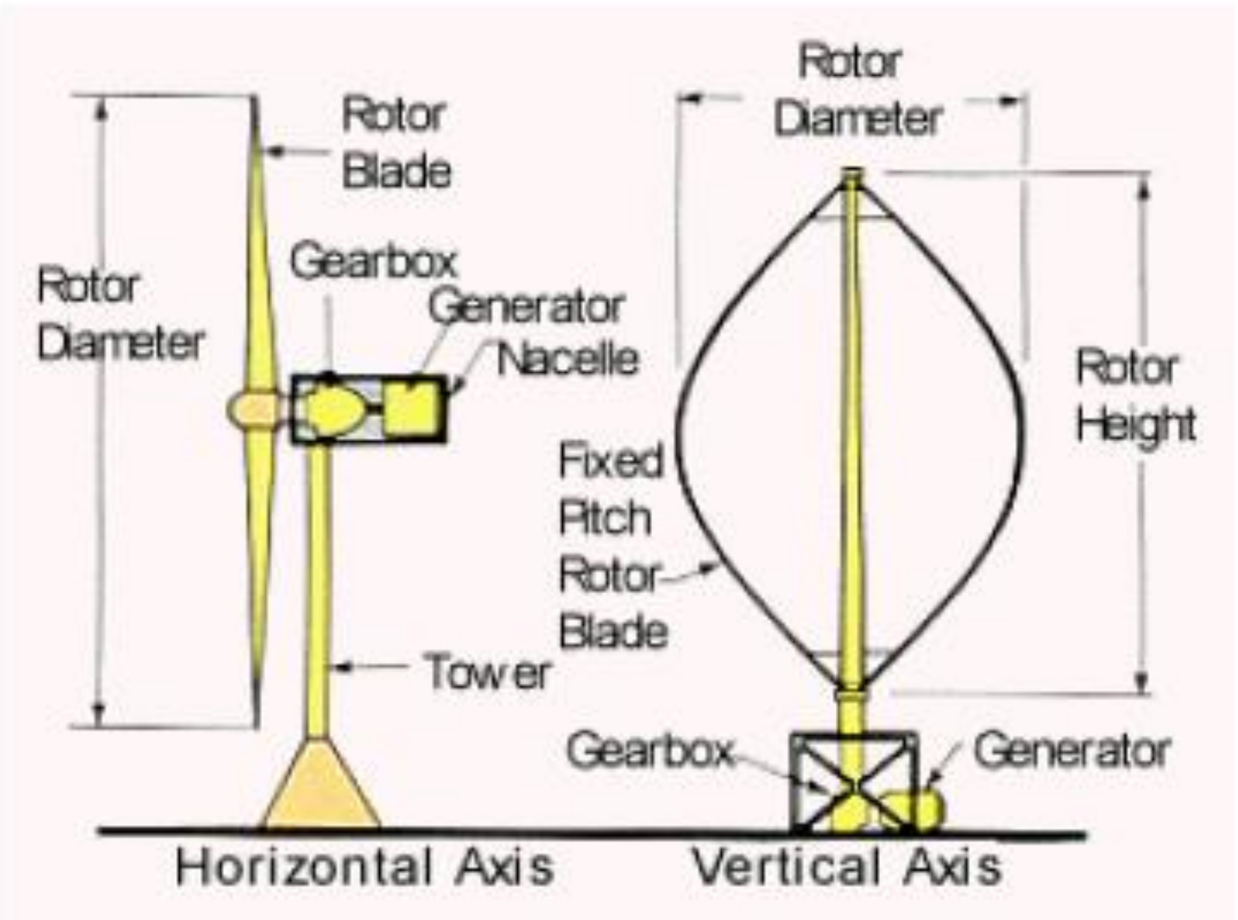
ii. Offshore Wind energy

WIND TURBINE TYPES AND THEIR CONSTRUCTION

TYPES OF Wind MILL AND Classification

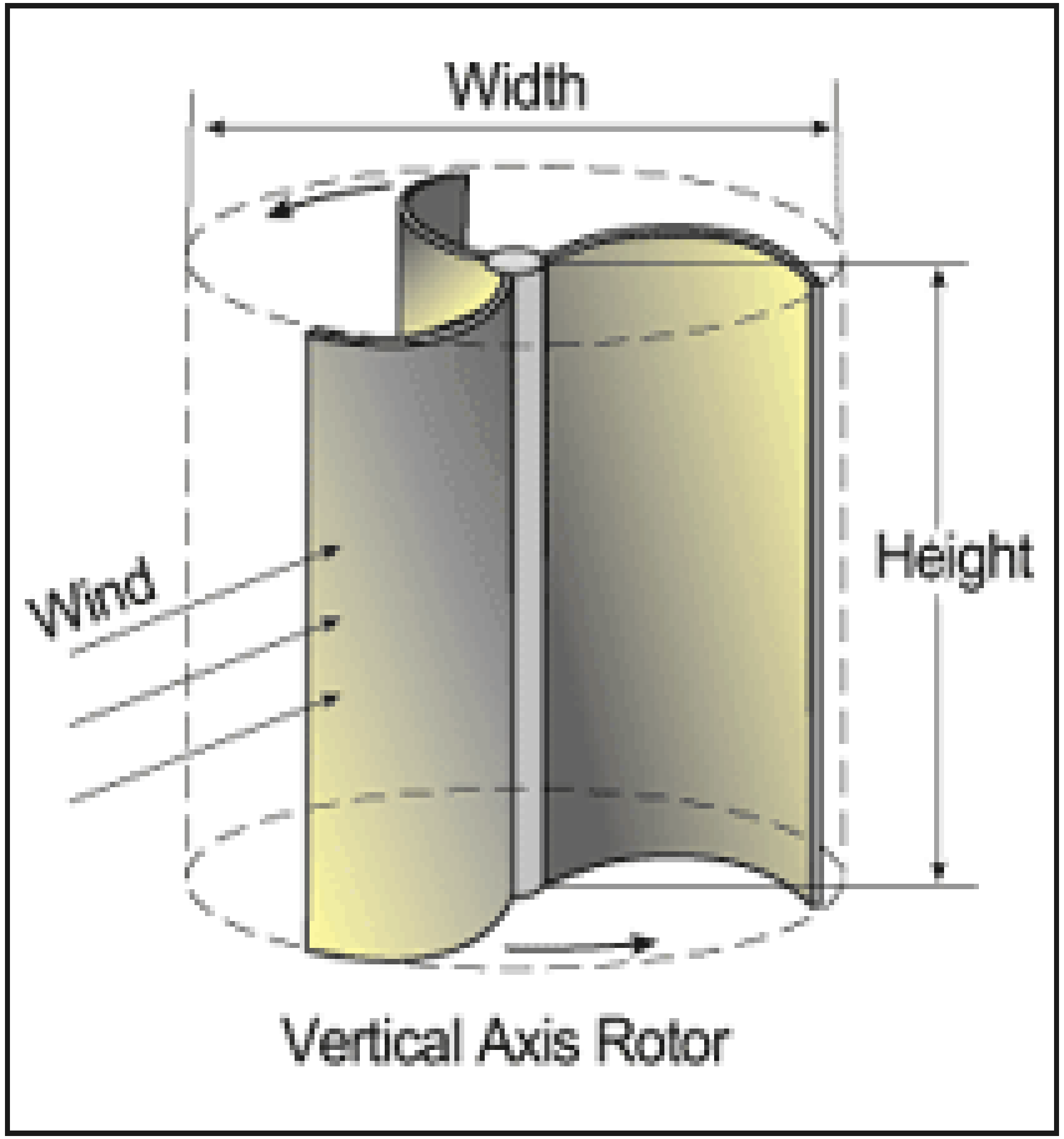
Wind Energy Design

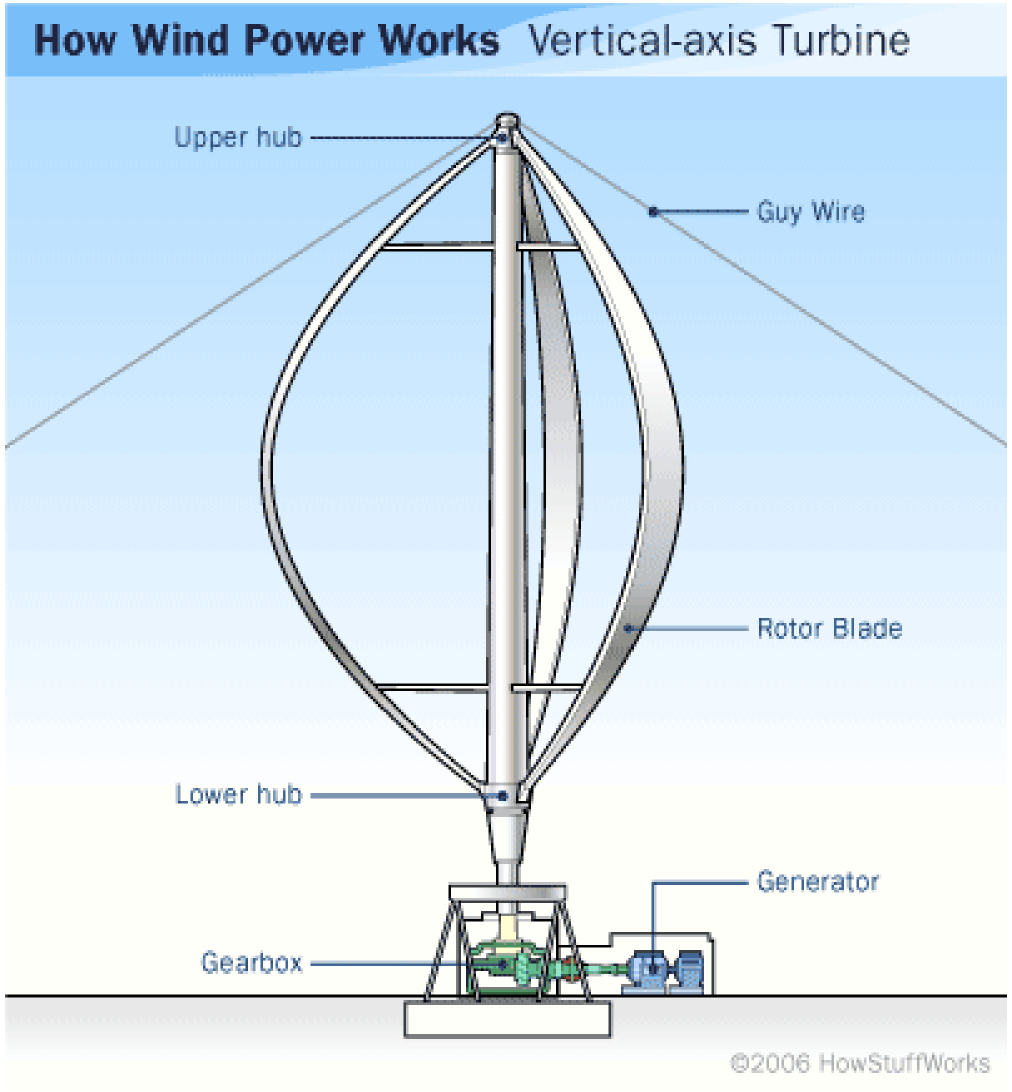
- **There are two basic designs** of wind electric turbines: **vertical-axis, or "egg-beater" style, and horizontal-axis machines**. Horizontal-axis wind turbines are most common today.



Wind Turbine Configurations

2.3.2.Wind energy- Classification





Vertical wind mill (Darrieus rotar)

WIND TURBINE TYPES AND THEIR CONSTRUCTION

- Wind turbines are broadly classified into two categories.

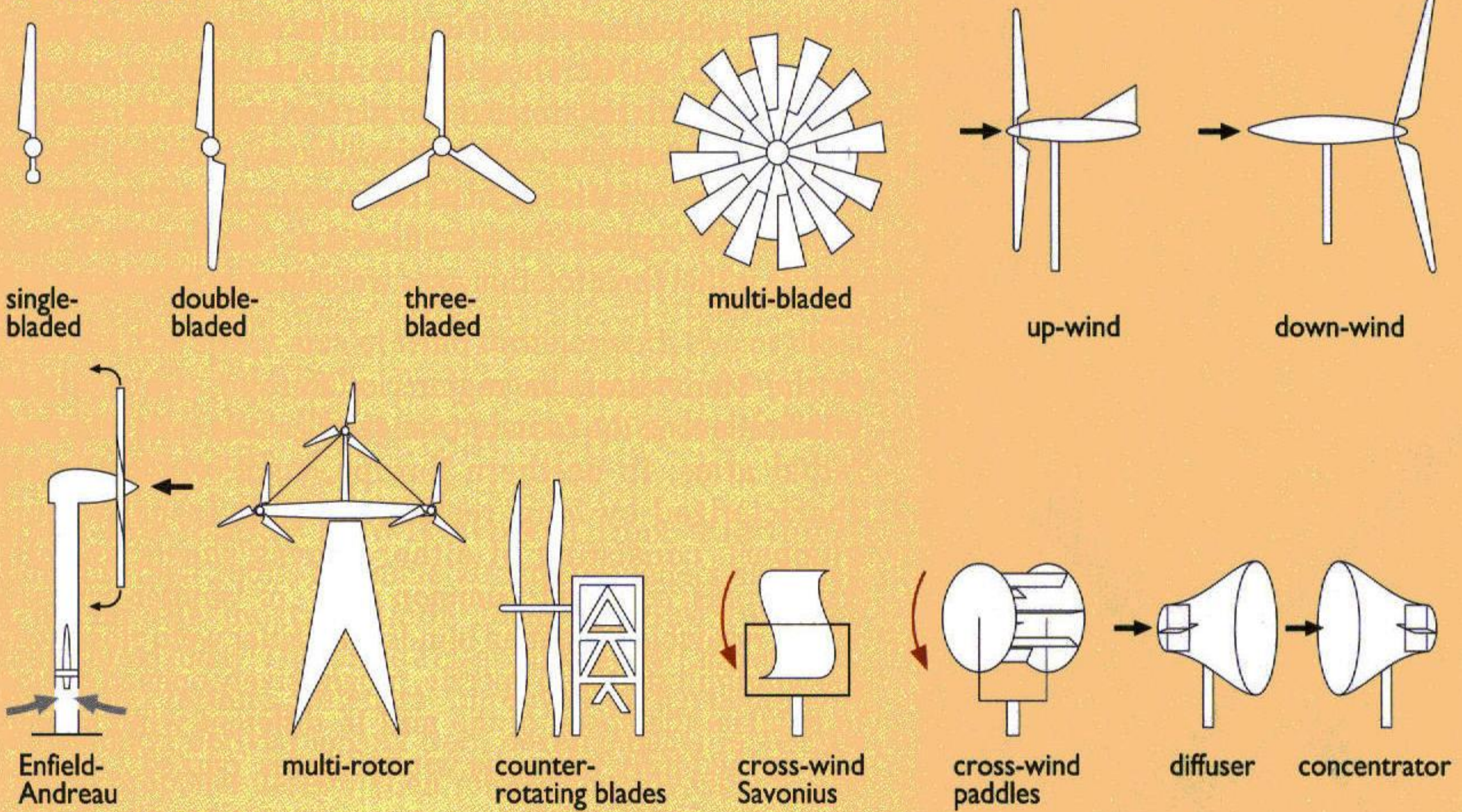
1. **Horizontal Axis Wind Turbine (HAWT),**
2. **Vertical Axis Wind Turbine (VAWT).**

- When the axis of rotation is **parallel** to the air stream (i.e. horizontal), the turbine is said to be a **Horizontal Axis Wind Turbine (HAWT), A horizontal axis machine has its blades rotating on an axis parallel to the ground**

- When it is **perpendicular** to the air stream (i.e. vertical), it is said to be a **Vertical Axis Wind Turbine (VAWT).**

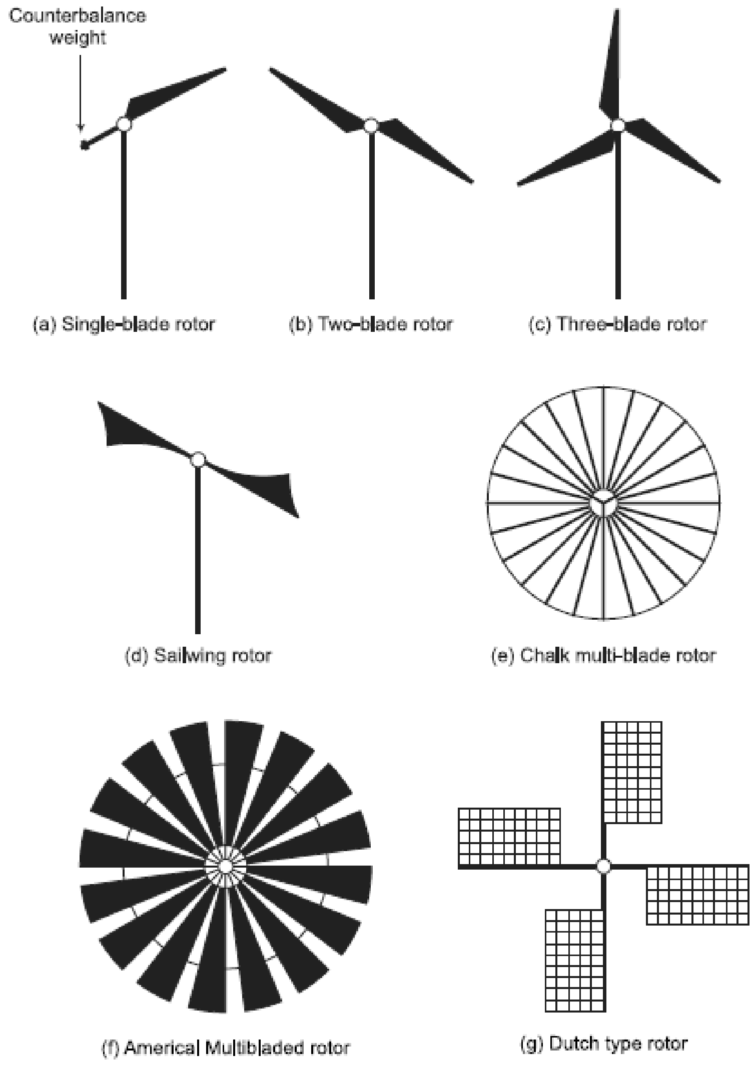
.A vertical axis machine has its blades rotating on an axis perpendicular to the ground.

Horizontal axis



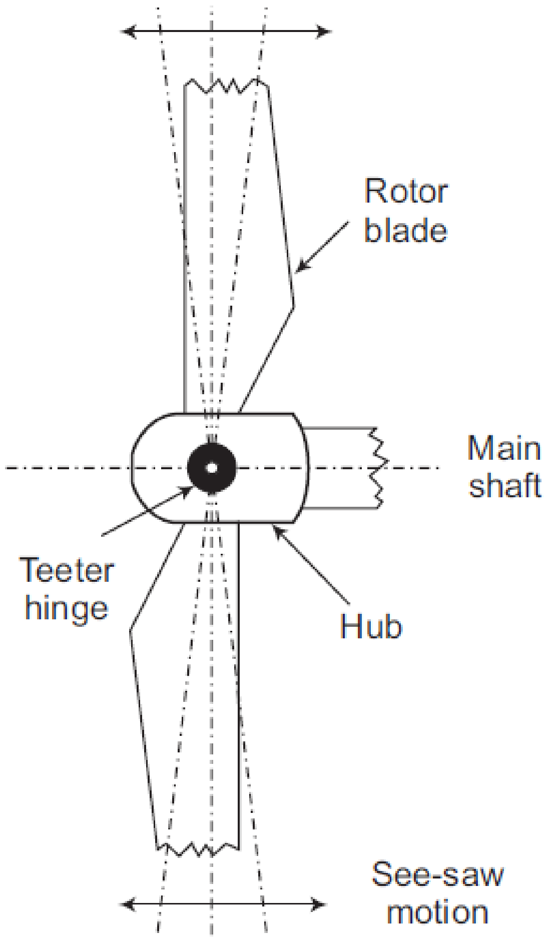
Horizontal Axis Wind Turbine (HAWT)

2. Types of Rotors



3. Teetering of Rotor

- As wind speed rises with height, the axial force on blade when it attains the upper position is significantly higher as compared to that when it is at lower position.
- For one and two blade rotors this causes cyclic (sinusoidal) load on a rigid hub leading to fatigue. This is greatly relieved by providing a teeter hinge (a pivot within the hub) that allows a see-saw motion to take place out of the plane of rotation



A teetered hub

Number of Blades – One

- Rotor must move more rapidly to capture same amount of wind
  - Gearbox ratio reduced
  - Added weight of counterbalance negates some benefits of lighter design
  - Higher speed means more noise, visual, and wildlife impacts
- Blades easier to install because entire rotor can be assembled on ground
- Captures 10% less energy than two blade design
- Ultimately provide no cost savings

Number of Blades - Two

- Advantages & disadvantages similar to one blade
- Need teetering hub and or shock absorbers because of gyroscopic imbalances
- Capture 5% less energy than three blade designs

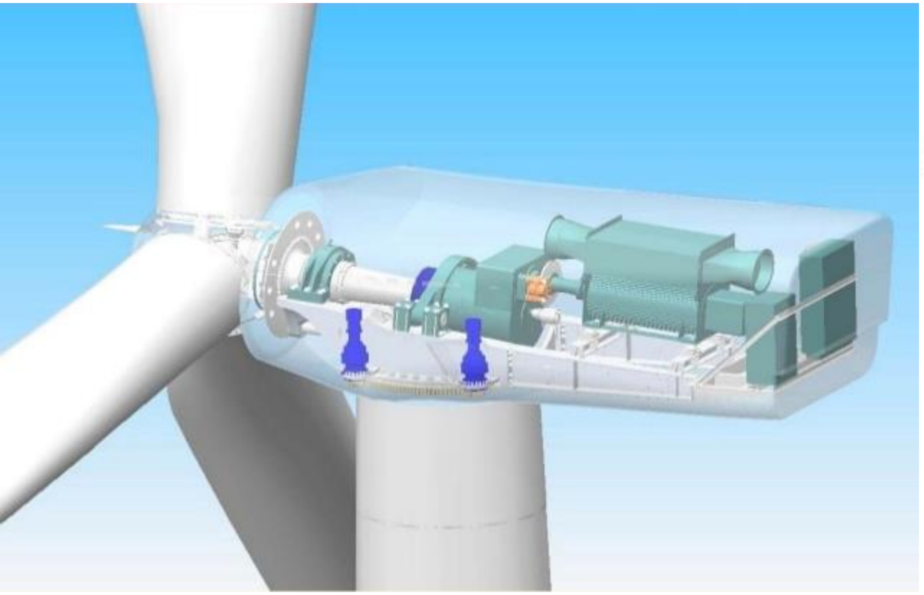
Number of Blades - Three

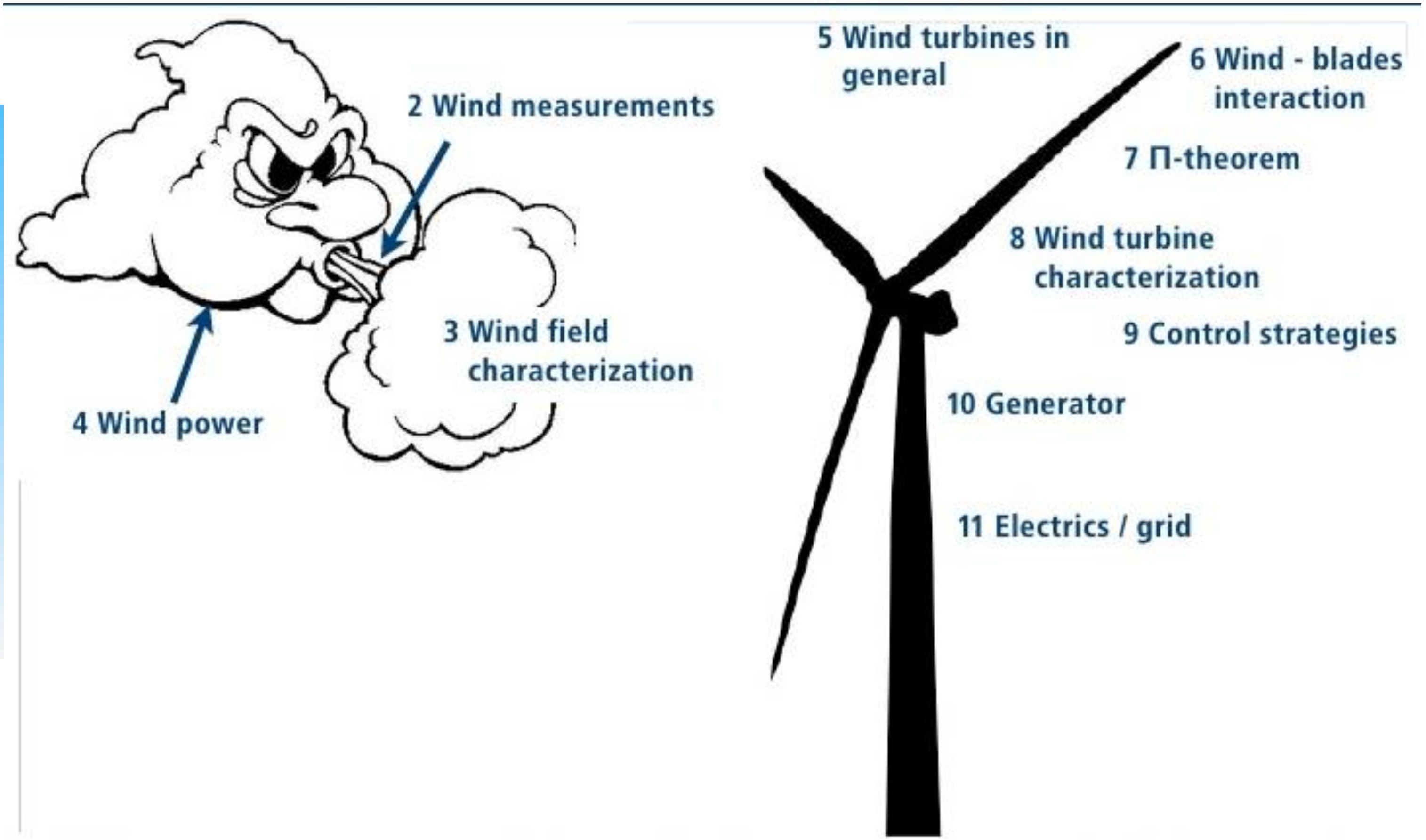
- Balance of gyroscopic forces
- Slower rotation
  - increases gearbox & transmission costs
  - More aesthetic, less noise, fewer bird strikes

Blade Composition Metal

- Steel
  - Heavy & expensive
- Aluminum
  - Lighter-weight and easy to work with turbine
  - Expensive
  - Subject to metal fatigue

WIND MILL SYSTEMS & ITS COMPONENTS





Horizontal-axis wind Mill

Rotor and Blades

Horizontal-axis wind turbines, which are the **most common** have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind.

Major components of System

- **Rotor, or blades,** which **convert the wind's energy into rotational shaft energy.**
- **Nacelle (enclosure)** containing a drive train, usually including a **gearbox (Some turbines operate without a gearbox) and a generator.**
- **Tower,** to support the rotor and drive train; and
- **Electronic equipment** such as controls, electrical cables, ground support equipment, and interconnection equipment.

Horizontal Axis Wind Turbine (HAWT)

1. Main Components

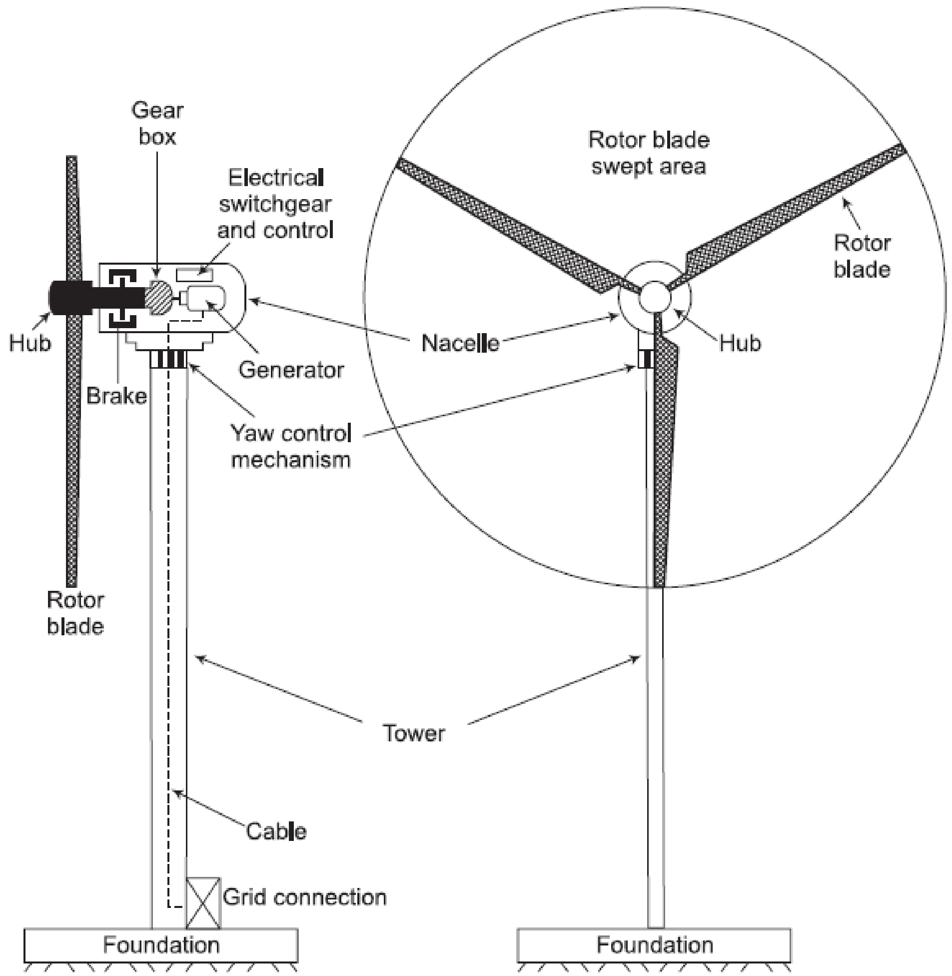
a) **Turbine Blades** - Turbine blades are made of high-density wood or glass fiber and epoxy composites. They have airfoil type cross-section.

b) **Hub** - The central solid portion of the rotor wheel is known as hub.

c) **Nacelle** - The term nacelle is derived from the name for housing containing the engines of an aircraft. The rotor is attached to nacelle, mounted at the top of a tower.

d) **Yaw Control Mechanism** - The mechanism to adjust the nacelle around vertical axis to keep it facing the wind is provided at the base of nacelle.

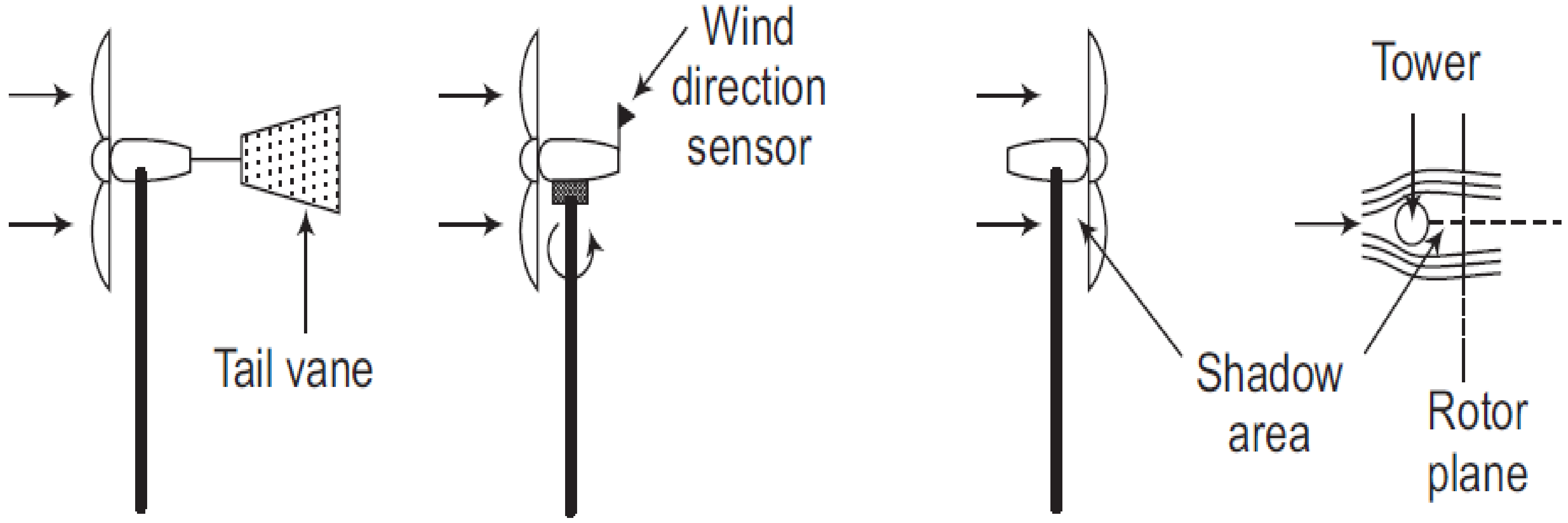
e) **Tower** - Tower supports nacelle and rotor. For medium and large sized turbines, the tower is slightly taller than the rotor diameter.



Horizontal Axis Wind Turbine (HAWT)

4. Upwind and Downwind Machines

- In upwind machine, rotor is located upwind (in front) of the tower
- whereas in downwind machine, the rotor is located downwind of (behind) the tower



(a) Upwind with tail vane passive yaw control

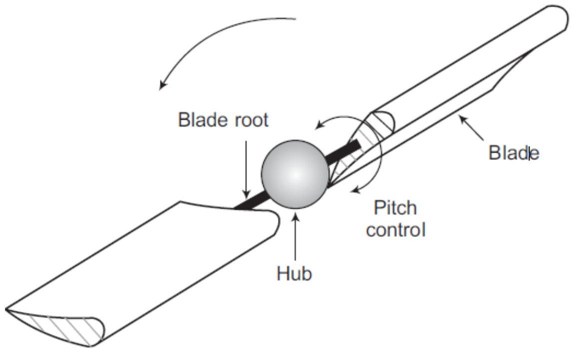
(b) Upwind with active yaw control

(c) Downwind with free yaw (or active yaw for large turbines)

Horizontal Axis Wind Turbine (HAWT)

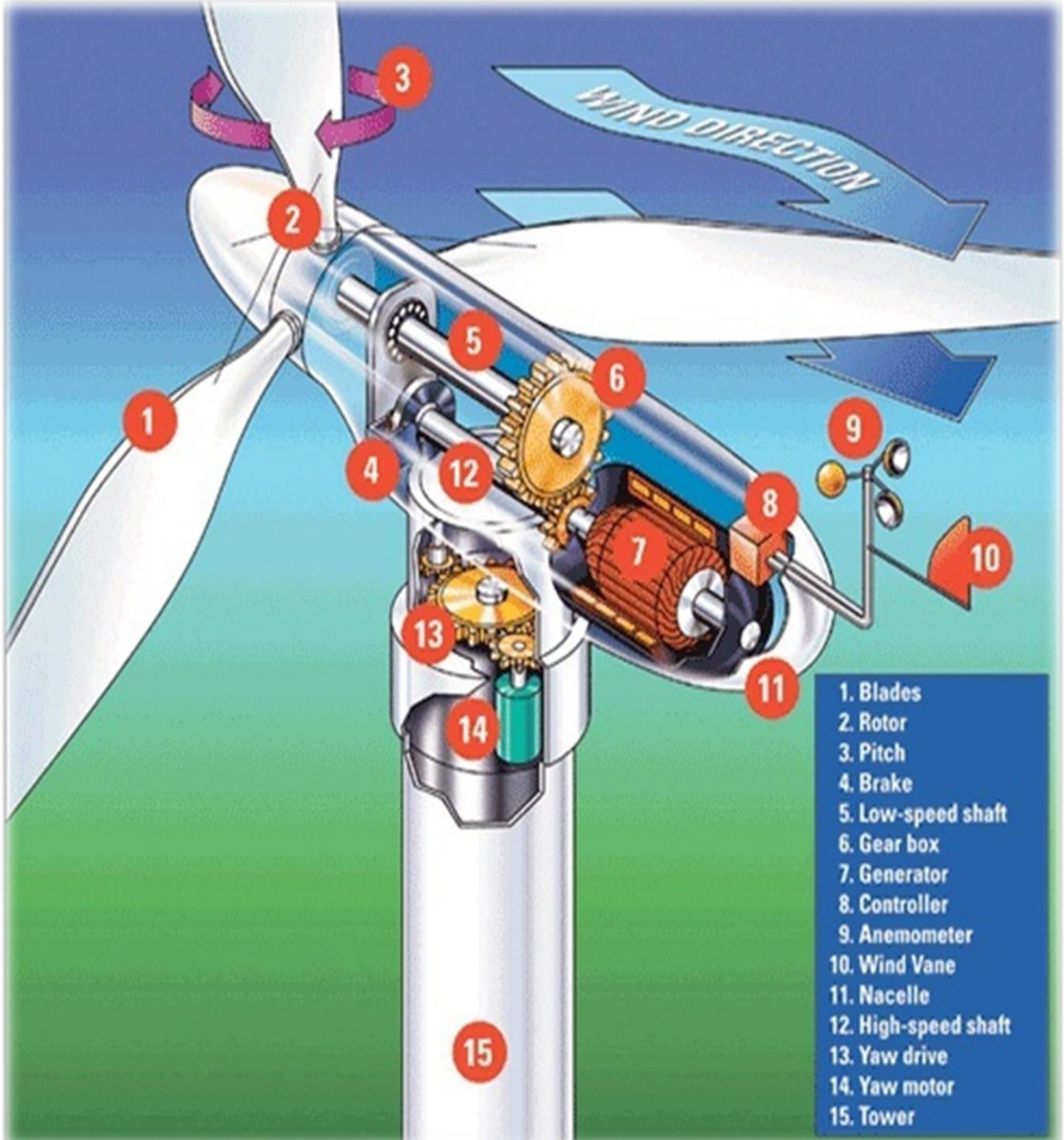
5. Yaw Control System

- Adjusting the nacelle about vertical axis to bring the rotor facing the wind is known as yaw control.
- The yaw control system continuously orients the rotor in the direction of wind.



6. Pitch Control System

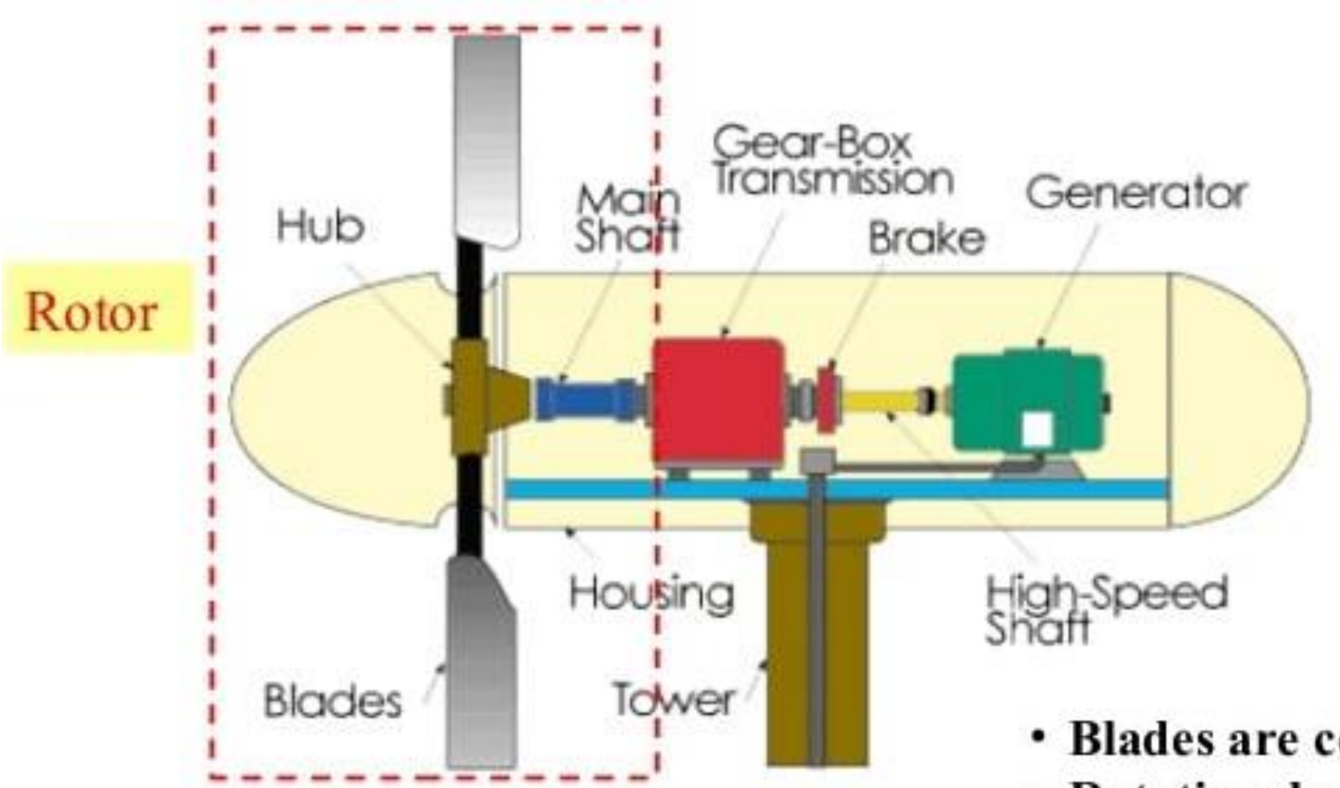
- Pitch control mechanism is provided through the hub using hydraulic jack in the nacelle.
- The control system continuously adjusts the pitch to obtain optimal performance.



Components of a Wind Turbine

1. ROTOR
2. DRIVE TRAIN
3. TOWER
4. CONTROL SYSTEM
5. YAW SYSTEM
6. MAIN FRAME
7. NACELLE

Rotor



- **Two- and three-bladed rotors are commonly used for power generation**.

Multi-bladed rotors have large starting torque in light winds and are used for water pumping and low frequency mechanical power.

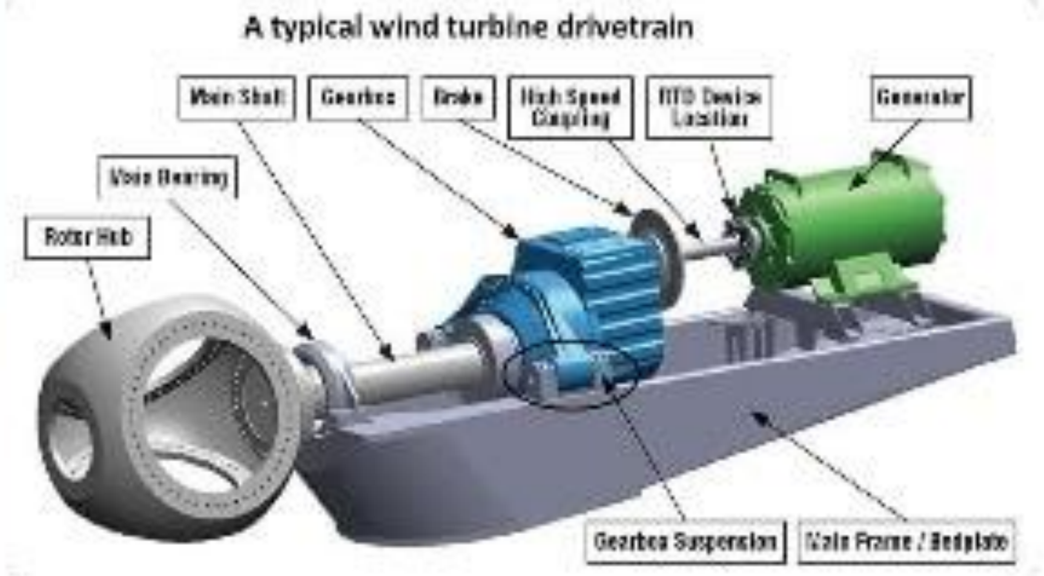
- **Blades are connected to a hub, which is connected to a shaft**
- **Rotational speed will depend on blade geometry, number of blades, and wind speed (40 to 400 revolutions per minute typical speed range)**
- **Gear box needed to increase speed to 1200-1800 RPM for generator**

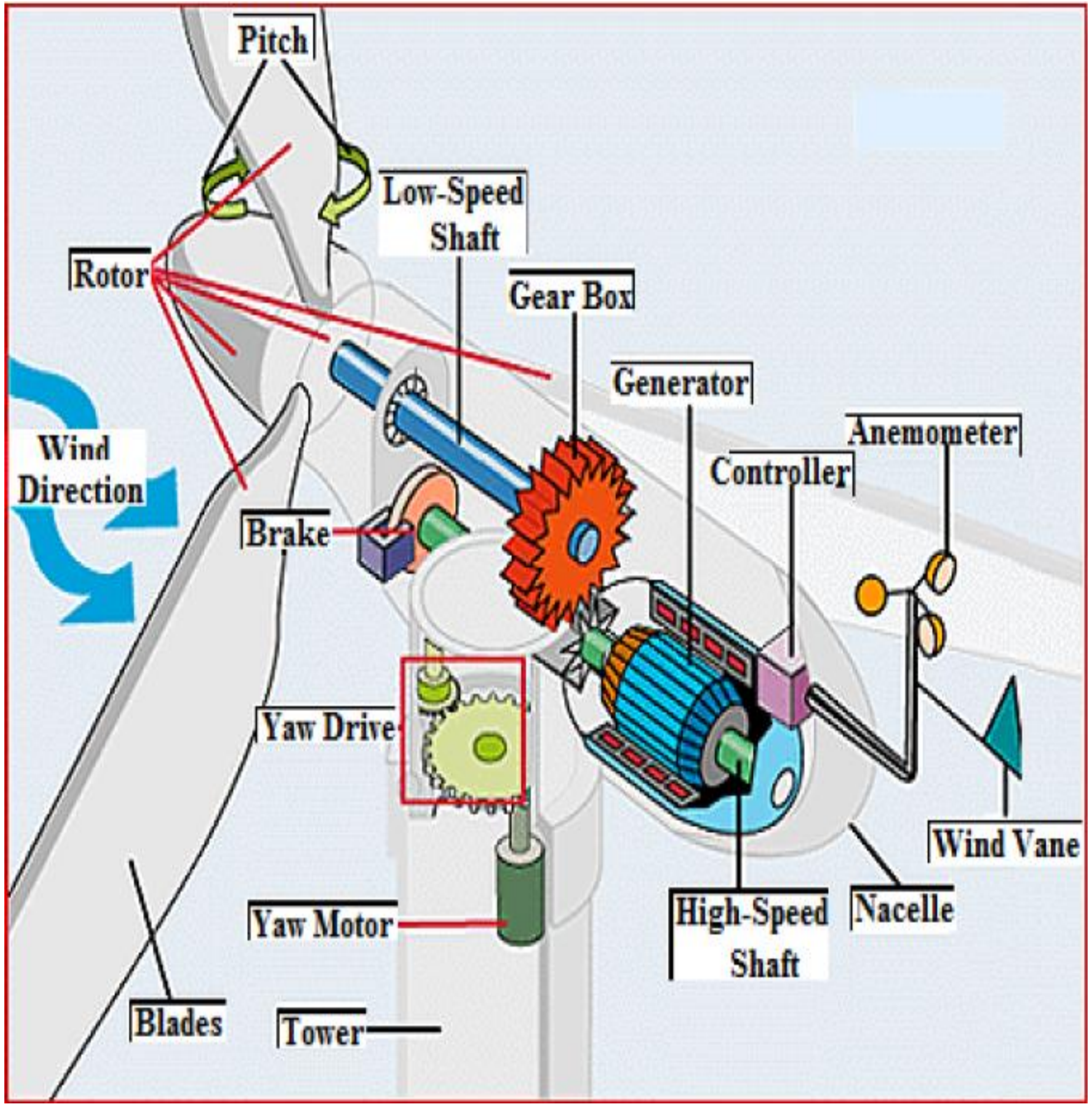
BLADES

- It has two or three thin, curved blades shaped like an egg beater in a profile, (Troposkien profile) with blades curved in a form that minimizes the bending stress caused by centrifugal forces.
- The blades have an airfoil cross section with constant chord length.
- The pitch of the blades cannot be changed.
- The diameter of the rotor is slightly less than the tower height.

NACELLE

- The term nacelle is derived from the name for housing (casing) containing the engines of an wind turbine (Aerogenerator).
- The rotor is attached to the nacelle, and mounted at top of a tower. It contains rotor brakes, gearbox, generator, low and high speed shafts, electrical switchgear and control.





***Nacelle Assembly*:** Nacelle is the part of wind turbine at top of tower housing containing gear box, generator assemblies and any control component.

Low-speed shaft: The low-speed shaft, which is the main shaft, is connected directly to the rotor hub. The rotor turns the low-speed shaft at about **30 to 60 rotations per minute.**

TOWER

- The tower supports the nacelle and rotor. Its height approximately two to three times the blade length. But, practically maximum height is estimated to be roughly 60 m.
- It is designed to withstand the wind load during gusts (strong rush of wind).
- At the bottom level of the tower there will be step-up transformers for the connection to the Electrical Grid.
- Inside of the tower there is a ladder to access to top of the tower for maintenance and setup processes and will also contain high voltage cables for transporting the electricity produced by the generator at the top of the turbine to its base.

TYPES OF TOWERS

1. The reinforced concrete tower,
2. The pole tower,
3. The built up shell-tube tower, and
4. The truss tower.

Tubular concrete

Tubular steel tower

Pole tower

Truss tower

Features of major Components & Systems

Tower

- Tubular Tower for better load carrying capacity
- Designed stiffness to eliminate critical natural
- frequencies
- Designed to reduce the dynamic stresses to
- minimum
- Load Separation plate inserted inside
- foundation for better stability and better load
- distribution.
- Ergonomically designed tower internals with
- necessary safety equipment, like fall arrester
- Superior cable management systems with
- specific designed clamp for less wear and tear
- while twisting
- Epoxy coating
- Ultrasonic and Radiography tests
- Less maintenance as compared to lattice

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

Technical specification

- Tower

Nominal Power -1500 kW
Rotor diameter - 82 m
Hub height- 78.5m
Rotor cone angle- 4.3°
Swept area -5281 m2
Rotor speed (at rated power) -16.30 rpm
Rotational speed 15.6 -18.4 rpm
Tip speed (at rated power)- 70 m/s
Blade length -40 m
Generator Stator Voltage -690 V
Speed at rated power and shortcut rotor- 1,511 rpm
Start wind 4 m/s
Stop wind 20 m/s

Vertical Axis Wind Turbine (VAWT)

- 1920 :Invented by G. M. Darrieus (French Engineer): Darrieus Rotor
- 500 kW, 34m long was undertaken in 1980 by Sandia national Lab, USA but leaving the business in 1997

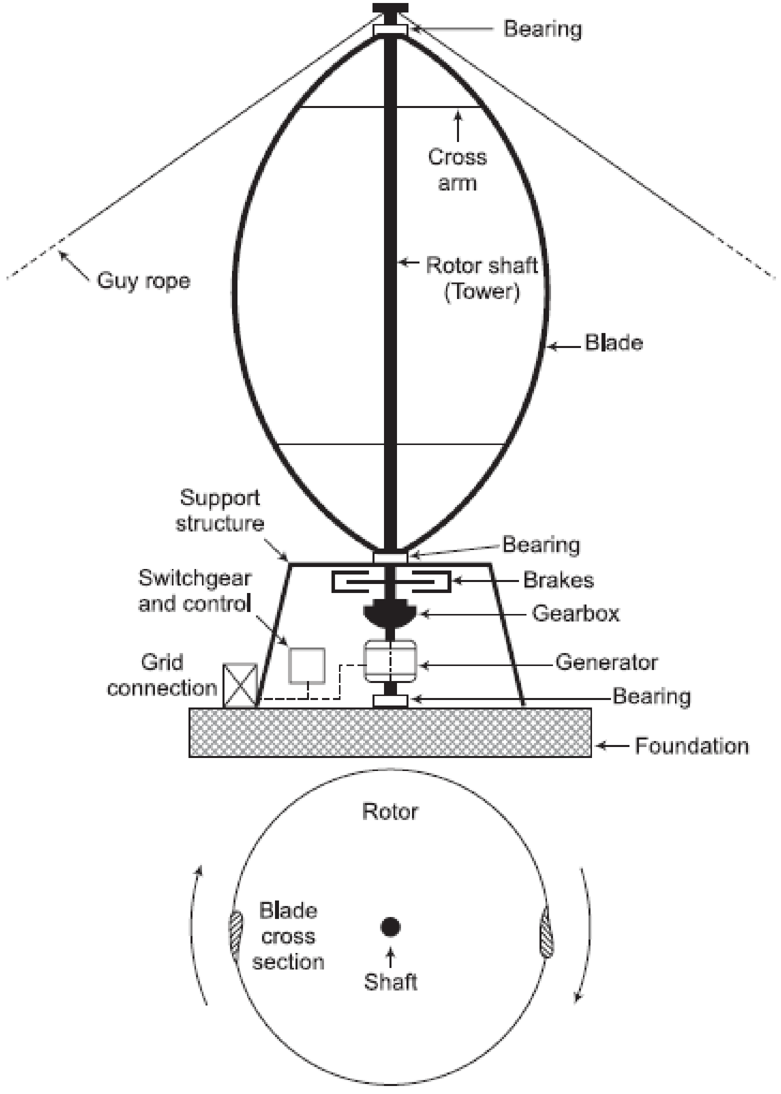
Vertical Axis Wind Turbine (VAWT)

1. Main Components

a) **Tower (or Rotor Shaft) -** The tower is a hollow vertical rotor shaft, which rotates freely about vertical axis between top and bottom bearings. It is installed above a support structure.

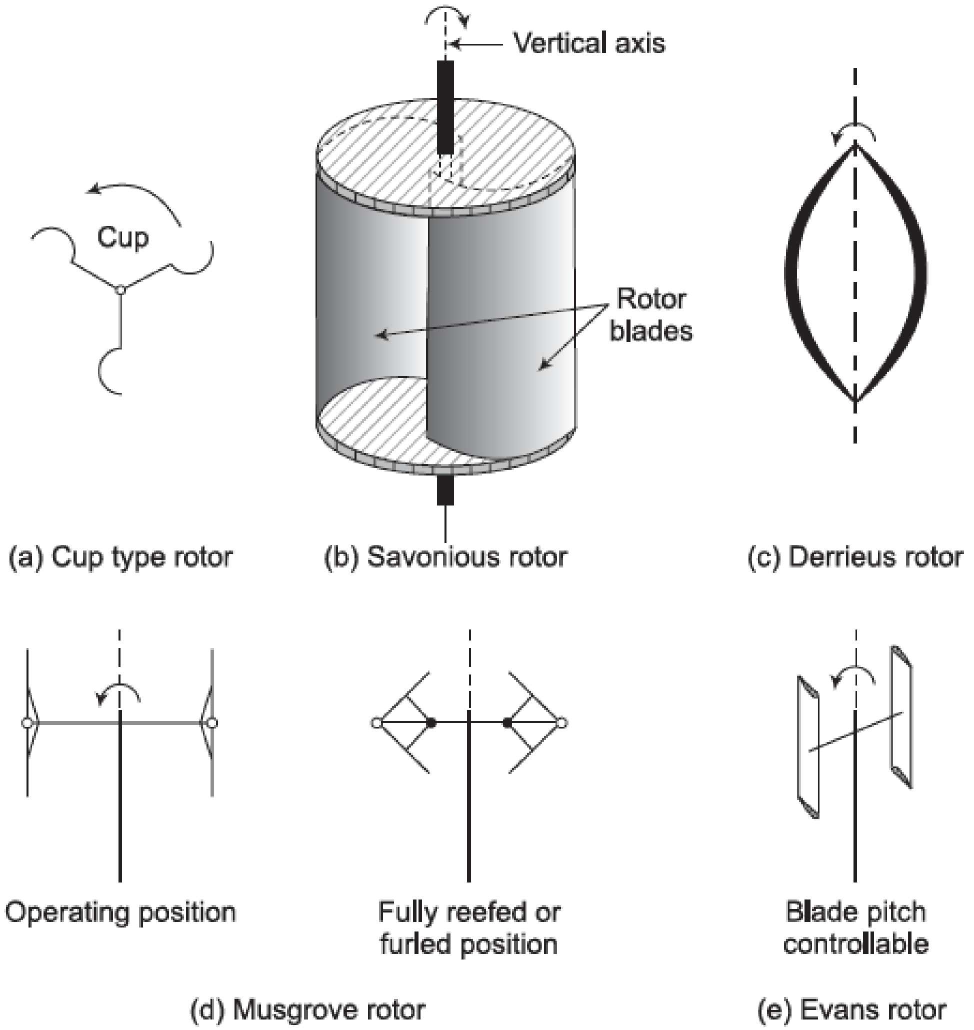
b) **Blades -** It has two or three thin, curved blades shaped like an eggbeater in profile, with blades curved in a form that minimizes the bending stress caused by centrifugal forces-the so-called 'Troposkien' profile. The blades have airfoil crosssection with constant chord length.

c) **Support Structure -** Support structure is provided at the ground to support the weight of the rotor. Gearbox, generator, brakes, electrical switchgear and controls are housed within this structure.



Vertical Axis Wind Turbine (VAWT)

2. Types of Rotors



Types of WT contd..

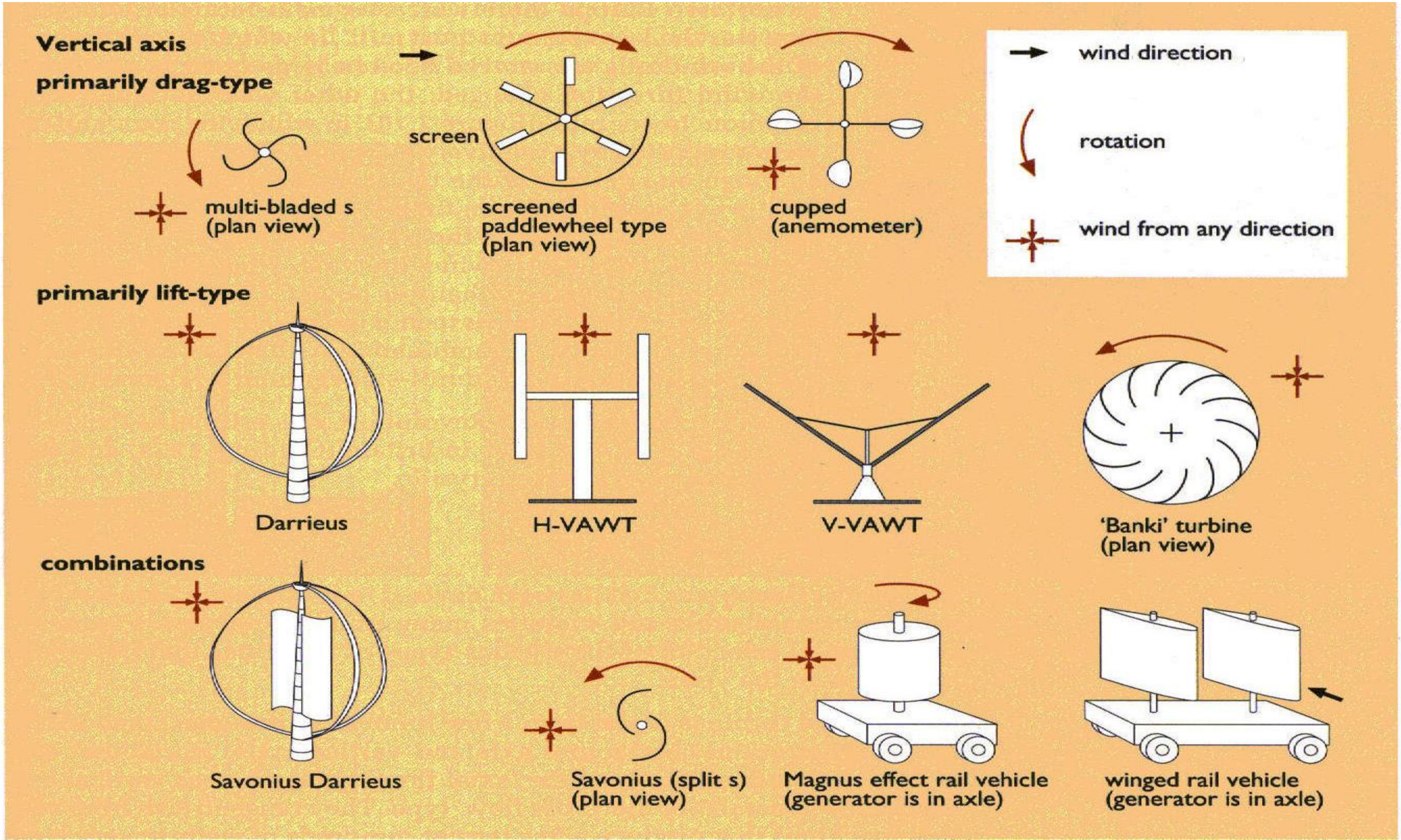


Figure 7.9 Some examples of the machines that have been proposed for wind energy conversion (source: adapted from Eldridge, 1975. For further information on these machines see Eldridge, 1975 and Golding, 1955)

TYPES OF WIND TURBINES

- **1. Onshore:**
- Onshore wind turbines are placed in hilly and mountainous places and are at least three kilometers away from the nearest shore.

- **2. Near-shore**

Near-shore wind turbines are installed within three kilometers from the nearest shore or on water within ten kilometers from land.

- **3.Offshore**
- Offshore wind turbines' developement zones are at least ten kilometers away from land.

Lift and Drag Type Machines

- Wind turbines make use of either lift force or drag force predominantly to cause motion and accordingly known as **lift or drag type machines.**
- In lift devices the ratio of lift to drag forces may be as high as 30:1.
- For the drag design, the wind literally pushes the blades out of the way.
- Drag devices are less efficient and turn slower than wind.
- They produce high torque and thus are suitable for pumping applications. At high wind speeds they spill wind instead of producing more energy.
- Thus they do not benefit from high energy density available in wind.
- The lift blade design employs the same principle that enables aeroplanes, 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.

Effect of Solidity

- High solidity rotors use drag force and turn slower.
- Solidity of Savonious rotor is unity and that of American multi-blade rotor it is typically 0.7.
- Low solidity rotors, on the other hand, use lift force.
- Lift devices usually have solidity in the range of 0.01 to 0.1.
- They have slender airfoil blades. When solidity is less than 0.1, the device will usually not start up without first being rotated to generate lift.

Horizontal Axis vs Vertical Axis Turbines

- Most wind turbines, used at present are of horizontal axis type.
- They have been well researched and have gone through extensive field trial.
- As a result, well-established technology is available for HAWTs.
- Some advantages of VAWT have recently generated considerable interest in this type of turbine.
- These are:

  (i) it can accept wind from any direction without adjustment, which avoids the cost and complexity of yaw orientation system,

  (ii) gearing and generators, etc., are located at ground level, which simplifies the design of tower, the installation and subsequent inspection and maintenance and (iii) also they are less costly as compared to HAWTs.

Wind turbines: Types

- Depending on Capacity
  - Utility scale (900kW to 2MW per turbine): used in wind farms which generate bulk energy sold in power markets.
  - Industrial scale (50kW to 250kW per turbine): used for commercial/community power applications, typically off-grid.
  - Residential Scale (400 watts to 50kW): used in remote, off-grid locations
- Depending on operations at different wind speeds

Variable speed	Fixed speed
Operates at a wider range of wind speeds by changing the blade's angle through *pitch control* or *yawing*	Attains peak efficiency at one speed
Greater annual energy yield, offsetting higher costs	Fewer moving parts, less complex, thus lower manufacturing costs
Supplies and controls reactive power to the grid	Consumes reactive power from other transmission systems

Turbines: Different Sizes and Applications

Small (≤10 kW)
- Homes (Grid-connected)
- Farms
- Remote Applications

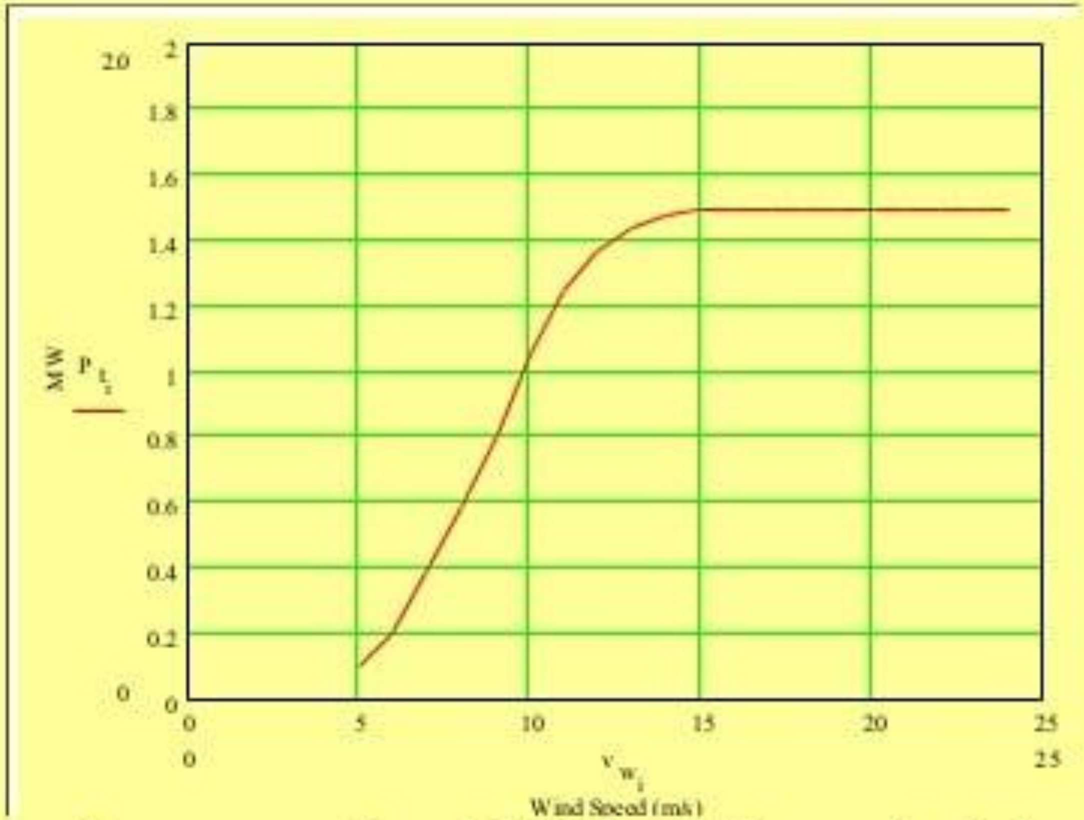
(e.g. battery changing, water pumping, telecom sites)

Intermediate

(10-500 kW)
- Village Power
- Hybrid Systems
- Distributed Power

Large (500 kW – 5 MW)
- Central Station Wind Farms
- Distributed Power
- Offshore Wind

Wind Turbine Technology



Power curve for a 1.5 MW variable-speed, pitch-controlled wind turbine. Note "flatness" of output for wind speeds at or above rated value

Source: AWEA

Part 4

WIND FIRMS

Wind farms

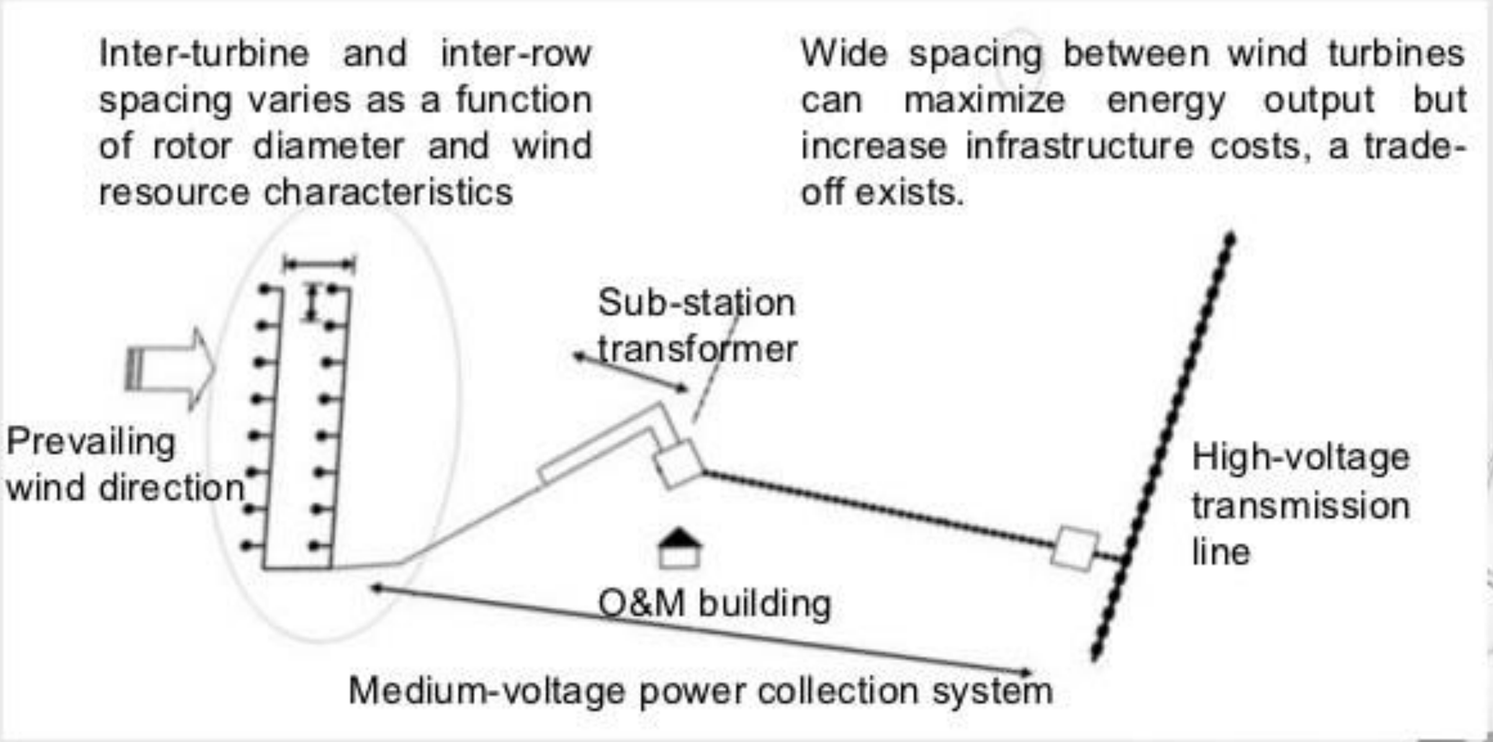
Source: http://news.medill.northwestern.edu/chicago/news.aspx?id=100757&print=1

Source: http://www.sharonpavey.org/luppitt-looking-forward-to-a-sustainable-future/

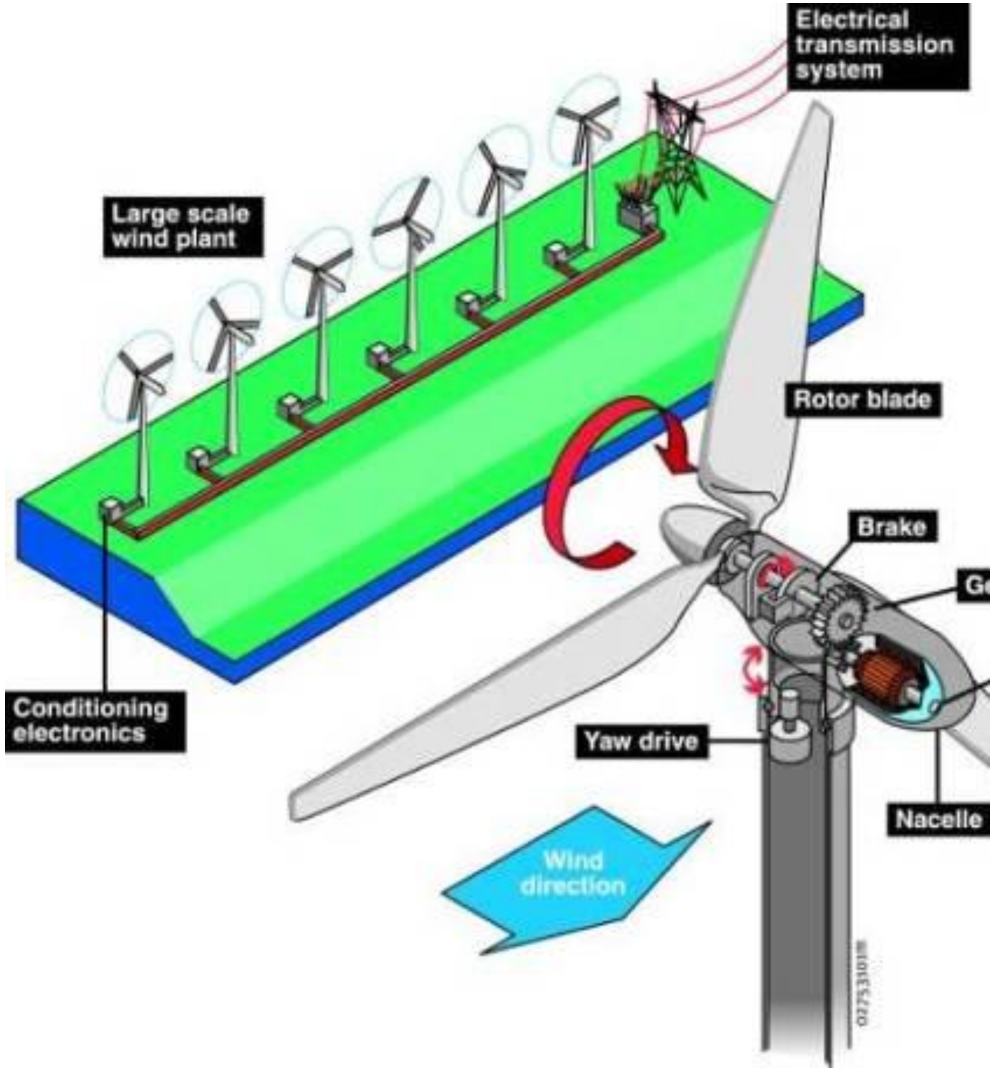
Most wind turbines are rather small in generating capacity (e.g., 50 to 500 kW. There are some very large units to about 1 MW. At these power levels, many turbines are needed to obtain desirable power levels – typically well above 100 MW. The many turbines are often organized into 'wind farms' as shown here.

Wind farms

- Group of wind turbines operating in the same area
- Sizes range between 20 and 300MW
- Can be typically set up in a year
  - quicker than conventional energy plants



Large Wind Turbines / Wind Farms



Part 4

On shore off shore

The Future of Wind - Offshore

- 1.5 - 6 MW per turbine
- 60-120 m hub height
- 5 km from shore, 30m deep ideal
- Gravity foundation, pole, or tripod formation
- Shaft can act as artificial reef
- Drawbacks- T&D losses (underground cables lead to shore) and visual eye sore

Onshore or offshore?

Onshore advantages

- A regular onshore turbine last for around 20 years
- Normally it takes about 2-3 months before the wind turbine has paid itself back. This also includes the energy, which were used to produce, install, maintain and remove the wind turbine.
- Cheaper foundation
- Cheaper integration with electrical-grid network

Onshore disadvantages

- Wind turbines are noisy
- Each one can generate the same level of noise as a family car travelling 70 mph
- Some people thinks that the large towers of wind turbines destroys the view of the landscape

Onshore or offshore?

Offshore advantages

- A offshore wind turbine is stronger than a onshore turbine. It lasts around 25-30 years, and produces about 50 % more energy than a onshore turbine.
- When a strong wind blows, it produces around 3-5 MW per hour.
- Higher and more constant wind speed

Offshore disadvantages

- More expensive to built
- More difficult to maintain and access

Speed Control Strategies for Wind Turbine

- Various options are available for speed control of a turbine. The particular control strategy depends on the size of the turbine.
- These methods may be grouped in the following categories:
    i. **No speed control at all**. Various components of the entire system are designed to **withstand extreme speed under gusty wind.**
    ii. **Yaw and tilt control**, in which the **rotor axis is shifted out of wind direction,** either by yaw control or by tilting the rotor plane with respect to normal vertical plane **when the wind exceeds the design limit.**
    iii. **Pitch control**, in which the pitch of the rotor blades is controlled **to regulate the speed**.
    iv. **Stall control**, in which the blades are shifted to a position such that they stall **when wind speed exceeds the safe limit**.

Wind Turbine Operation and Power versus Wind Speed Characteristics

a) **Low Speed Region (Zero to Cut-in Speed)** In this region, the turbine is kept in braked position till minimum wind speed (about 5 m/s), known as cut-in speed becomes available. Below this speed the operation of the turbine is not efficient.

b) Maximum Power **Coefficient Region** In this region, rotor speed is varied with wind speed so as to operate it at constant tip-speed ratio, corresponding to maximum power coefficient, CP max. In this range the nature of characteristics is close to that of maximum power available in the wind

c) **Constant Power Region (Constant Turbine Speed Region)** During highspeed winds (above 12 m/s), the rotor speed is limited to upper permissible value based on the design limits of system components. In this region the power coefficient is lower than CP max.

d) **Furling Speed Region (Cut-out Speed and Above)** Beyond certain maximum value of wind speed (around 25 m/s) rotor is shut down and power generation is stopped to protect the blades, generator and other components of the system.