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VISVODAYA INSTITUTE OF TECHNOLOGY & SCIENCE

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WIND ENERGY

UNIT-III

CLASS-IV-I SEM

Subject: RENEWABLE ENERGY SYSTEMS

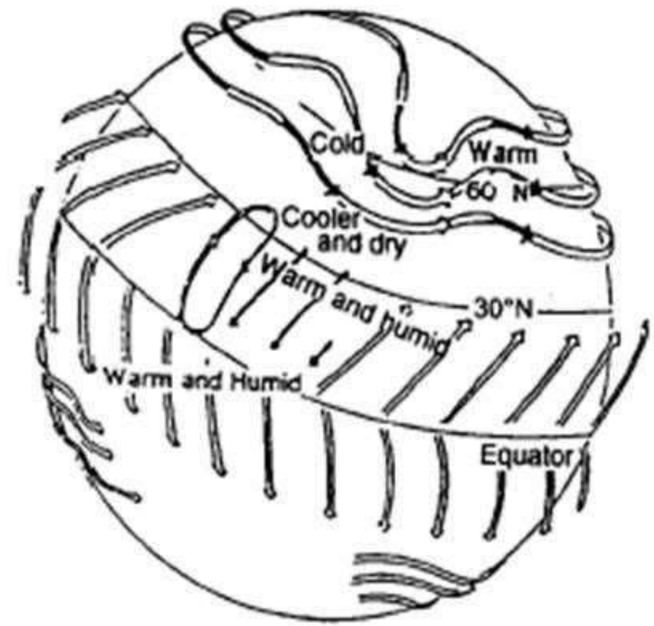
SYLLABUS

UNIT-III----------> WIND ENERGY

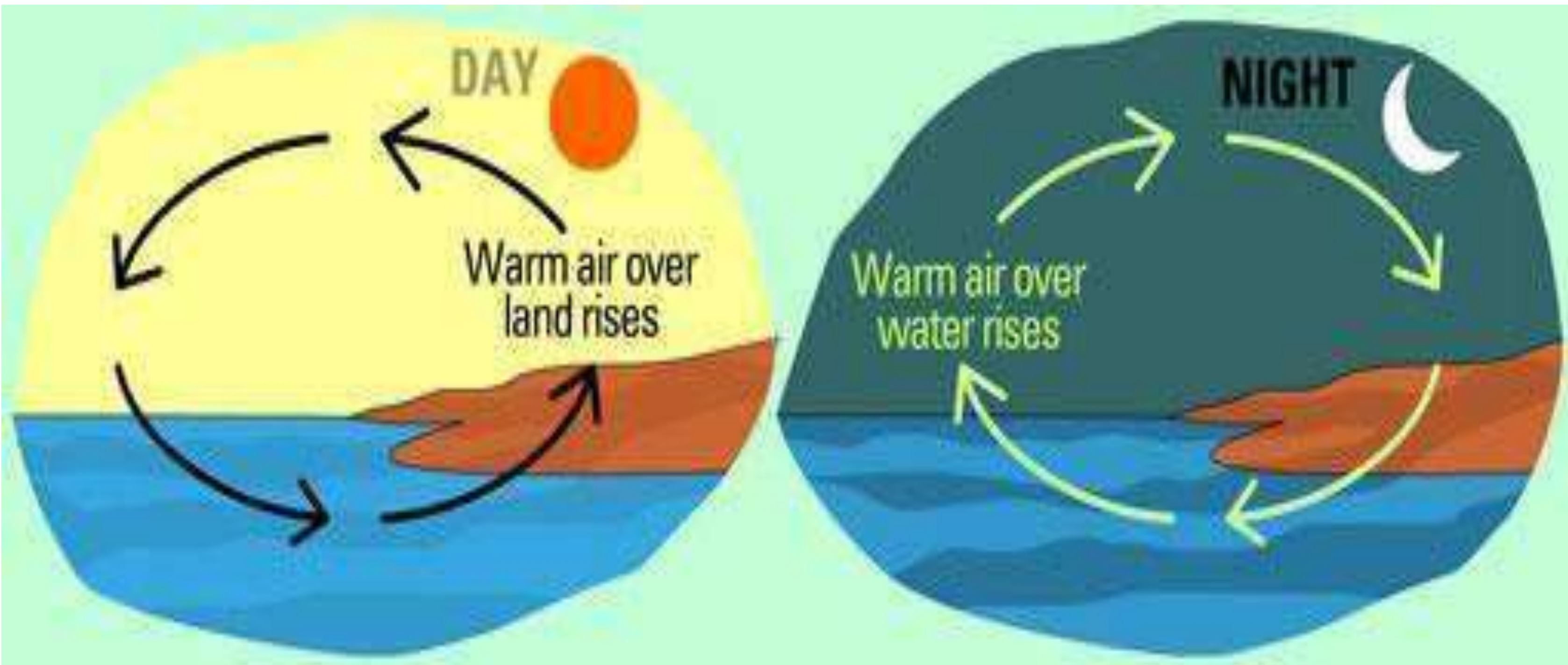
Principle of wind energy conversion; Basic components of wind energy conversion systems; windmill components, various types and their constructional features; design considerations of horizontal and vertical axis wind machines: analysis of aerodynamic forces acting on wind mill blades and estimation of power output; wind data and site selection considerations.

PRINCIPLE OF WIND ENERGY CONVERSION

- When solar radiation enters the earth's atmosphere, different regions of the atmosphere are heated to different degrees because of earth curvature.
- This heating is higher at the equator and lowest at the poles.
- Air tends to flow from warmer to cooler regions, this causes what we call winds.
- The kinetic energy of the air flow is called as wind energy.



PRINCIPLE OF WIND ENERGY CONVERSION



Advantages of Wind energy

- The wind energy is free, inexhaustible and does not need transportation.
- Wind mills will be highly desirable and economical to the rural areas which are far from existing grids.
- Wind energy is pollution free and environmental friendly

Disadvantage of Wind energy

- Wind power is not consistent and steady which makes the complications in designing the whole plant.
- Special and costly designs and controls are always required.
- The cost factor which has restricted the development of wind power in large scale for feeding to the existing grid .
- It has low efficiency.
- Careful survey is necessary for plant location

Applications of Wind Energy

- Power generation
- Grain grinding
- Water pumping

WIND ENERGY CONVERSION SYSTEM

- The system which is used to convert wind energy into mechanical energy which is converted into electrical energy is called as wind energy conversion system.
- The basic wind energy conversion device is known as **wind turbine**.

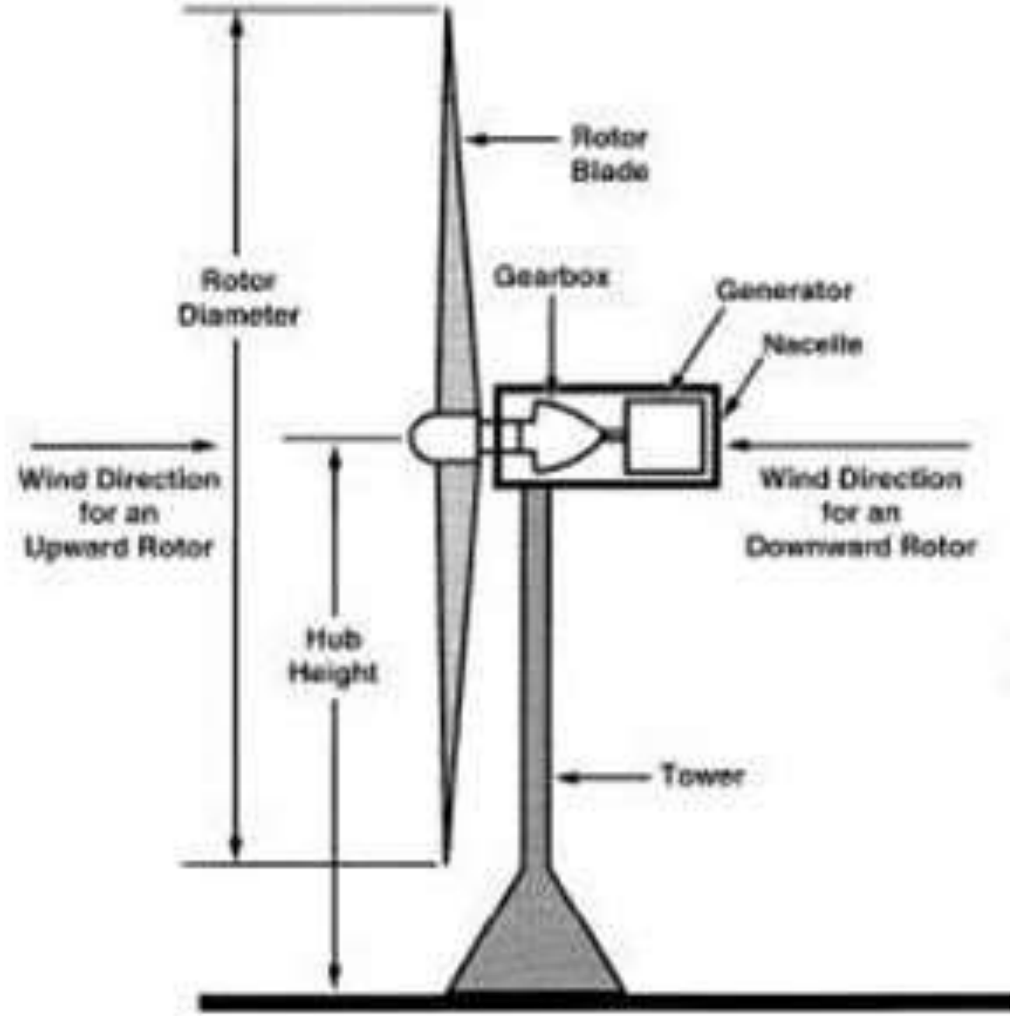
CLASSIFICATION OF WIND TURBINES

- Wind turbines are classified into two categories:

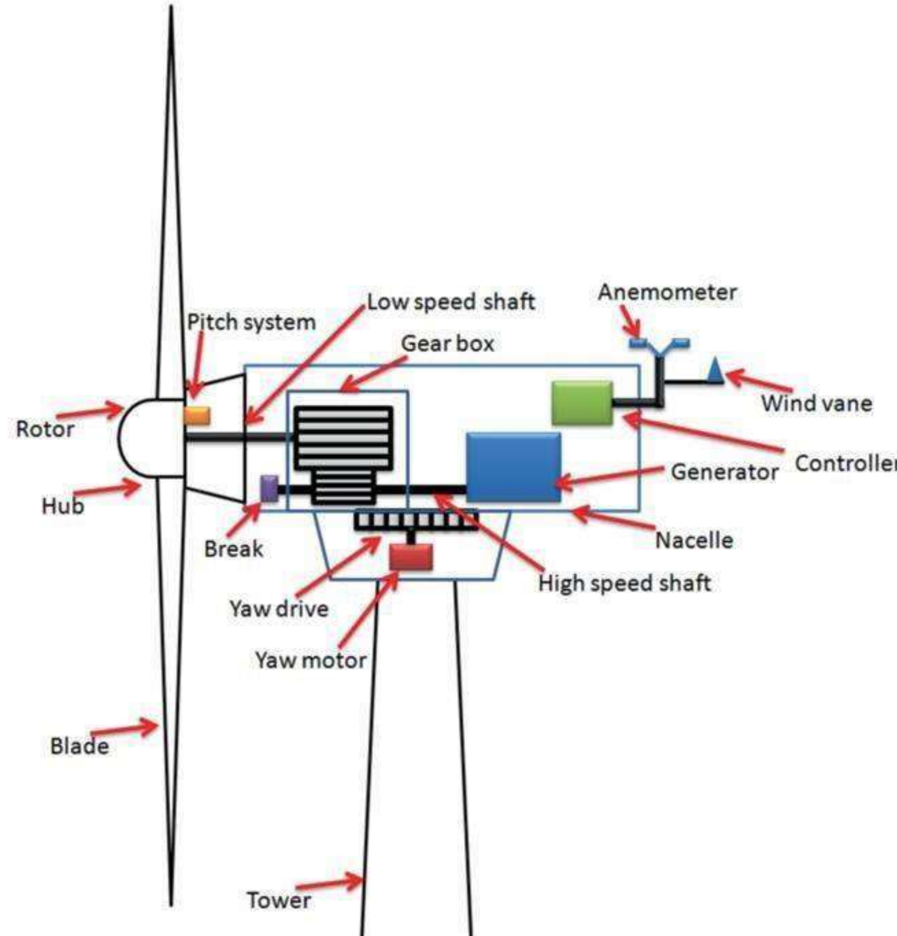
1. **Based on axis of rotation:**
   - ❑ Horizontal axis wind turbine.
   - ❑ Vertical axis wind turbine.
2. **Based on power output:**
   - ❑ Small scale plant (up to 2 KW)
   - ❑ Medium scale plants (2-100KW)
   - ❑ Large scale plants (> 100KW)
3. **Based on utilization of output:**
   - ❑ Battery storage
   - ❑ Direct connection to an electromagnetic energy converter
   - ❑ Other forms of storage (thermal potential)
   - ❑ Interconnection with conventional electric utility grids.

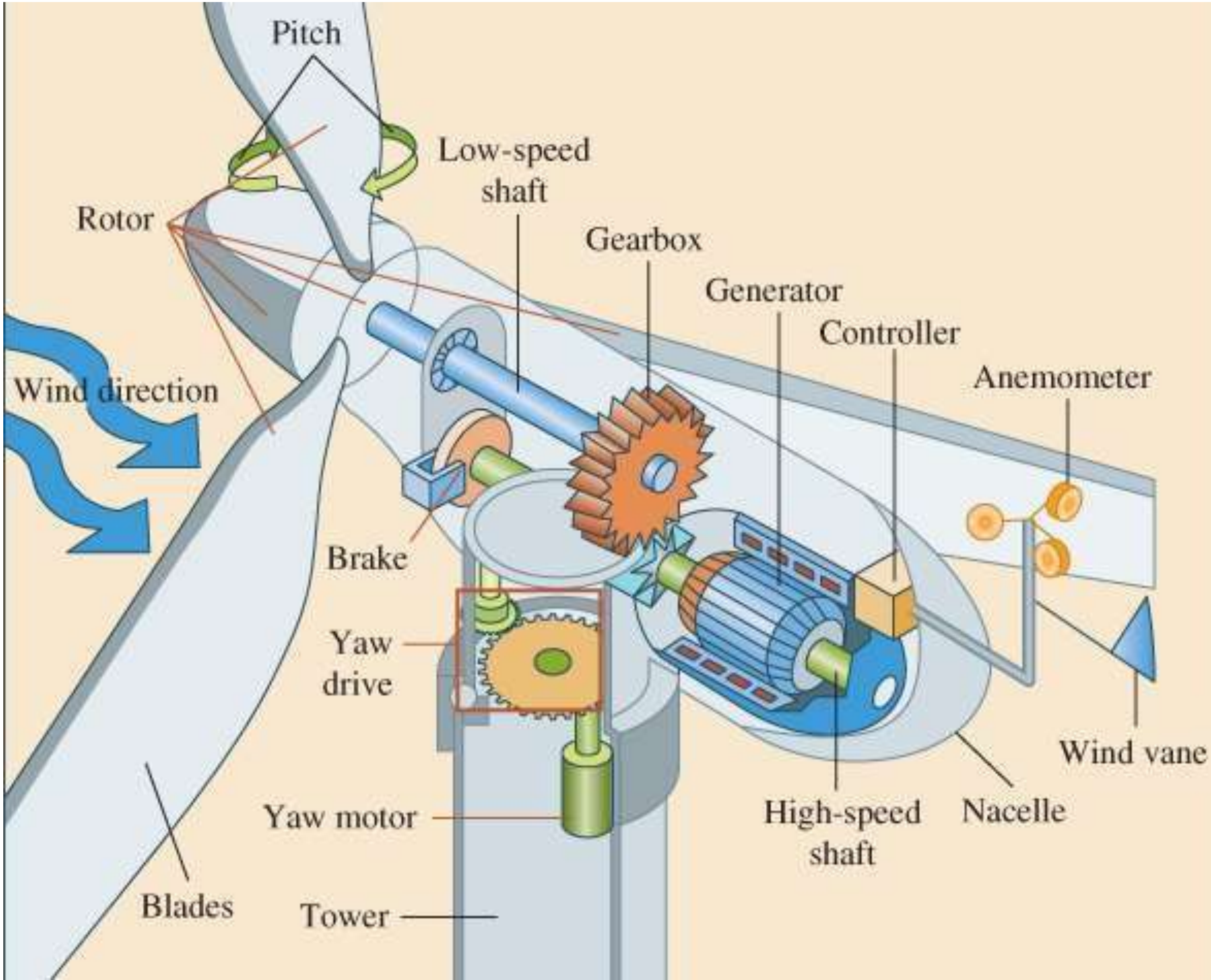
BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM

- When the axis of rotation is parallel to the air stream (i.e., horizontal) , the turbine is called as a **Horizontal axis wind turbine.**
- **BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM**
  - ✓ Hub
  - ✓ Turbine blades:
  - ✓ Nacelle or Housing
  - ✓ Gear box
  - ✓ Generator
  - ✓ Tower
  - ✓ Yaw control system



WINDMILL COMPONENTS





Pitch
Low-speed shaft
Rotor
Gearbox
Generator
Controller
Anemometer
Wind direction
Brake
Yaw drive
Yaw motor
Blades
Tower
High-speed shaft
Nacelle
Wind vane

HAWTPARTS

Hub

- The central solid portion of the rotor is called as hub.
- All blades are attached to the hub.

Turbine blades

- ✓ Turbine blades are made of high density wood or glass fiber and composite materials.
- ✓ They have an aerofoil type of cross section.
- ✓ The care should be taken in the design of blades. Because number of factors to be considered for centrifugal force, fatigue due to vibrations, gravitational forces, directional changes, wind turbulence etc.
- ✓ The three blade turbine provides better results compared to two blade turbine.

HAWT PARTS

NACELLE OR HOUSING

The rotor is attached to the nacelle and it is mounted at the end of the tower. It contains rotor brakes, gearbox, generator and electrical switch gear. Brakes are used to stop the rotor when the power generation is not required.

GEAR BOX:

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 ranges in between 1200 to 1800.

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.

HAWTPARTS

Generator

- The generator converts the turning motionof 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).
- They are available in a large range of output power ratings.
- The generator size is based on the length of the wind turbine's blades because more energy is captured by longer blades.

HAWTPARTS

TOWER:

- Tower is used to support nacelle and rotor.
- For medium and large sized turbines, the tower is slightly tallerthan the rotor diameter.
- In case of a small sized turbines, the tower is larger than the rotor diameter.
- Steel and concrete towers are preferred to be used.

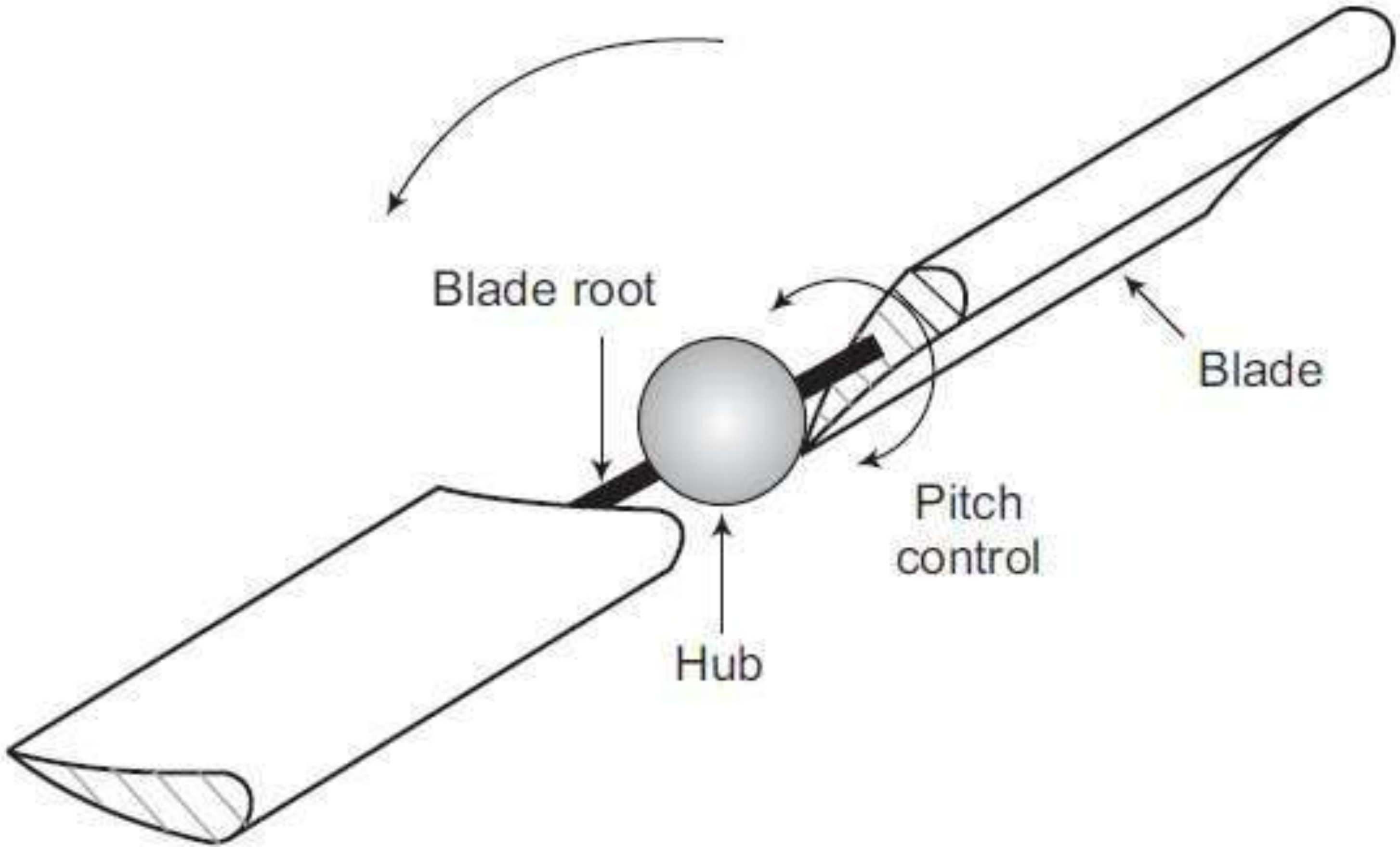
YAW CONTROL SYSTEM

- Adjusting the nacelle for bringing the rotor facing the wind is known as yaw control.
- The yaw control system is continuously orients the rotor in the direction of wind.
- In small wind turbines, the tail vane is used for maintaining orientation.
- In large turbines, power steering and wind direction sensor are used to maintain orientation.

PITCH CONTROL SYSTEM

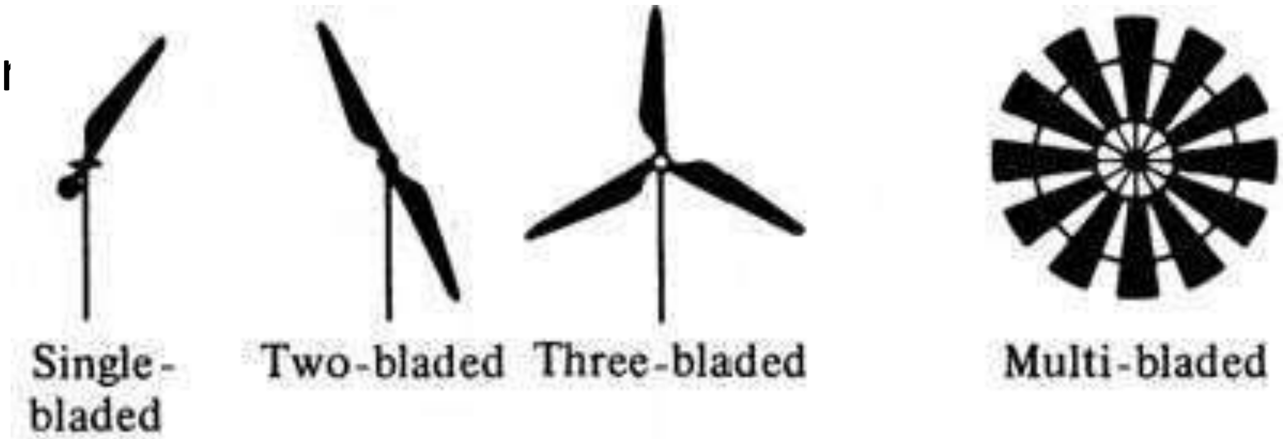
- Pitch of a blade is controlled by rotating it from its root, where it is connected to the hub as shown in Fig.
- Pitch control mechanism is provided through the hub using hydraulic jack in the nacelle.
- The control system continuously adjusts the pitch to obtain optimal performance.
- In modern machines, pitch control is incorporated by controlling only outer 20 per cent length of the blade (i.e. tip), keeping remaining part of the blade as fixed.

PITCH CONTROL SYSTEM

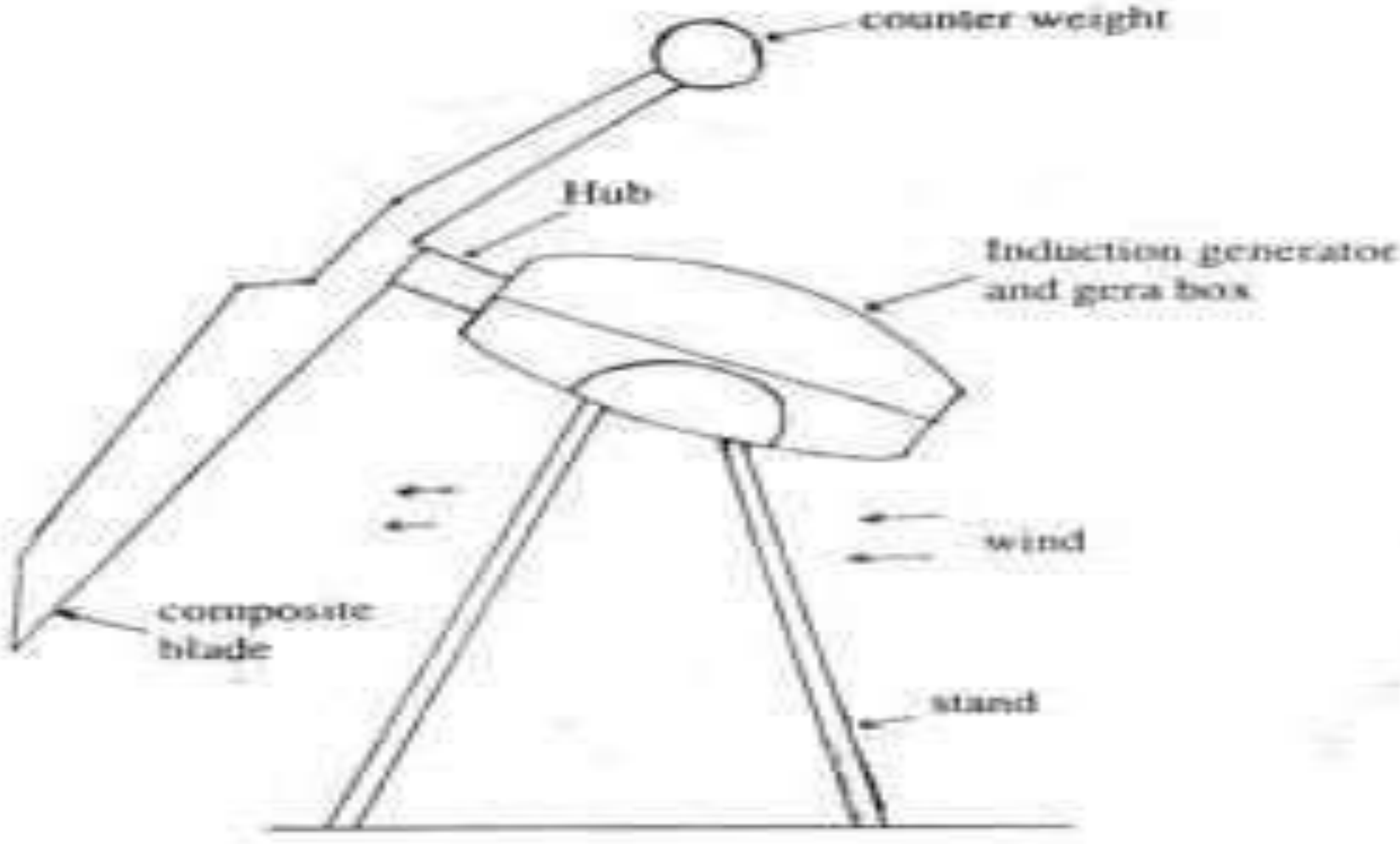


TYPES OF ROTORS FOR HAWT

- Single blade Rotor
- Two blade rotor
- Three blade rotor
- Multi blade rotor
- Dutch type rotor



SINGLE BLADE HAWT



SINGLE BLADE HAWT

- The single long blade which is centrifugally balanced by a low cost counter weight as shown in fig.
- This turbine is used to reduce rotor cost.
- The rotor hub consists of a Universal Joint between the rotor shaft and blade allowing for blade.
- This type of hub design contains fewer parts and less cost.

Fig: The NASA test of a one-bladed wind turbine rotor configuration at Plum Brook Station near Sandusky, Ohio

TWO OR DOUBLE BLADE HAWT

- The two blade rotor is usually designed to be oriented down wind of the tower.
- In this arrangement rotor drives generator through a step-up gear box.
- The components are mounted on a bed plate which is mounted at the Top of the tower.

TWO OR DOUBLE BLADE HAWT

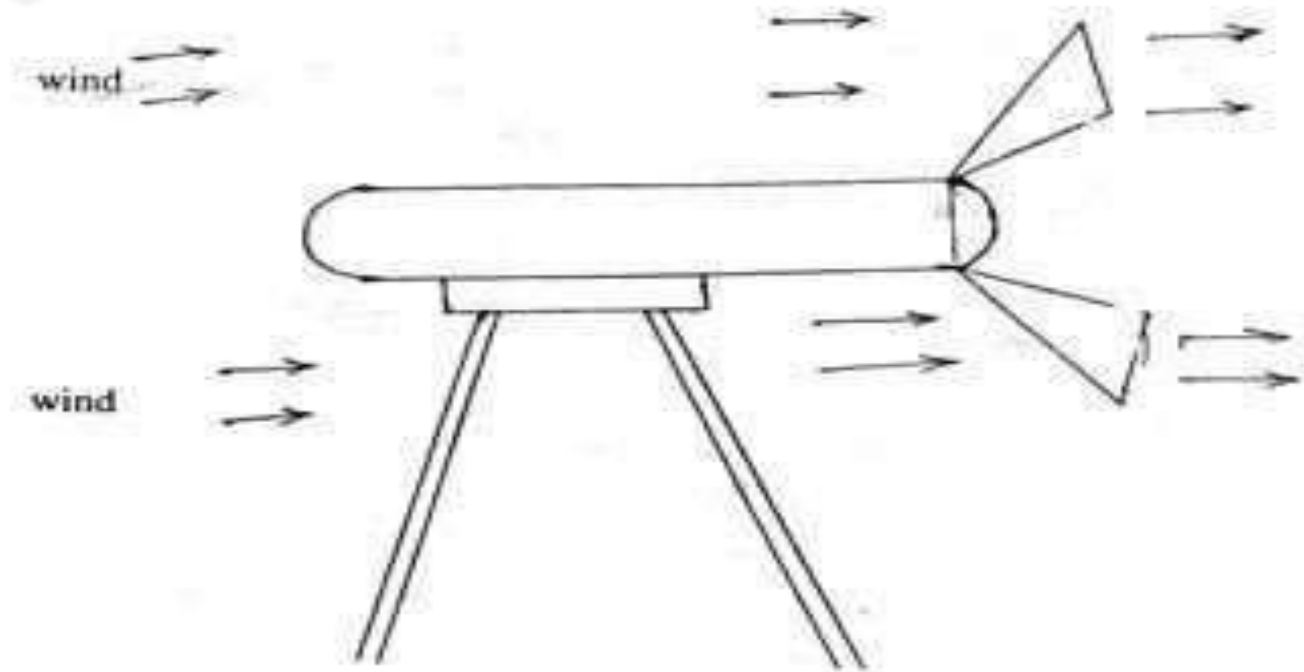


Fig: Two-bladed NASA/DOE Mod-5B wind turbine was the largest operating wind turbine in the world in the early 1990s (rotor dia= 98m)

THREE BLADED HAWT

- A turbine with three blades has very little vibration.
- This is because when one blade is in the horizontal position, its resistance to the yaw force is counter-balanced by the two other blades.
- So, a three-bladed turbine represents the best combination of high rotational speed and minimum stress.

MULTI BLADE HAWT

- The rotors of this design have high strength to weight ratios and have been known to survive hours of free wheeling operation in 100kmph winds.
- They have good power Co- efficient, high starting torque and added advantage of simplicity and low cost.

Horizontal axis- Dutch type wind mill

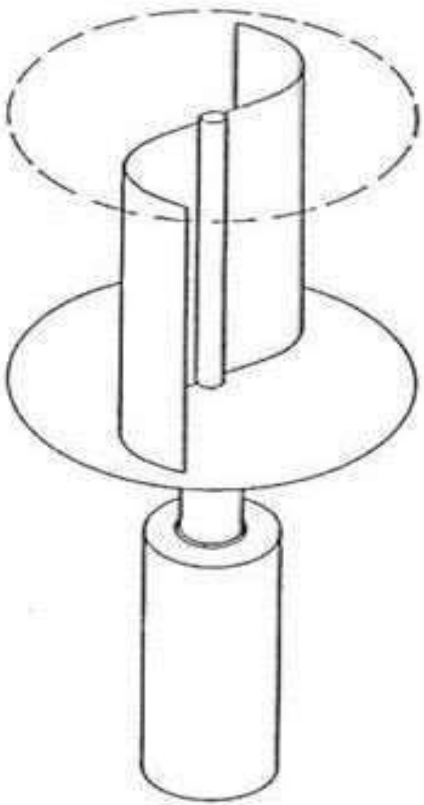
In dutch type, the blade surfaces are made of wooden boards which feather at high speeds.

Horizontal axis- American multi blade wind mill

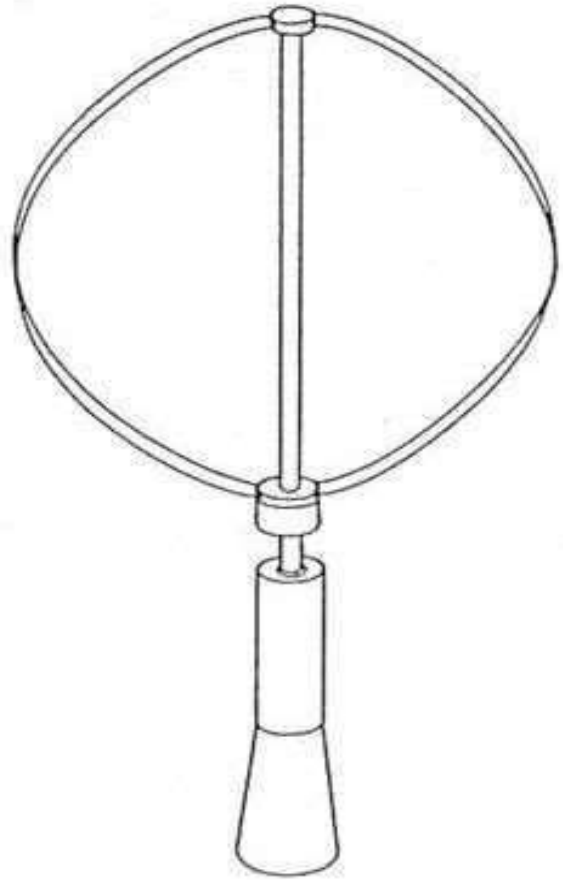
TYPES OF VERTICAL AXIS WIND TURBINE

- Vertical axis wind turbines have advantage that they are omni-directional . That means, they need not to be turned to force based on the wind direction. The Vertical mounted Wind Machines eliminate the need of yaw control system.
- Types are …
  - Darrieus rotor blade VAWT
  - Savonious rotor VAWT
  - Gyromill or H type rotor VAWT

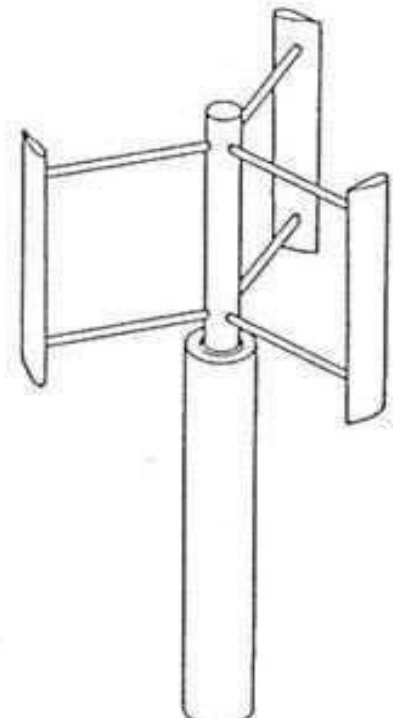
Savonius-Rotor



Darrieus-Rotor

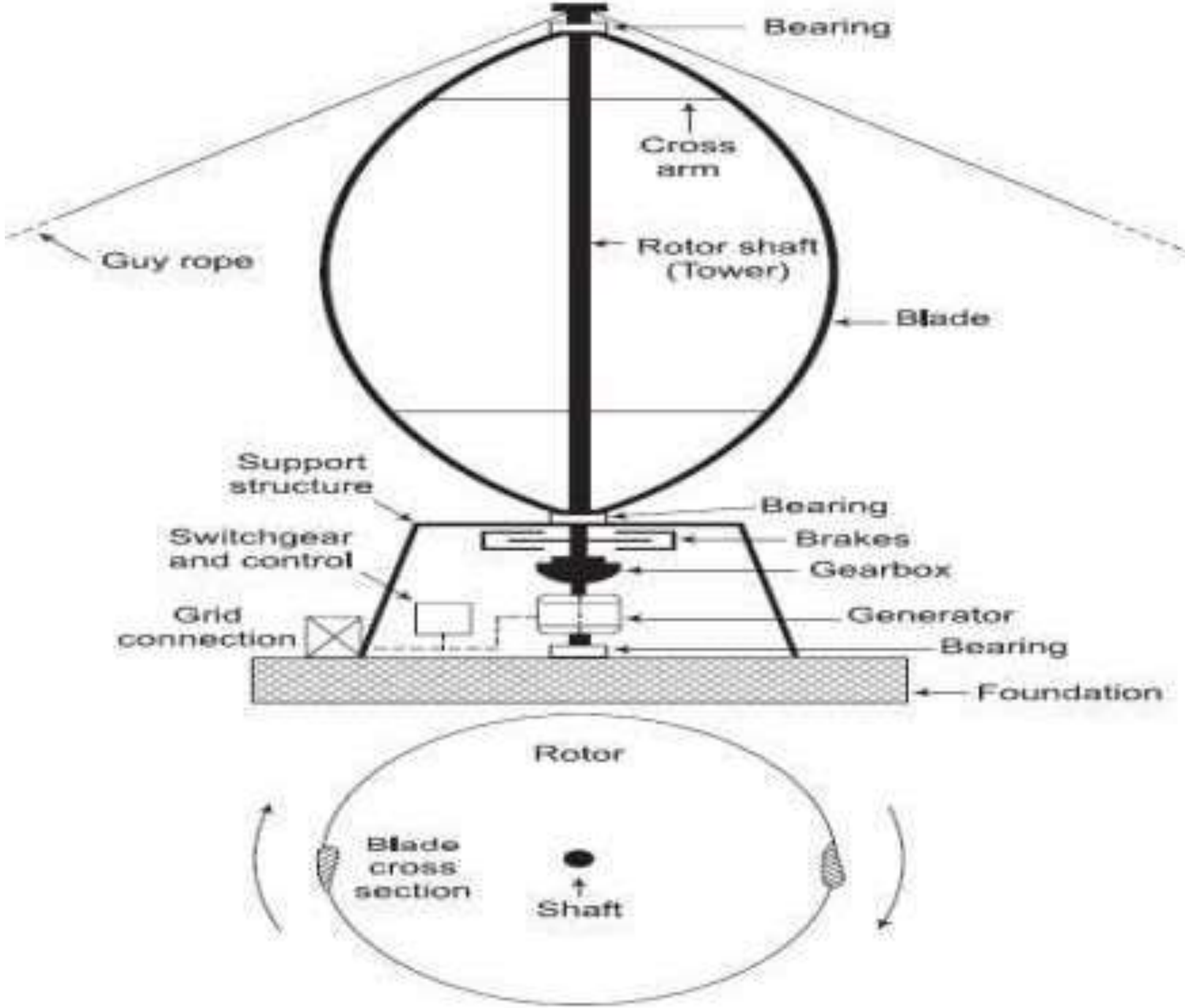


H-Darrieus-Rotor



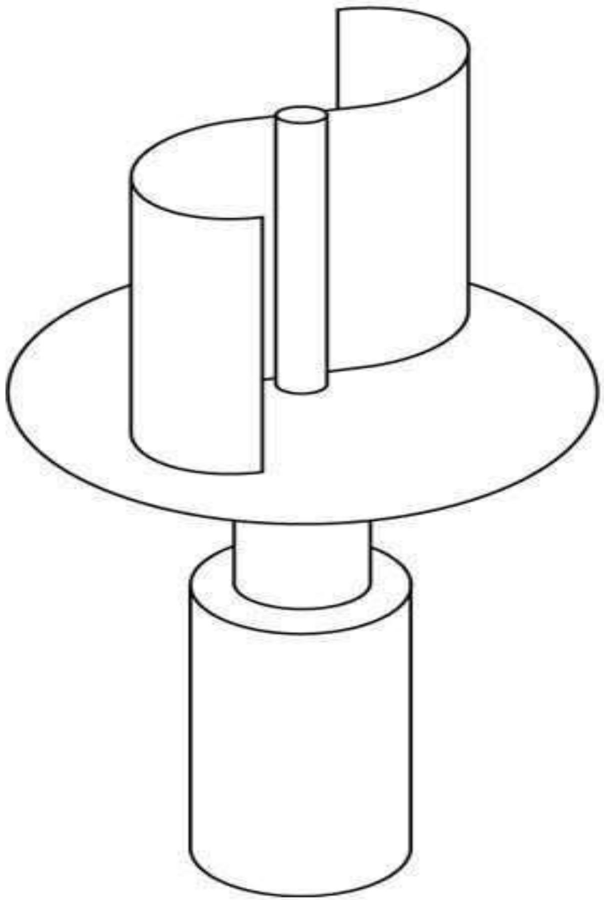
THE DARRIEUS ROTOR VAWT

- The Darrieus rotor consists of two or three convex metal blades with an aerofoil cross section, mounted on a central shaft which is supported by bearings at the top and bottom.
- The rotor assembly is held in position by guy wires which are connected from the top of the rotor to the ground.
- With the help of air velocity, the Darrieus rotor turns, the aerofoil blades move in a circular path and the rotor shaft rotates.
- The power is estimated with the help of torque and speed.


Bearing
Cross arm
Guy rope
Rotor shaft (Tower)
Blade
Support structure
Bearing
Switchgear and control
Brakes
Gearbox
Grid connection
Generator
Bearing
Foundation
Rotor
Blade cross section
Shaft

SAVONIOUS ROTOR VAWT

- It is also called as S rotor which consists of two half cylinders attached to a vertical axis and facing in opposite direction as shown in figure.
- It has high starting torque, low speed and low efficiency.
- It can produce power even from very slow wind.
- it is used for low power applications.
- It is mostly suitable for water
- pumping , grain grinding applications .
- Its best qualities are the simplicity, the reliability, very low noisy production



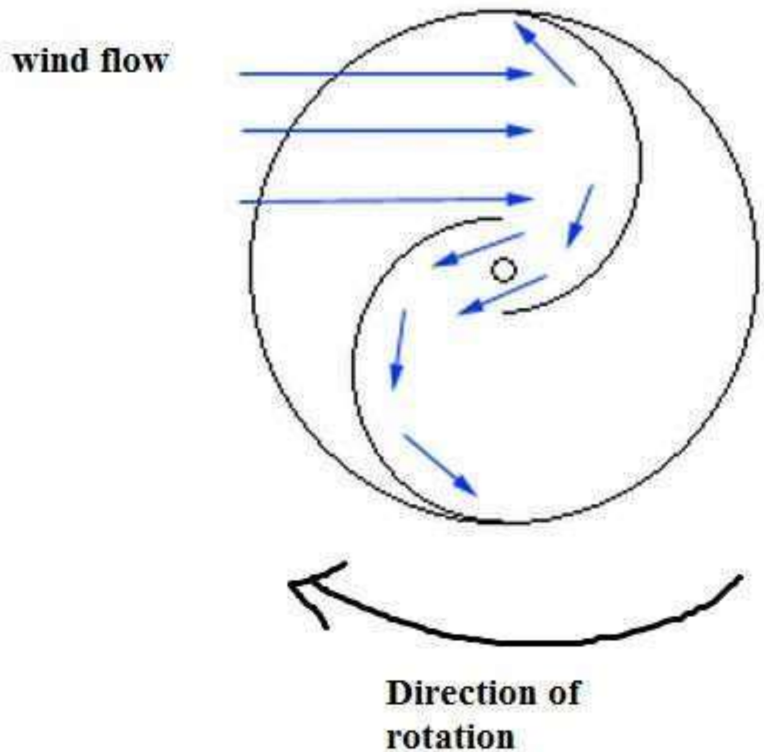


Fig: Savonious principle

Fig: Two blade Savonious rotor VAWT

Fig: Three blade Savonious rotor VAWT

THE GIROMILL TYPE VAWT

- The Giromill (or) H- bar design, in which the long egg beater blades of the Darrieus design are replaced with straight Vertical blade sections attached to the central tower with horizontal supports.

DESIGN CONSIDERATIONS OF HORIZONTAL AXIS WIND MACHINES

Aerodynamic Design

- ✓ Blade profile and airfoil selection
- ✓ Lift and drag considerations
- ✓ Wind tunnel testing

Structural Design

- ✓ Material selection
- ✓ Stress and fatigue analysis
- ✓ Tower design

AERODYNAMIC DESIGN (HAWT)

Blade profile and airfoil selection:

- The aerodynamic design of the rotor blades is crucial for efficient energy capture.
- Engineers carefully select airfoil shapes and blade profiles to optimize lift and minimize drag, which ultimately determines the turbine's performance.

AERODYNAMIC DESIGN (HAWT)

Lift and drag considerations:

- The lift force is generated by the pressure difference between the upper and lower surfaces of the blade’s airfoil as wind flows over it.
- This lift force contributes to the rotation of the blades. Drag, on the other hand, is the resistance force experienced by the blades as they move through the air.
- Engineers aim to maximize lift and minimize drag to improve overall turbine efficiency.

AERODYNAMIC DESIGN (HAWT)

Wind tunnel testing:

- Before constructing full-scale wind turbines, small-scale models are tested in wind tunnels to evaluate their aerodynamic performance.
- Wind tunnel testing helps identify potential design improvements and ensures that the final turbine design is efficient and stable under various wind conditions.

STRUCTURAL DESIGN (VAWT)

Material selection:

- HAWTs are subjected to significant stresses and loads due to wind forces and their rotating nature.
- Engineers carefully choose materials, often composites or metals, that offer a balance of strength, weight, and durability to withstand these forces over the turbine's operational lifespan.

AERODYNAMIC DESIGN (HAWT)

Stress and fatigue analysis

- The structural components, including the blades, hub, tower, and supporting structures, undergo stress and fatigue analysis to ensure their integrity and safety during their operational lifetime.
- Continuous cyclic loading from wind forces requires a thorough analysis of potential fatigue failure to prevent unexpected damage.

AERODYNAMIC DESIGN (HAWT)

Tower design:

- The tower provides support and elevation for the wind turbine components.
- The height of the tower is determined based on the wind conditions at the site and the desired power output.
- The tower’s design must also account for factors like wind-induced vibrations and tower resonance.

DESIGN CONSIDERATIONS OF VERTICAL AXIS WIND MACHINES

Aerodynamic Design

- Blade Shape and Orientation
- Start-up Wind Speed
- Torque Ripple

Structural Design

- Support Structure
- Durability and Longevity
- Material Innovation

AERODYNAMIC DESIGN (VAWT)

Blade Shape and Orientation:

- ✓ Blade shape and orientation play a critical role in the performance of VAWTs.
- ✓ Blade profiles need to be designed to efficiently convert wind energy into rotational motion.

AERODYNAMIC DESIGN (VAWT)

Start-up Wind Speed

✓ VAWTs often require specific wind speeds to start turning, so the blade design must be optimized to achieve self-starting at the lowest possible wind speed.

AERODYNAMIC DESIGN (VAWT)

Torque Ripple:

- ✓ Torque ripple refers to fluctuations in torque during the turbine’s operation, leading to vibrations and wear.
- ✓ The design must consider smoothing the torque to reduce mechanical stress

STRUCTURAL DESIGN (VAWT)

Support Structure:

- ✓ The support structure must be robust and lightweight to withstand wind forces and vibrations while minimizing material costs.

Durability and Longevity:

- ✓ Designing for durability is key to ensuring a long life span, as VAWTs are exposed to constant fatigue loading and environmental effects.

Material Innovation:

- ✓ New materials and manufacturing techniques can improve efficiency, reduce weight, and enhance durability, offering opportunities for design optimization.

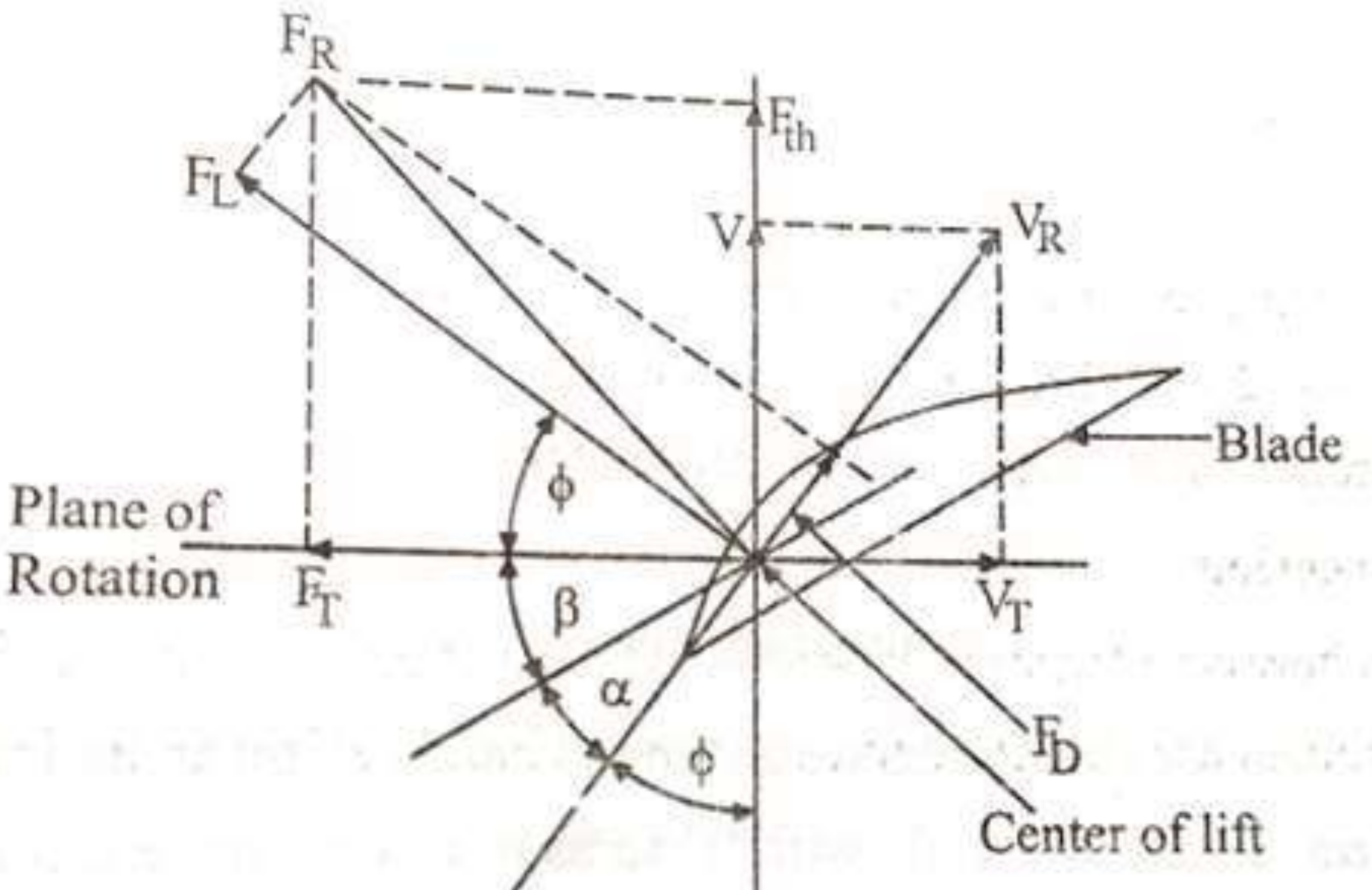
ANALYSIS OF AERODYNAMIC FORCES ACTING ON WIND MILL BLADES

- Aerodynamic forces acting on a blade element tending to make it rotate, these are important parameters for a system engineer.
- These are several basic types of blades on aero turbine may have, eg.,sails, planes and aerodynamic surfaces based on the air craft wing cross-section for which there are many kinds.
- The early history of wind mills is based on the first two; modern higher efficiency wind-electric generators are based on use of blades with aerodynamic surfaces.

ANALYSIS OF AERODYNAMIC FORCES ACTING ON WIND MILL BLADES

- Consider the aerodynamic blade shown in fig.,. The blade can be through of as a typical cross-sectional element of a two-bladed aeroturbine .
- The element shown is at some radius ‘r’ from the axis of rotation.
- It is moving to the left. Because the blade is moving in the plane of rotation it sees a tangential wind velocity, V_T, in the plane of rotation.

VECTOR DIAGRAM OF FORCES ON A ELEMENTAL BALDE SECTION OF AN AERO TURBINE



NOMENCLATURE OF A AEROTURBINE BLADE CROSS SECTION

$V \rightarrow$ Impinging wind velocity,

$V_T \rightarrow$ Wind velocity in plane of rotation due to blade turning,

$V_R \rightarrow$ Resultant wind velocity seen by Aeroturbine blade,

$F_L \rightarrow$ Lift force (Normal to V_R),

$F_D \rightarrow$ Drag force (Parallel to V_R),

$F_R \rightarrow$ Resultant force on blade,

$F_T \rightarrow$ Torque producing component of F_R making aeroturbine rotate,

$F_{th} \rightarrow$ Thrust force component of F_R,

$\alpha \rightarrow$ Angle of attack of blade, and

$\beta \rightarrow$ Blade pitch angle.

ANALYSIS OF AERODYNAMIC FORCES ACTING ON WIND MILL BLADES

- This component added vectorially to the impinging wind velocity gives the resulting wind velocity, V_R, seen by the rotating balde element.
- At right angles to V_R, is the lift force F_L, caused by the aerodynamic shape of the blade.
- The drag force, F_D is parallel to V_R.
- The vector sum of F_L and F_D is F_R which has a torque producing component, F_T and a thrust producing component.
- The former is what drives the aero-turbine rotationally and the later tends to flex and also overturn the aerogenerator.

ANALYSIS OF AERODYNAMIC FORCES ACTING ON WIND MILL BLADES

- The vector diagram is centred on the centre of lift of the aerodynamic blade.
- As is well known from aircraft wind theory, one of the critical parameters is ’α’ the angle of attack of the aerodynamic element, It determines lift and drag forces and hence speed and torque output of the aeroturbine.
- This quantities can be varied by changing the blade pitch angle ‘β’, and this is the basis torque control method used on large variable pitch wind-electric generators.
- The torque would determine the AC output power if a synchronous generator was used.

ANALYSIS OF AERODYNAMIC FORCES ACTING ON WIND MILL BLADES

- Since V_T, increases linearly as we go out radically, ‘r’, on an inclined aeroturbine blade, it is necessary to adjust ‘β’ with ‘r’ so as to always have a positive angle of attack and to maintain reasonable stress levels within the blade.
- This mean that at large ‘r’, ‘β’ is made small while at small ‘r’, ’β’ is large.
- Thus the blade ‘bites’ the air more in close than near the tips.
- These the considerations result in an aeroturbine blade with an apparent twist in it.

SITE SELECTION CONSIDERATIONS

- The power produced by the wind turbine depends on the available wind speed.
- Therefore, the wind turbines are located at a place where persistent and strong wind is available.
- The wind varies daily. So, we need to analyze the data for a month or year.

SITE SELECTION CONSIDERATIONS

- To select the location for a wind turbine, the below-listed matters need to be considered;
  - ✓ Wind speed
  - ✓ Grid structure
  - ✓ Distance
  - ✓ Altitude of location
  - ✓ Nature of ground
  - ✓ Land cost

WIND SPEED

- The power generated by the wind turbine depends on the cubic values of the velocity of the wind.
- Therefore, a small change in wind speed varies more generated power.
- We need to consider the average wind speed available for a particular location. For that, we required the data of wind speed for a year or month.
- After data analysis, we need to consider an average wind speed and select a site with a strong wind speed.

GRID STRUCTURE

- The power generated by the wind turbine is transferred to the load via a grid.
- The power output of the wind turbine depends on the wind speed and it fluctuates with respect to time.
- So, power output is also fluctuating with respect to time which gives poor power quality.
- Hence, the connection of wind turbines with the grid is the most important task.

DISTANCE

- The transmission line is used to connect the wind turbine with the substation or load center.
- If the distance of wind power plants is more, it will increase the transmission cost.
- Therefore, we need to select the site near the load center to reduce the transmission cost.

ALTITUDE OF LOCATION

- At high altitude, the wind density is high which increase the output of wind turbine.
- In a place where the altitude is not available, the tower size is increased to get a high altitude.
- The height of the wind turbine is calculated from the sea level.

NATURE OF GROUND

- To achieve high-density wind, the wind turbine is constructed at height.
- It requires a big and strong foundation to the ground.
- So, the nature of the ground is free from erosion and the place is free from land sliding problems.

LAND COST

- The initial cost of a wind turbine is very high because it uses costly material and very big construction of blades.
- The cost of land is also including in the capital cost. therefore, the cost of land must be as low as possible to reduce the capital cost.
- In most cases, the wind turbines are placed the non-useable lands.