UNIT-III

1. What is wind? How much amount of energy is contained in the wind?

A. Wind is the movement of air caused by the uneven heating of the Earth by the sun. Wind is moving air and is caused by differences in air pressure within our atmosphere. Air under high pressure moves toward areas of low pressure. The greater the difference in pressure, the faster the air flows.

An average onshore **wind** turbine with a capacity of 2.5–3 MW can produce more than 6 million kWh in a year – enough to supply 1,500 average EU households with **electricity**.

2. Write the short notes on Darrieus rotor

A. The Darrieus rotor is a vertical axis wind turbine (VAWT) provided with two or more blades having an aerodynamic airfoil. The blades are normally bent into a chain line and are connected to the hub at the upper and lower side. However, also Darrieus rotors with straight blades (H-Darrieus) have been developed which therefore have large hubs provided with spokes. The energy is taken from the wind by a component of the lift force L working in the direction of rotation. The same principle is used for a horizontal axis wind turbine (HAWT).

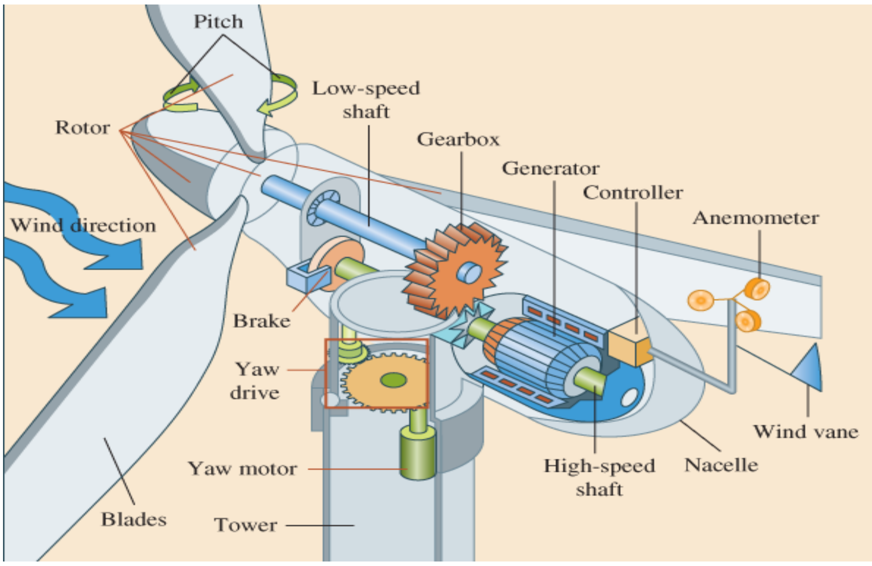
1.Vertical axis wind turbine

2.Horizontal axis wind turbine

3. **Explain horizontal axis wind turbine main components and their function.**

   A. We call the wind turbines that have horizontal shaft as horizontal axis wind turbines or in short HAWT. In HAWT the turbine rotor couples the electrical generator and this turbine generator set is placed on the top of the turbine tower.

   The horizontal-axis wind turbine (HAWT) is a wind turbine in which the main rotor shaft is pointed in the direction of the wind to extract power. The principal components of a basic HAWT are shown in Figure 1.



- **The tower** is the physical structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine equipment. Typical commercial wind towers are usually 50–120 m long and they are constructed from concrete or reinforced steel.
- **Blades** are physical structures, which are aerodynamically optimized to help capture the maximum power from the wind in normal operation with a wind speed in the range of about 3–15 m/s. Each blade is usually 20 m or more in length, depending on the power level.

- **The nacelle** is the enclosure of the wind turbine generator, gearbox, and internal equipment. It protects the turbine's internal components from the surrounding environment.
- **The rotor** is the rotating part of the wind turbine. It transfers the energy in the wind to the shaft. The rotor hub holds the wind turbine blades while connected to the gearbox via the low-speed shaft.
- **Pitch** is the mechanism of adjusting the angle of attack of the rotor blades. Blades are turned in their longitudinal axis to change the angle of attack according to the wind directions.
- **The shaft** is divided into two types: low and high speed. The low-speed shaft transfers mechanical energy from the rotor to the gearbox, while the high-speed shaft transfers mechanical energy from gearbox to generator.
- **Yaw** is the horizontal moving part of the turbine. It turns clockwise or anticlockwise to face the wind. The yaw has two main parts: the yaw motor and the yaw drive. The yaw drive keeps the rotor facing the wind when the wind direction varies. The yaw motor is used to move the yaw.
- **The brake** is a mechanical part connected to the high-speed shaft in order to reduce the rotational speed or stop the wind turbine over speeding or during emergency conditions.
- **Gearbox** is a mechanical component that is used to increase or decrease the rotational speed. In wind turbines, the gearbox is used to control the rotational speed of the generator.
- **The generator** is the component that converts the mechanical energy from the rotor to electrical energy. The most common electrical generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).
- **The controller** is the brain of the wind turbine. It monitors constantly the condition of the wind turbine and controls the pitch and yaw systems to extract optimum power from the wind.
- **Anemometer** is a type of sensor that is used to measure the wind speed. The wind speed information may be necessary for maximum power tracking and protection in emergency cases.
- **The wind vane** is a type of sensor that is used to measure the wind direction. The wind direction information is important for the yaw control system to operate.

4. What are the basic components of the horizontal wind mill.

A. Same as above answer

5. **How do you classify windmills? Explain any one type with neat sketches.**

A. **Windmills are those machines that help us harvest the wind energy to produce electricity. Windmills convert the kinetic energy of wind to electricity.** Types/ Designs of Windmills

There are two types of designs in windmill:

1. ***Vertical axis windmills***
2. ***Horizontal axis windmills***

Let us go into its description one by one.

Vertical Axis Windmills

In the early development stage, vertical axis wind mills were very popular and were in wide use. It is in such a design that the blades will be perpendicular to the ground. These vertical axis wind mills were replaced by the horizontal axis windmills later due to its incompetence. This was mainly used for grinding grains or pumping water.

The vertical axis windmill is called as horizontal windmills. Thus please do not confuse yourself with both the names as if you miss the word "axis", the whole idea and meaning will change, giving you the antonym.

Horizontal Axis Windmills

Horizontal axis windmills won the hearts of many due to its efficiency and productivity. It is known for its elasticity design as it harness more wind and easy for the operating person to change the direction according to the wind flow.

This horizontal axis windmills are called as vertical windmills. There are different kinds of horizontal axis windmills, namely,

- Post Mill
- Smock Mill
- Tower Mill
- Fan mill

Post Mill

It was the most old horizontal axis windmill. The unique feature is that it is mounted on a single vertical post, on which it can be turned. Post mills have different categories:

- Sunk Post Mill
- Open Trestle Post Mill
- Post Mill with roundhouse
- Hollow Post Mill
- Composite Mill
- Paltrok mill

The 19th century saw the decline in Post mills when they were replaced by other powerful windmills such as tower and smock mills.

Smock Mill

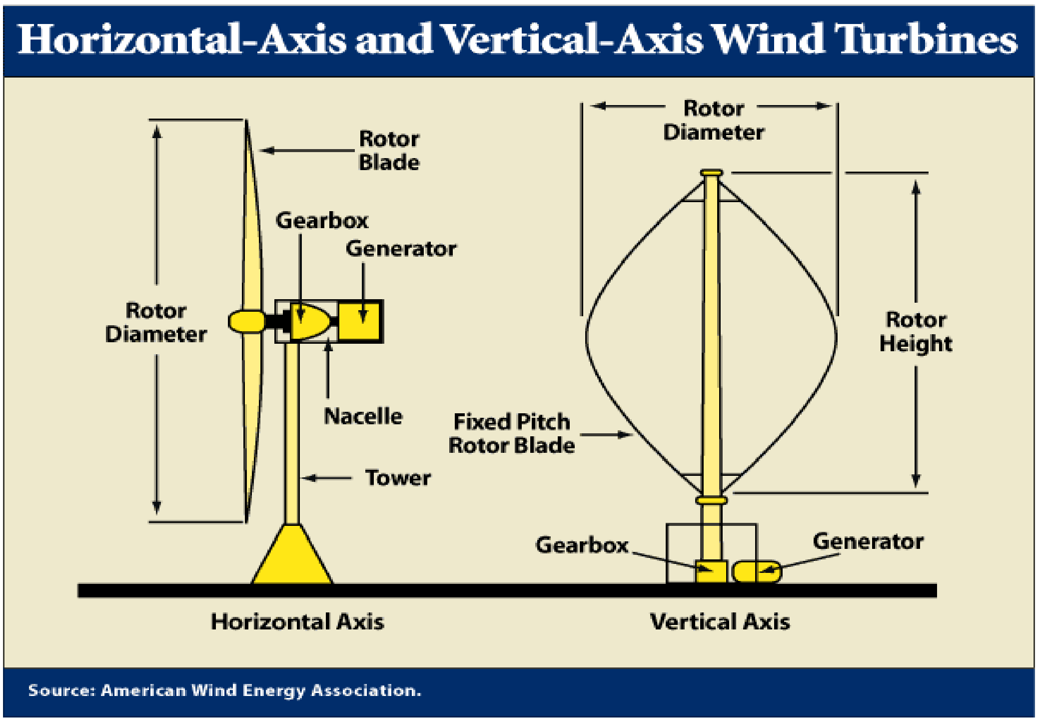
Smock mills are those horizontal boarded towers which generally have six to eight sides. The name got originated from the shape of its body as it looks like a smock.The main feature of the smock mill is that, the top part of it is flexible. Thus, this part can be moved around according to the direction of wind, while the other part remains stable. The main body part being stable, it can be much bigger and taller. As we know, the taller the tower, the more wind it could harvest. The productivity will be always high.

Tower Mills

Tower mill is very similar to that of the smock mill. The only difference is that the body of the tower mill is made of bricks or stones, making it very strong and resistant. The body can be built in any height since it is made with the stones or bricks.

Fan Mills

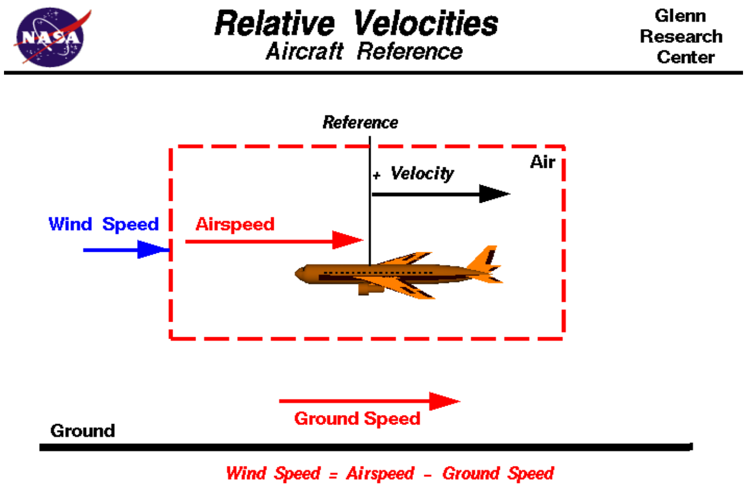
Fan mills are small windmill designs for single use purpose. It has four to twenty blades and mainly used for pumping water.



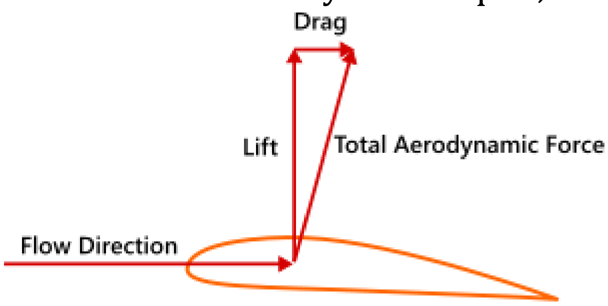
6. **What is a windmill? What are various classifications of a windmill? Explain them in detail with neat sketches.**
   A. Same as above answer (5)

7. **With the help of diagram, explain the terms, (i) Free and relative wind velocities (ii) Drag and lift forces and (iii) Pitch angle and chord**

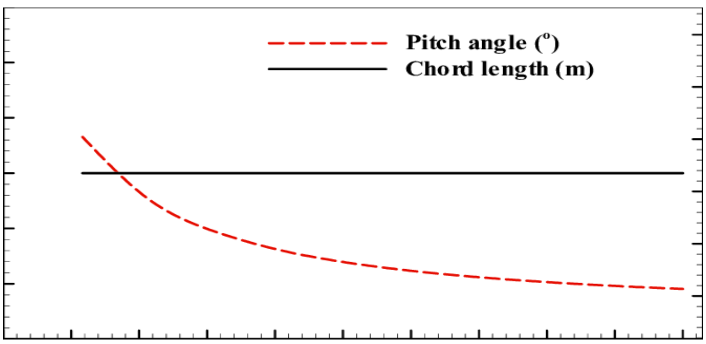
A . 1.Free and relative wind velocities: This vector is the **relative wind** or the **free** stream **velocity** vector. The angle between the chord line of an airfoil and the **relative wind** defines the angle of attack. The **relative wind** is of great importance to pilots because exceeding the critical angle of attack will result in a stall, regardless of airspeed.



2.Drag and lift forces: Lift is the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is the component of the force parallel to the flow direction. If the surrounding fluid is air, the force is called an aerodynamic force. In water or any other liquid, it is called a hydrodynamic force.



3. **Pitch angle and chord:** Chord Length, is the length of the chord line and is the characteristic dimension of the aerofoil section.*Pitch angle (α):* The angle between the chord of the aerofoil section and the plane of rotation, also called as setting angle. It is also called as angle of attack.



8. **Derive an expression for energy available in the wind.**

A. Wind energy is a renewable source of energy that determines the total power in the wind. The wind turbines which convert kinetic energy to mechanical power, wherein the mechanical power is converted into electricity which acts as a useful source.

The wind energy formula is given by,

$$P = \frac{1}{2}\rho A V^3$$

Where,

P = power,

ρ = air density,

A = swept area of blades given by $A = \pi r^2$

where r is the radius of the blades.

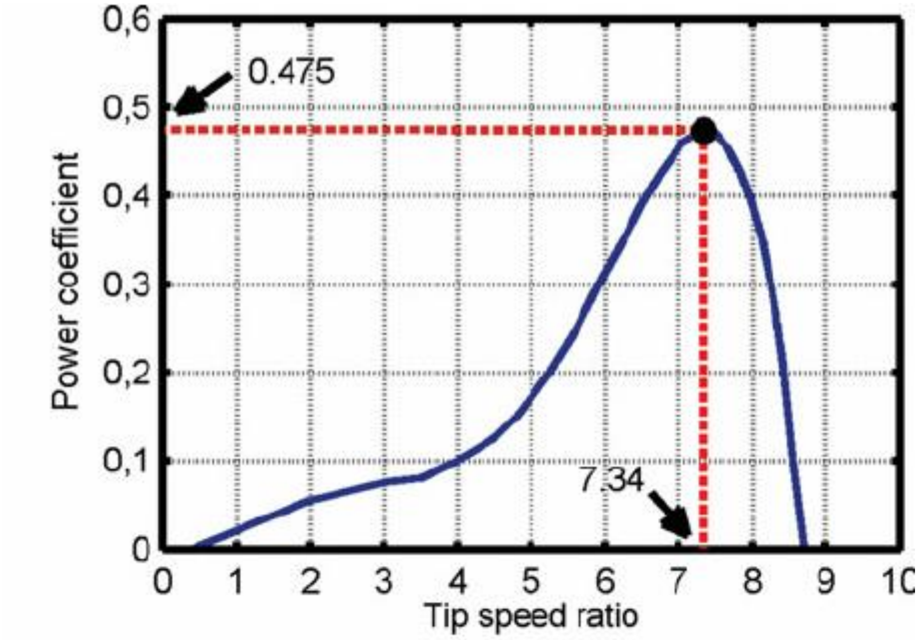
V = velocity of the wind.

9. **What are the factors to be considered to the site selection of windmill?**

A. 1. High annual average wind speed
2. Availability of anemometry data
3. Availability of wind V(t) Curve at the proposed site
4. Wind structure at the proposed site
5. Altitude of the proposed site
6. Terrain and its aerodynamic
7. Local Ecology
8. Distance to road or railways
9. Nearness of site to local centre/users
10. Nature of ground
11. Favourable land cost

10. **Draw the performance characteristic curves of different windmills.**

A.



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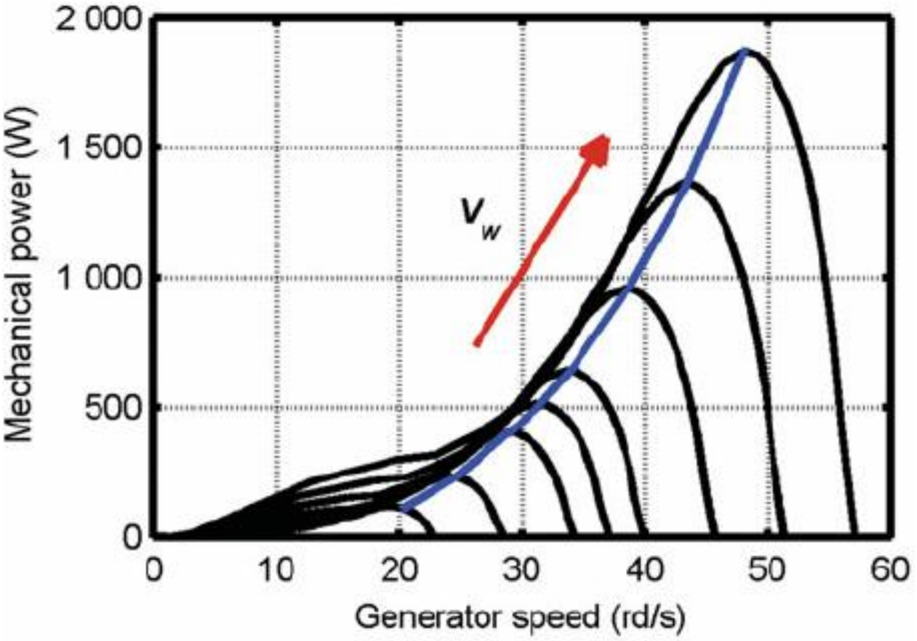

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11. Define, (i) cut-in speed (ii) Cut-out speed (iii) Yaw control (iv) Coefficient of performance of a windmill.

A.1)Cut-in speed: The **cut-in speed** (typically between 6 and 9 mph) is when the blades start rotating and generating power. As **wind speeds** increase, more electricity is generated until it reaches a limit, known as the rated **speed.** This is the point that the **turbine** produces its maximum, or rated power

2)Cut-out speed: A turbine's **cut**-in and **cut-out speed** (also called '**cut-off' speed**) are determined by the manufacturer to protect the turbine from damage. The **cut**-in **speed** is simple; it's the point at which the turbine starts generating electricity from turning.

3)Yaw control: Yaw refers to the rotation of the entire **wind turbine** in the horizontal axis. **Yaw control** ensures that the **turbine** is constantly facing into the **wind** to maximize the effective rotor area and, as a result, power.

4)Coefficient of performance of a windmill: The **coefficient of performance**, CP, also called the power **coefficient** of a **wind turbine**, is defined as the ratio of the power captured by the rotor of the **wind turbine**, PR, divided by the total power available in the **wind**, P, just before it interacted with the rotor of the **turbine**.

12. Write short notes on Savonius rotor.

A. savonius rotor creates high torque and is self- starting even at low wind speeds ,but is relatively low in efficiency rating .

The performance analysis of savonius rotor with twisted blades, renewable energy 31,PP. The geometry of the blade shape (skeleton line) of savonius rotor with two blades was optimized in order to obtain better performance of output power and static torque.

In order to improve sharp bending streamlines occurring in overlap area of savonius rotor with two blades , the novel rotor is composed of three blades in other to adjust angle of accepting air flow of the oriented blade.

13. Why tall tower is essential for mounting a horizontal axis wind turbine?

A. The **tall tower** base allows access to stronger **wind** in sites with **wind** shear. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.**High** efficiency, since the blades always move perpendicularly to the **wind**, receiving **power** through the whole rotation.

14. Why does a wind turbines have 3-blades?

A. Two-bladed **wind turbines** are more prone to a phenomenon known as gyroscopic precession, resulting in a wobbling. Any number of **blades** greater than **three** would create greater **wind** resistance, slowing the generation of electricity and thus becoming less efficient than a **three blade turbine**.

15.What are the main considerations while designing a wind turbine blade?

A.The shape and dimensions of the blades of the wind turbine are determined by the aerodynamic performance required to efficiently extract energy from the wind, and by the strength required to resist the forces on the blade.

- You want laminar flow for efficiency and power.
- Smooth flow cuts turbulence that introduces vibration and early fatigue failure.
- Lower rotation speed is important as well it determines the blade speed in the air. Slower speeds. Lower drag. Lower rotation forces.
- Blade materials need to be weather resistant and environmentally stable.
    - Length, chord, attachment requirements.
    - Flutter, pitch, need for vortex generators.
    - Fatigue from turbulent air, impact from foreign objects including birds and hail.
    - Temperature stability and creep.
    - Is it designed for a variable pitch hub and how is it feathered.
-

16. What is Betz criteria?

A. Betz's law indicates the maximum power that can be extracted from the wind, independent of the design of a wind turbine in open flow. According to Betz's law, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind. The factor 16/27 (0.593) is known as Betz's coefficient.

17. Using Betz model of wind turbine derive an expression for power extracted from wind.

A.

18. What are various characteristics of the wind? Discuss them in detail.

A. As the wind power is proportional to the cubic wind speed, it is crucial to have detailed knowledge of the site-specific wind characteristics. Even small errors in estimation of wind speed can have large effects on the energy yield, but also lead to poor choices for turbine and site. An average wind speed is not sufficient. Site-specific wind characteristics pertinent to wind turbines include:

- mean wind speed: Only interesting as a headline figure, but does not tell how often high wind speeds occur.
- wind speed distribution : diurnal, seasonal, annual patterns
- turbulence: short-term fluctuations
- long-term fluctuations
- distribution of wind direction
- wind shear (profile)

19. List out the difficulties encountered in general in operating large wind power generators.

A. Wind power must still compete with conventional generation sources on a cost basis. Even though the cost of wind power has decreased dramatically in the past several decades, wind projects must be able to compete economically with the lowest-cost source of electricity, and some locations may not be windy enough to be cost competitive.

Good land-based wind sites are often located in remote locations, far from cities where the electricity is needed. Transmission lines must be built to bring the electricity from the wind farm to the city. However, building just a few already-proposed transmission lines could significantly reduce the costs of expanding wind energy.

Wind resource development might not be the most profitable use of the land. Land suitable for wind-turbine installation must compete with alternative uses for the land, which might be more highly valued than electricity generation.

Turbines might cause noise and aesthetic pollution. Although wind power plants have relatively little impact on the environment compared to conventional power plants, concern exists over the noise produced by the turbine blades and visual impacts to the landscape.

Wind plants can impact local wildlife. Birds have been killed by flying into spinning turbine blades. Most of these problems have been resolved or greatly reduced through technology development or by properly siting wind plants.

20. Describe the main considerations in selecting a site for wind generators.

A. same as question 15

21. What is tower shadowing effect?

A. Tower shadow effect is the alteration in uniform flow of wind due to the presence of the **tower**. For an upwind turbine, when the blade is directly in front of the **tower**, it experiences minimum wind.

LAQS

1. What Betz constant? Prove the maximum power coefficient C_P for a windmill is 0.593.

A. Betz's law indicates the maximum power that can be extracted from the wind, independent of the design of a wind turbine in open flow.

The "*power coefficient* C_p (= P/P_{wind}) is dimensionless ratio of the extractable power P to the kinetic power P_{wind} available in the undistributed stream. It has a maximum value $C_{p\,max}$ = 16/27 = 0.593 (or 59.3%; however, coefficients of performance are usually expressed as a decimal, not a percentage).

2. Describe the basic components of the horizontal wind mill in detail.

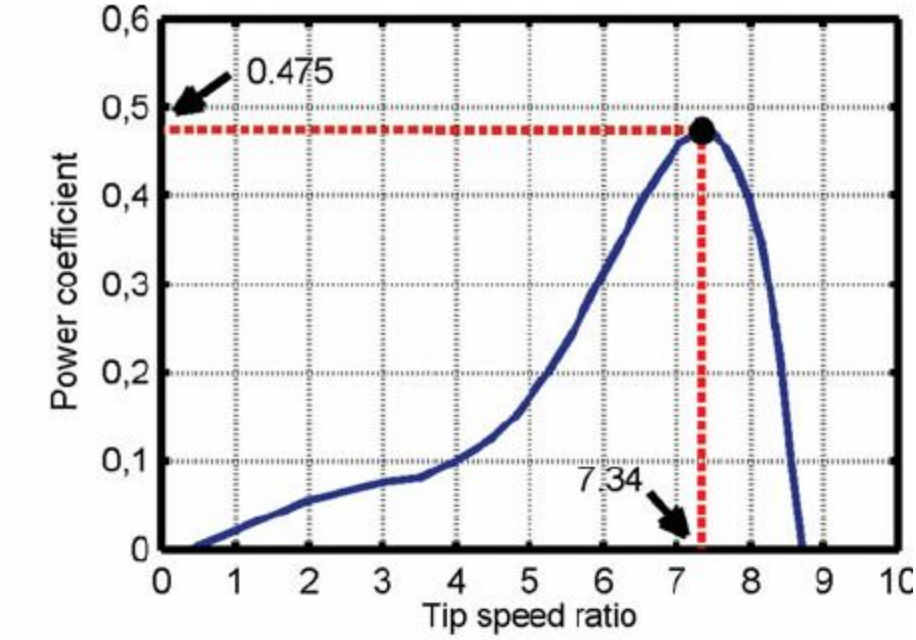
The basic Components of Horizontal wind mill are:

A. **The tower** is the physical structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine equipment. Typical commercial wind towers are usually 50–120 m long and they are constructed from concrete or reinforced steel.
B. **Blades** are physical structures, which are aerodynamically optimized to help capture the maximum power from the wind in

normal operation with a wind speed in the range of about 3–15 m/s. Each blade is usually 20 m or more in length, depending on the power level.

C. **The nacelle** is the enclosure of the wind turbine generator, gearbox, and internal equipment. It protects the turbine's internal components from the surrounding environment.
D. **The rotor** is the rotating part of the wind turbine. It transfers the energy in the wind to the shaft. The rotor hub holds the wind turbine blades while connected to the gearbox via the low-speed shaft.
E. **Pitch** is the mechanism of adjusting the angle of attack of the rotor blades. Blades are turned in their longitudinal axis to change the angle of attack according to the wind directions.
F. **The shaft** is divided into two types: low and high speed. The low-speed shaft transfers mechanical energy from the rotor to the gearbox, while the high-speed shaft transfers mechanical energy from gearbox to generator.
G. **Yaw** is the horizontal moving part of the turbine. It turns clockwise or anticlockwise to face the wind. The yaw has two main parts: the yaw motor and the yaw drive. The yaw drive keeps the rotor facing the wind when the wind direction varies. The yaw motor is used to move the yaw.
H. **The brake** is a mechanical part connected to the high-speed shaft in order to reduce the rotational speed or stop the wind turbine over speeding or during emergency conditions.
I. **Gearbox** is a mechanical component that is used to increase or decrease the rotational speed. In wind turbines, the gearbox is used to control the rotational speed of the generator.
J. **The generator** is the component that converts the mechanical energy from the rotor to electrical energy. The most common electrical generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).
K. **The controller** is the brain of the wind turbine. It monitors constantly the condition of the wind turbine and controls the pitch and yaw systems to extract optimum power from the wind.
L. **Anemometer** is a type of sensor that is used to measure the wind speed. The wind speed information may be necessary for maximum power tracking and protection in emergency cases.
M. **The wind vane** is a type of sensor that is used to measure the wind direction. The wind direction information is important for the yaw control system to operate.

3. Draw and the performance characteristic curves of different windmills and explain salient points.



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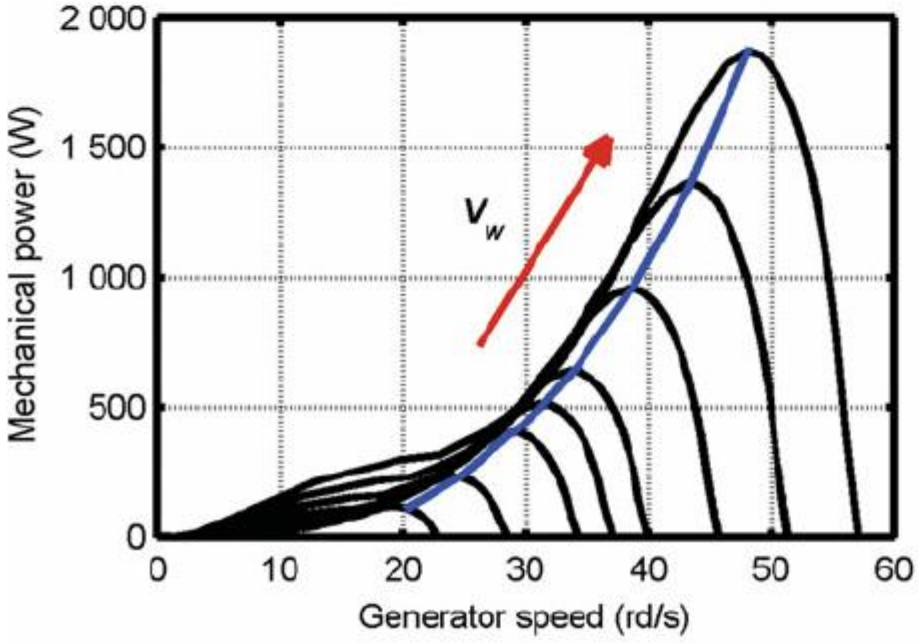

A

(b)

4. Show that for horizontal wind mill the maximum power can be obtained when exit velocity= (wind velocity)/3 and the maximum power is (8/27)(ρAV^3)

A.

5. Calculate the total thrust and aerodynamic power developed in a 3-blade wind turbine at wind velocity of 9m/sec. The machine specifications are as follows:

Diameter=9m, Rotational speed=100rpm, Blade length=4m, Tip speed ratio=5.23, Chord length=0.45m, pitch angle=5^0, Aerofoil section:NACA23018, Distance from shaft to inner edge of the blade=0.5m

$i_1=24.81^0$	$C_{L1}=0.95$	$C_{D1}=0.0105$
$i_2=10.98^0$	$C_{L2}=1.20$	$C_{D2}=0.0143$
$i_3=5.81^0$	$C_{L3}=0.75$	$C_{D3}=0.0092$
$i_4=3.15^0$	$C_{L4}=0.46$	$C_{D4}=0.0078$

6. Explain the working principle of horizontal axis windmill with suitable diagrams.
    - The rotor receives energy from the wind and produces a torque on a low-speed shaft. The low-speed shaft transfers the energy to a gearbox, high-speed shaft, and generator, which are enclosed in the nacelle for protection.
    - The low-speed shaft connects to the gearbox, which has a set of gears that increase the output speed of the shaft to approximately 1,800 rpm for an output frequency of 60 Hz (or a speed of 1,500 rpm if the frequency is 50 Hz). For this reason, the shaft from the gearbox is called the high-speed shaft. The **high-speed shaft** is then connected to the generator, which converts the rotational motion to AC voltage. This speed is critical if it is used to turn the generator directly because the frequency of the ac from the generator is related directly to the rate at which it is turned.
    - Almost all horizontal-axis wind turbines have similar components to those discussed in this article, but there are some exceptions**. For example**, **direct-drive wind turbines** do not have a gearbox, and they usually have a DC generator rather than an AC generator. These may or may not include a converter to AC (which can be located at the tower base).
    - In commercial turbines, a computer or programmable logic controller (PLC) is the controller. The controller takes data from an anemometer to determine the direction the wind turbine should be pointed, how to optimize the energy

harvested, or how to prevent over-speeding in the event of high winds.

- **Controlling the Output Frequency of Wind Turbine**
- Controlling the output frequency and keeping it constant despite varying winds can be done in one of **three ways**.
- **One way** is to control the speed at which the generator shaft turns, which can be accomplished by adjusting the pitch and yaw.
- ***Pitch** is the rotational angle of the blades on a wind turbine; **yaw** is the direction the wind turbine blades and nacelle are facing.*

- Pitch and yaw can be adjusted so that a high-speed shaft runs at a constant rate to produce the required output frequency (typically 50 Hz or 60 Hz) from the generator.
- HAWTs may also use a gearbox or set of gears, which changes the slow rotation of the blades into a faster rotation for the generator.
- The optimum blade rotation is generally between 10 and 20 rpm, and the gear ratio can be used to make the high-speed shaft rotate at the speed the generator requires.

The **second method** for controlling the frequency is to allow the turbine to run freely at any speed that is within its ratings and send the voltage to a power electronic frequency converter. This method is also used with vertical-axis wind turbines (VAWTs).

- When a frequency converter is used, the rotational speed of the turbine is not controlled until the maximum speed is reached, at which point speed controls take over.
- The frequency converter consists of the features shown in Figure 2. The inverter accepts single-phase or three-phase AC to its input circuits within a specified range of frequency and voltage level.
- The AC is filtered and converted to DC by the rectifier and smoothed with passive filters to remove any trace of the input frequency.
- The next section has an inverter that converts the DC voltage back to single-phase or three-phase AC voltage at the precise frequency and phase required by the grid.

This method has the advantage of having a wider range of operating conditions without requiring more complicated gearing.

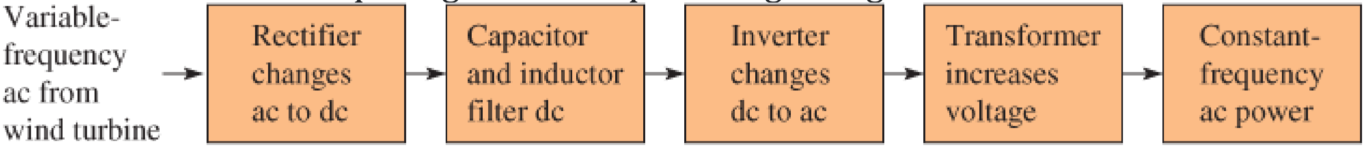

Figure 2 Block Diagram for Power Electronic Frequency Converter

A few applications can use pure DC, which can be obtained from a point before the inverter.

Figure 3: World's Largest Horizontal-Axis Wind Turbine

Vestas has plans for the world's largest wind turbine. The blades for this wind turbine will be 164 meters (538 feet) in diameter and will have a rated capacity of 8 megawatts. The new wind turbine will be an offshore wind turbine located near Aberdeen Bay in Scotland.

The internal parts for a commercial power electronic frequency converter are shown in Figure 4.

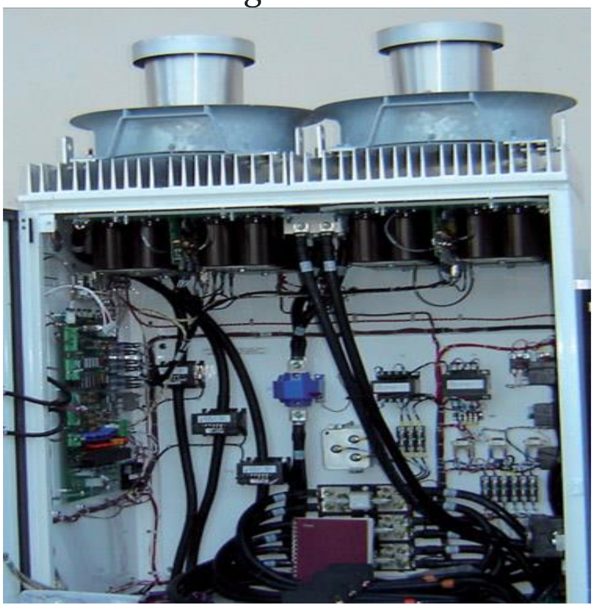

Figure 4 Power Electronic Frequency Converter

The **third way** to control the output frequency of the generator is to use a double-feed, inductive-type generator in which the AC field current is tightly controlled to the required output frequency by feeding the current through an electronic circuit that produces an exact frequency.

7. Explain how to decide the number of blades of a wind turbine considering the tower shadowing effect.