Program : **Diploma in Electrical and Electronics Engineering**	
Course Code : **5033A**	Course Title: **Renewable Energy Power Plants**
Semester : **5**	Credits: **4**
Course Category: **Program Core**	
Periods per week: **4 (L:3 T:1 P:0)**	Periods per semester: **60**

MODULE III
WIND ENERGY

CO3	**Illustrate electric power generation from wind energy.**		
M3.01	Summarize the principle of wind energy conversion	4	Understanding
M3.02	Classify wind energy conversion systems and wind turbines	3	Understanding
M3.03	Illustrate the block diagram of of wind power plants	3	Understanding
M3.04	Explain various schemes for wind electric power generation	4	Understanding

Contents

Principles of wind energy conversions- introduction-advantages- disadvantages - applications - criterion for selection of sites - Wind energy conversion system-block diagram-basic components -turbines-classifications- schematic diagrams -horizontal axis - vertical axis - comparison between horizontal axis and vertical axis machines Wind power plant-block diagrams- standalone - grid interactive -power output from a wind turbine (equation only) - simple problems. Schemes for electric generation-principle of induction generators-block diagrams - schemes for electric power generation- constant speed constant frequency - variable speed constant frequency- variable speed variable frequency

INTRODUCTION:

Non-conventional source of energy offers several advantages. Due to fast depletion of conventional sources, man has to depend on Non-conventional source of energy and its conversion into electrical energy. The movement of air on earth is called wind. Winds result from differential heating of the earth and its atmosphere by the sun and are subjected to several forces altering their direction and speed of flow. Wind energy is in equal race with fossil fuels. Wind energy can be economically used for generation of electrical energy by using wind mill.

CALCULATION OF POWER IN THE WIND

The power in the wind can be computed by using of Kinetics (Kinetic means relating to or resulting from motion). The wind mill works on the principle of converting Kinetic energy of the wind to mechanical energy.

We know that power is equal to energy per unit time. The energy available is the kinetic energy of the wind. The kinetic energy of any particle is equal to one half its mass times the square of its velocity.

i.e., Kinetic Energy of particle $= \frac{1}{2} mv^2$ ... (5.1)

Kinetic Energy of particle = ½ mv^2

Where

M : Mass of particle (kg)

V : Velocity of particle (m/s)

The amount of air passing in unit time, through an area 'A', with velocity 'V' is A x V, and its mass 'm' is equal to its volume multiplied by its density 'ρ' of air.

i.e., $m = \rho AV$ ... (5.2)

$m = \rho\ AV$

Where, m is the mass of air transversing the area 'A' swept by the rotating blades of a wind mill type generator.

Substituting Equ. (5.2) in Equ. (5.1),

We get,

$$\text{Kinetic Energy} = \frac{1}{2} \rho AV \times V^2$$

$$= \frac{1}{2} \rho AV^3 \text{ (Watts)} \quad \text{... (5.3)}$$

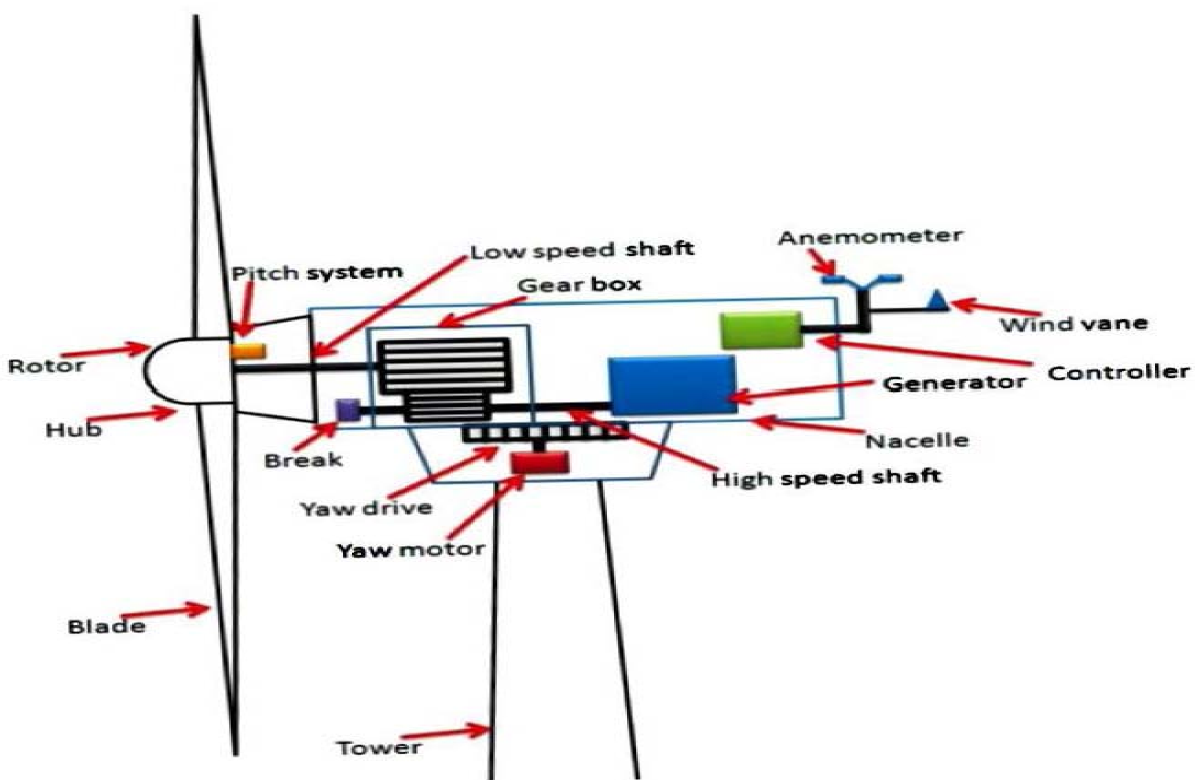
Site Selection Considerations

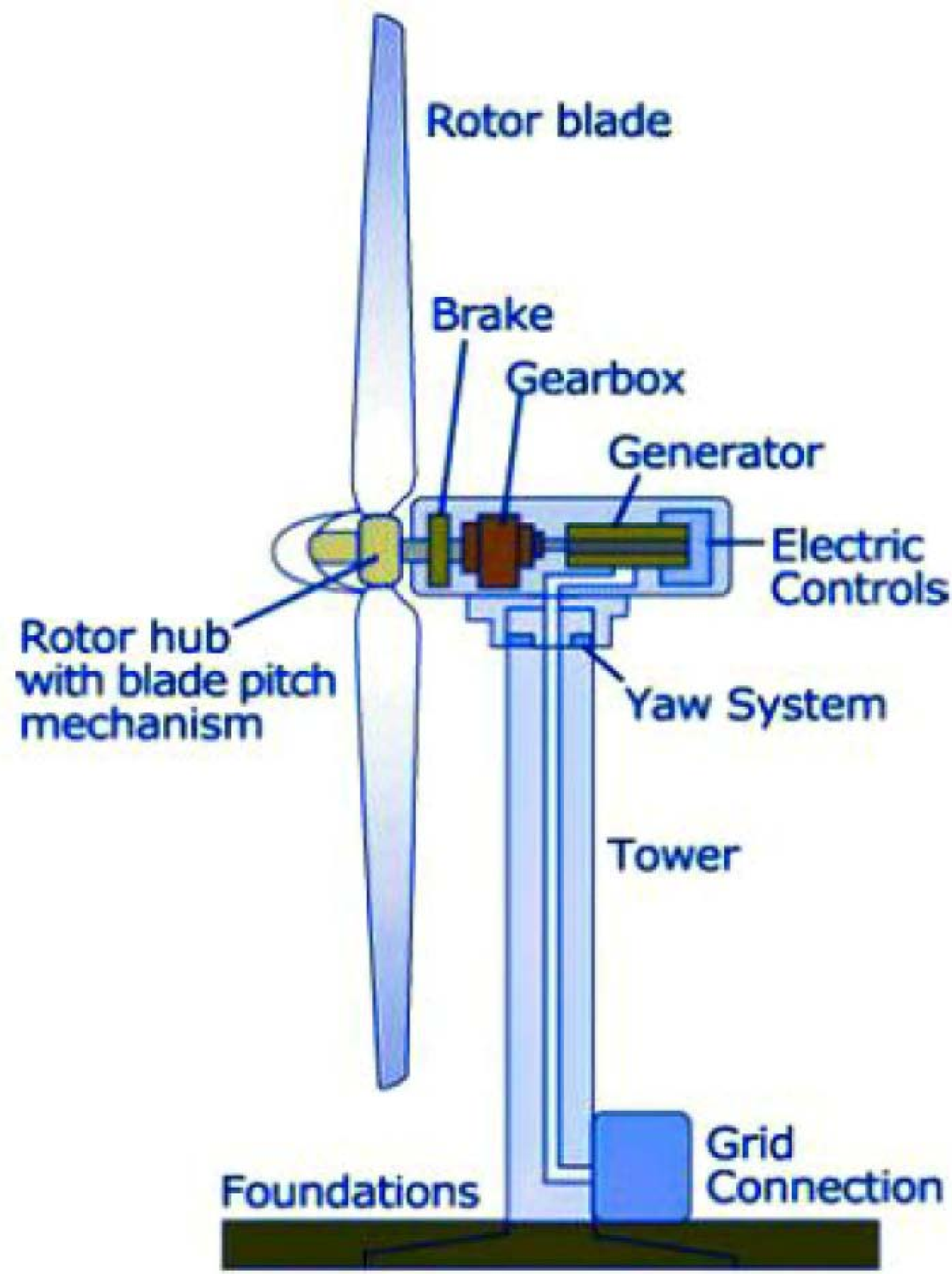
Some of the important considerations for site selection for Wind Energy Conversion System (WECS) are given below:

1. The wind energy conversion machine should be located in areas where the winds are strong and persistent. An ideal site will be one where a smooth steady wind flows all the time. The minimum average wind speed at which WECS works is about (3.5 - 4.5m).
2. Site for WECS should be at high altitude because, the winds tend to have higher velocities at higher altitude.
3. The land cost should be low and the ground conditions at the site should be suitable for installation.
4. The site selected should be near to the users of generated electrical energy.
5. At the site, the environmental conditions should not affect the aero turbine blades and electrical apparatus.
6. The site should be near to the transport facilities such as road and railway facilities.

BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM (WECS)

Energy from the wind is converted to electricity by suitable conversion system. The wind mills designed for this purpose are called wind turbines. In this case, the turbine rotor drives a generator through a gear box and generator to produce the electrical energy. The electrical energy produced depends on wind speed and size of the blades.




Rotor blade
Brake
Gearbox
Generator
Electric Controls
Rotor hub with blade pitch mechanism
Yaw System
Tower
Grid Connection
Foundations

Various major components of a wind mill or wind turbine are

1. **Rotor blades** - Rotor blades convert the wind energy into mechanical or rotational energy. It is usually made of fibre glass. The turbine blades material is chosen such that they posses light weight.
2. **Rotor Hub** - It is the central portion of the rotor wheel. All the blades are attached to the hub. Pitch angle control mechanism is also provided inside the hub.
3. **Gear box -** The low speed of the rotor blades shaft is transformed into high speed shaft of the generator.
4. **Generator -** This converts the mechanical energy of the shaft into electrical energy. Large WTGs used with grid connected system use induction generators. Medium capacity WTGs use Synchronous generators and small capacity WTGs use DC Generators.
5. **Yaw mechanism** (Wind orientation control) – As the direction of the wind changes frequently, the yaw control continuously track and keep the rotor axis in the wind direction. It ensures the rotor blades are parallel to wind orientation.
6. **Nacelle -** It houses all the components of the turbine ie, the Generator, gearbox, brakes, hydraulic systems and yaw mechanism.
7. **Access ladder** - It helps in, climbing the tower in case of any trouble or for maintenance.
8. **Anemometer** - It measures the wind speed.
9. **Wind vane**: Wind vane monitors the wind direction. lt sends a signal to the controlling computer which activates the yaw mechanism to make the rotor face the wind direction.
10. **Brake** - Used to stop the rotor while servicing the wind mill. Hydraulic disc brakes are fitted to the high speed shaft of the gear box.
11. **Tower –** Nacelle and rotor are mounted on the tower
12. **Connection To The Electric Grid :**
13. **Foundation:** Cement concrete and steel are used for foundation.

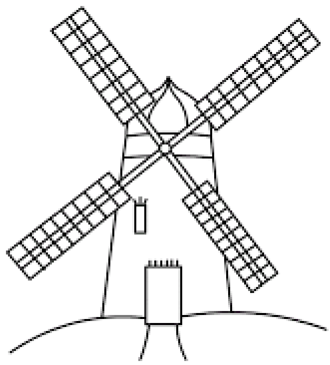
CLASSIFICATIONS OF WEC SYSTEM

Wind energy conversion devices can be broadly categorized into two types according to their axis alignment.

1. Horizontal Axis wind mills or turbines
    a. Dutch type grain grinding or sail type wind mills
    b. Multiblade type wind mill
    c. High speed propeller type wind mill.

2. Vertical Axis wind mills or turbines.
    a. Savonius (rotor) type wind mill
    b. Darrieus (rotor) type wind mill.

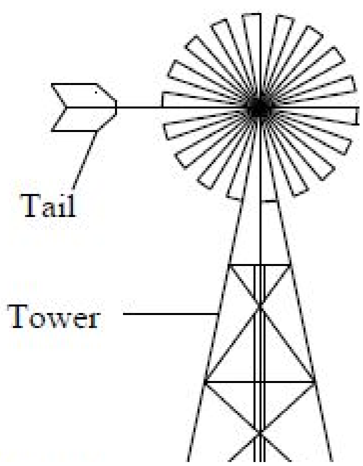
1(a). Dutch Type Windmill:



Man has used Dutch windmills for a long time. In fact the grain grinding windmills that were widely used in Europe since the middle ages was Dutch.

- The blades are made of wooden slats.
- The blades, generally four, are inclined at an angle to the plane of rotation.
- Operated by the thrust exerted by the wind.
- The wind is deflected by the turbine and exerts a force in the direction of rotation.

1 (b). Multiblade Type Windmill:

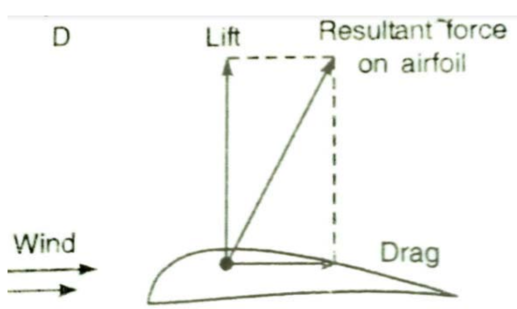


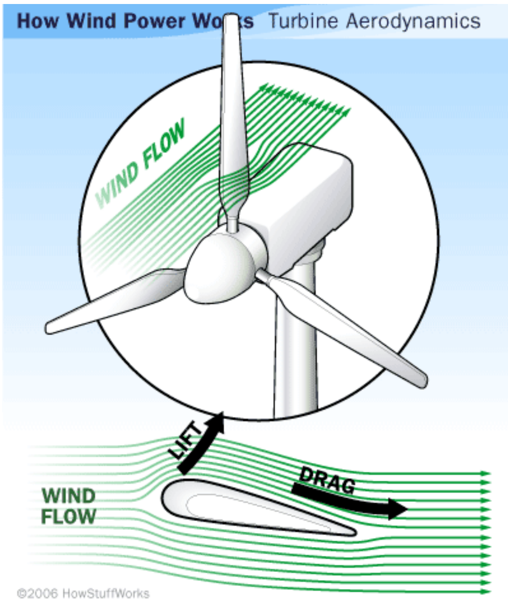
- Has more number of blades usually 12-20.
- The large number of blades gives a high torque, required for driving a centrifugal pump, even at low wind speeds.
- Blades are made of sheet metal or aluminium or flat steel plates
- The width of plate increases from centre to periphery
- Blades are hinged(welded) to a metal ring to ensure structural strength
- The diameter of rotor ranges from 2-5m.
- Speed is about 60 to 80 rpm
- The orientation is generally achieved by tail vane.
- Low cost and used normally for pumping water

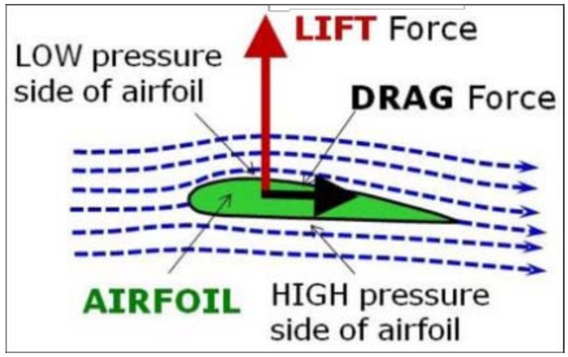
1 (c). High speed propeller type wind turbines

Propeller type wind turbines work based on the aerodynamic forces that develop when wind flows around a blade of aerofoil design. [**Airfoil** is the cross-section of the wind turbine blade. When the wind passes over the surface of the rotor blade, it creates a low pressure area above the airfoil and a high pressure area above the airfoil as shown in figure. This pressure difference between the top and the bottom surfaces results in a force called the aerodynamic **lift** that causes the airfoil to rise. In addition to the lift force, a **drag** force perpendicular to the lift force also acts on the blade which impedes rotor rotation. The resultant force of lift and drag causes rotation of rotor about the hub. The prime objective in wind turbine design is the desired lift-to-drag ratio of the blade (airfoil structure).]

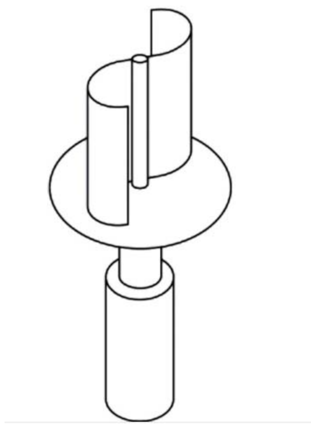
- Working of the turbine depends mainly on the aerodynamic forces that develop when wind flows around a blade of aerofoil design.
- The propeller rotor comprises two or three aerodynamic blades made from strong but lightweight material such as **fibre glass** reinforced plastic.
- The diameter of the rotor ranges from 2 m to 25 m







2 (A) Savonius Type Wind Turbines



- The basic equipment is a drum cut in two halves vertically. The two parts are attached to the two opposite sides of a vertical shaft.
- As the wind blowing into the structure, meets with two dissimilar surfaces one convex and the other concave
- Pressure difference between the two sides develops a torque which causes the rotation of the rotor.
- By providing a certain amount of overlap (one third the drum diameter) between the two drums, the torque can be increased.
- It is self starting and the driving force is mainly of drag type.

2 (b) The Darrieus wind turbine :

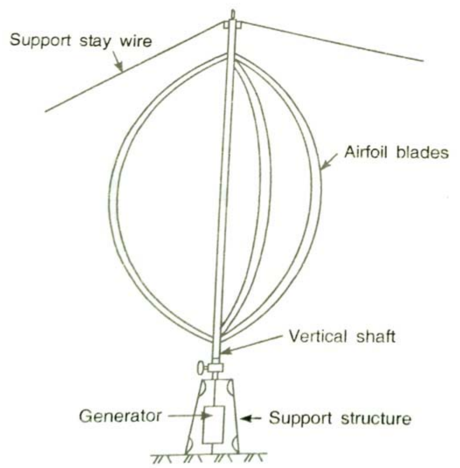


Figure 7.5 Darrieus rotor.

- This rotor has two or three thin curved blades made of flexible metal strips
- It looks like an egg beater and operates with the wind coming from any direction.
- Both the ends of the blades are attached to a vertical shaft
- It can be installed close to the ground eliminating the cost of the tower structure
- Lift is the driving force, creating maximum torque when the blade moves across the wind.
- It is not self starting and has to be started using some external means.

2 (c) Giromill or H-Type windmill

- A variant of Darrieus wind turbine
- The blades are straight resulting in simple construction.

H-Rotor

Advantages of Wind Energy

1. Wind Energy is an inexhaustible source of energy and is virtually a limitless resource.
2. Energy is generated without polluting environment.
3. This source of energy has tremendous potential to generate energy on large scale.
4. Like solar energy and hydropower, wind power taps a natural physical resource
5. Windmill generators don't emit any emissions that can lead to acid rain or greenhouse effect.
6. Wind Energy can be used directly as mechanical energy
7. In remote areas, wind turbines can be used as great resource to generate energy.
8. In combination with Solar Energy they can be used to provide reliable as well as steady supply of electricity.
9. Land around wind turbines can be used for other uses, e.g. Farming.

Disadvantages of Wind Energy:

1. Wind energy requires expensive storage during peak production time.
2. There is visual and aesthetic impact on region.
3. It is unreliable energy source as winds are uncertain and unpredictable.
4. Requires large open areas for setting up wind farms.
5. Wind energy can be harnessed only in those areas where wind is strong enough and weather is windy for most parts of the year.
6. Noise pollution problem is usually associated with wind mills.
7. Usually wind farms are established in open areas away from load centres, Transmission from such places increases cost of electricity.
8. The average efficiency of wind turbine is very less as compared to fossil fuel power plants. We might require many wind turbines to produce similar impact.
9. It can be a threat to wildlife. Birds do get killed or injured when they fly into turbines.
10. Maintenance cost of wind turbines is high as they have mechanical parts which undergo wear and tear over the time.
11. Large area is required.

DIFFERENCE BETWEEN HORIZONTAL AND VERTICAL AXIS WIND TURBINE:

The various differences between horizontal and vertical axis wind turbines/machines are tabulated in the below table

S.No	Horizontal Axis	Vertical Axis
1	Axis of rotation is parallel to the ground.	Axis of rotation is perpendicular to the ground.
2.	All the blades work at a time.	Only one blade works at a time.
3.	Wind turbine works only for specific wind direction.	Wind turbine works in all wind directions.
4.	More efficiency (Since all blades works at a time).	Efficiency is less.
5.	More ground area is needed.	Less area is needed (compared to horizontal axis).
6.	Can be located in remote area due to large area requirement.	Can be installed in urban areas.
7.	Height is more.	Height is less.
8.	Power transmission cost increases.	Power transmission cost is less.

WIND ELECTRIC SYSTEM

A wind electric system is made up of a wind turbine mounted on a tower to provide better access to stronger winds. In addition to the turbine and tower, small wind electric systems also require balance-of-system components.

- TURBINE
- TOWER
  - Freestanding
  - Guyed
- BALANCE OF SYSTEM COMPONENTS

1. TURBINES

Most small wind turbines manufacture today are horizontal-axis, upwind machines that have two or three blades. Rotor is the prime part of the wind turbine that extracts energy from the wind. It constitutes the rotor blade and hub assembly. The blades are usually made of a composite material, such as fibreglass. The turbine's frame is the structure onto which the rotor generator and tail are attached. The amount of energy a turbine will produce is determined primarily by the diameter of its rotor. The diameter of the rotor defines its "swept area," or the quantity of wind intercepted by the turbine. The tail keeps the turbine facing into the wind.

2. TOWERS: Because wind speeds increase with height a small wind turbine is mounted on a tower. In general the higher the tower, the more power the wind system can produce. Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, a 10% increase in overall system cost, but it can produce 25% more power. Most turbine manufacturers provide wind energy system packages that include towers.

Types of towers are

- Self-supporting (free-standing)
- Guyed.
- Tilt-down versions of guyed towers

Most home wind power systems use a guyed tower, which are the least expensive and are easier to install than self- supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height guyed towers require enough space to accommodate them. Tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller light-weight turbines, usually 10 kilowatt or less. Tilt-down towers can also be lowered to the ground during hazardous weather such as hurricanes.

3. BALANCE OF SYSTEM COMPONENTS

The balance-of-system parts needed for a small wind electric system and the tower- will depend on your application. For example, the parts required for a water pumping system will be much different from what you need for a residential application. The balance-of-system parts required will also depend on whether your system is grid-connected, stand-alone, or hybrid. those in addition to the wind turbine

Energy Converters: An electronic component that converts direct current (DC) electricity to alternating Current (AC) and vice versa is necessary to shape the power from the turbine into energy that is useful for industrial and household appliances.

Most manufacturers can provide you with a system package that includes all the parts you need for you particular application. For a 'residential grid-connected application, the balance-of-system parts may include the following

- A controller
- Storage batteries
- An inverter (power conditioning unit)
- Wiring
- Electrical disconnect switch
- Grounding system
- Foundation for the tower.

Cooling Systems: is provided to ensure that the various parts do not overheat and cause any damage to the plant.

Control System: is provided to monitor various parameters and capable of shut down the wind mill in case of a fault.

SCHEMES FOR WIND POWER GENERATION:

Based on the speed and frequency, generally following schemes of wind power generations are identified:

1. CSCFS (Constant Speed Constant Frequency Scheme).
2. DSCFS (Dual Speed Constant Frequency Scheme)
3. VSCFS (Variable speed constant frequency scheme).
4. VSCF with DO (Variable speed constant frequency with double output).
5. VSVFS (Variable speed variable frequency schemes).

1. CSCFS (Constant Speed Constant Frequency Scheme).

Constant speed drives are used for large generators that feed the generated power to the grid. Commonly synchronous generators (alternator) or squirrel cage induction generators (IG) are used for power generation.

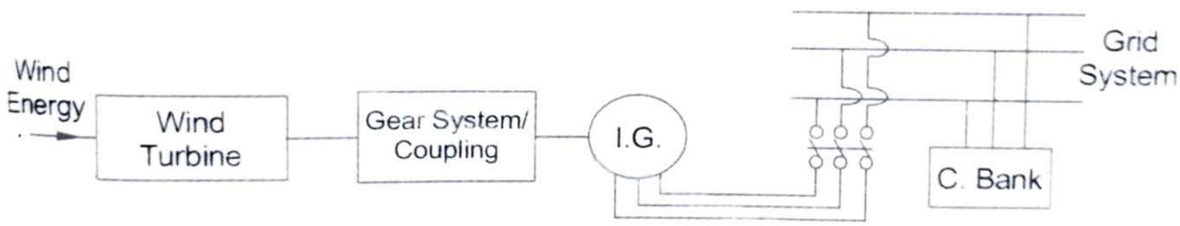


Fig. 3.11 CSCF SCHEME

If the stator of an induction machine is connected to the power grid and if the rotor is driven above Synchronous speed Ns, the machine delivers a constant line frequency (f = PNs/120) power to the grid. The slip of the generators is between 0 and 0.05. The torque of the machine should not exceed max. Torque to prevent run away (speed continues to increase unchecked).

Compared to synchronous generator, Induction generators are preferred because they are simpler, economical, easier to operate, control and maintain and have no synchronization problem. However, Capacitors (Capacitors bank) have to be used to avoid reactive volt ampere burden on the grid (Reactive power required by the Induction Generator can be supplied by installing the Capacitor)

2. DSCFS (Dual Speed Constant Frequency Scheme)

In this scheme a dual speed wind turbine is coupled to double winding induction generator that is specially fabricated with 2 stator windings wound with different number of poles Pl and P2 (P1 > P2).

When wind speed is low, winding with P1 poles gets connected and power is generated with grid frequency. Similarly, when wind speed is high, winding with P2 poles gets connected and feed the power to grid at the same frequency.

It is important to note that the difference in speed should be small. Reactive power required by the Induction Generator can be supplied by installing the Capacitor bank as usual. Feedback system can be used to monitor and control various parameters to get desired performance.

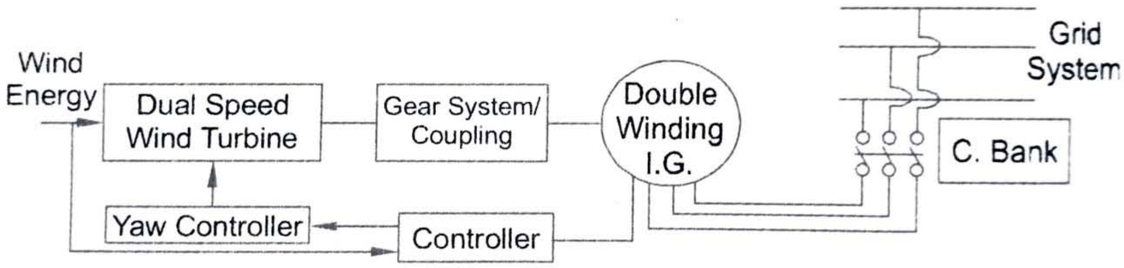
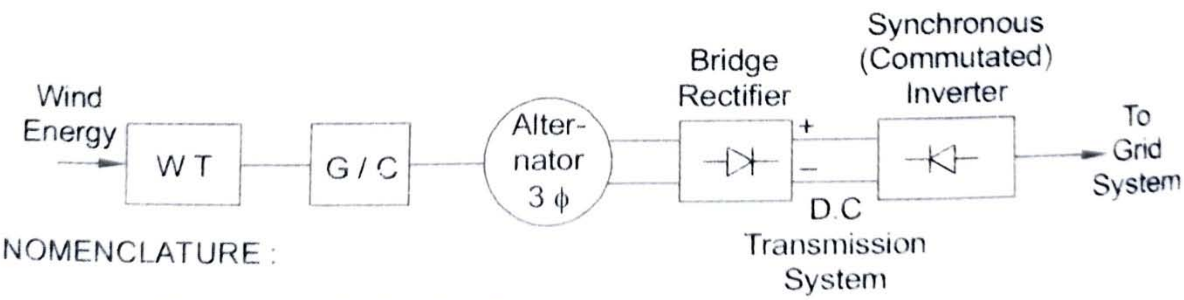


Fig. 3.12 DSCF SCHEME

3. VSCFS (Variable Speed Constant Frequency Scheme)

In this scheme the output of three phase alternator (synchronous generator) is rectified by bridge rectifier. The DC output is transmitted through DC transmission lines and then converted back to AC using synchronous inverters and fed to grid system



NOMENCLATURE :

WT = WIND TURBINE

G/C = GEAR BOX/COUPLING

Fig. 3.13 VSCF SCHEME

This scheme, involves small wind generator commonly used in autonomous applications such as street lighting. Due to variable speed operation, it yields higher power of both low and high wind speeds. Both horizontal axis and vertical axis turbines are suitable.

4. Variable Speed Constant Frequency With Double Output (VSCF With DO)

In this scheme, to increase the power generating capacity of the system, squirrel cage induction generators are replaced by slip ring induction generator. Rotor power output at slip frequency is converted to line frequency power using rectifier. Output power is obtained both from stator and rotor. Rotor output power increases with increase in slip and speeds. Therefore, operating speed range is Ns to 2Ns i.e. slip ranging from 0 to 1.

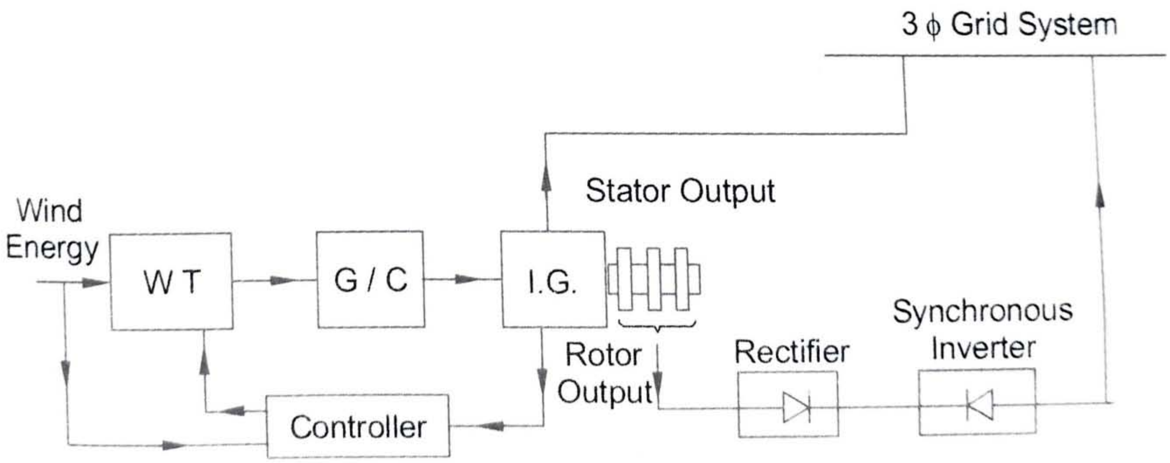


Fig. 3.14 VSCF WITH DO SCHEME

5. VSVFS (Variable Speed Variable Frequency Scheme)

This scheme is suitable for loads that are frequency insensitive such as heating load. Depending upon the wind speed, squirrel cage Induction Generator generates power at variable frequency. Such generators are excited by Capacitor-bank. The magnitude and frequency of the generated emf depends upon the wind turbine speed, excitation capacitance and load impedance. If load requires constant dc voltage, output of generators is converted into d.c. using chopper controlled rectifiers. Feedback system can be used to monitor and control to get desired performance.

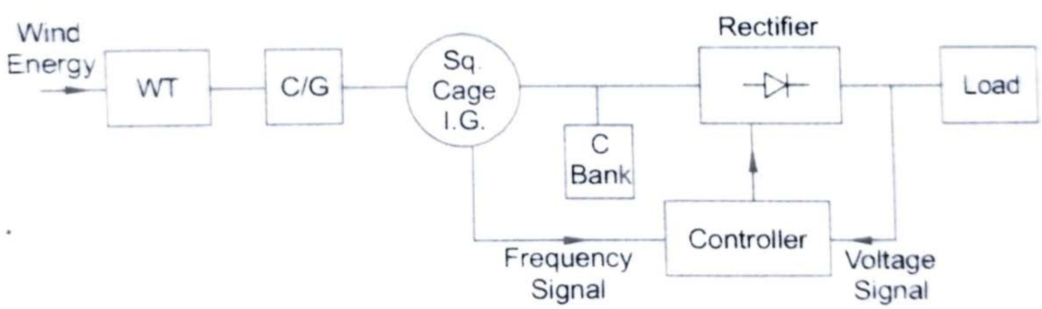


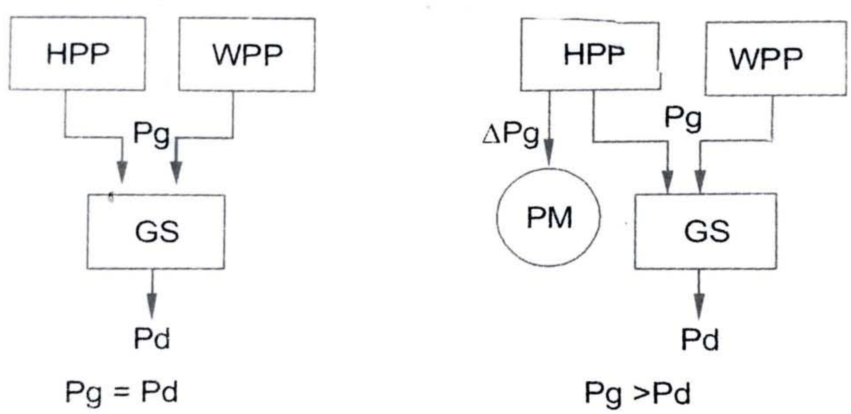
Fig. 3.15 VSVF SCHEMES

WIND ENERGY STORAGE:

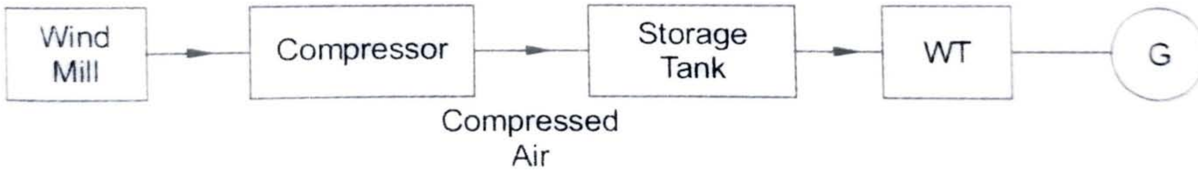
Wind power turbines have operational limitations over very high and very low speeds. When the power generated exceeds the demand, excess energy can be stored to be used at other times.

- Excess energy can be conveniently stored in storage batteries in the form of chemical energy.
- Excess energy can also be stored in water power storage in the form of mechanical energy. Wind power plant (WPP) along with Hydroelectric power plant (HPP), when generated power (Pg) exceeds the power demand (Pd), helps to partly divert hydro power plant output to Pumping motor (PM) to pump water from an auxiliary reservoir at the bottom of the dam to main reservoir.

- Excess energy can also be stored in the form of compressed air.



When wind is not blowing, energy stored in compressed air could be used to drive wind turbine whose shaft would then drive a generator, thus supplying the needed power



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.

Example 1

Determine the power in the wind if the wind speed is 20 m/s and blade length is 50 m.

Solution:

Given:

Wind speed v = 20 m/s,

Blade length l = 50 m,

Air density ρ = 1.23 kg/m.

The area is given by, $A = \pi r^2$

A = π × 2500

= 7850 m

The wind power formula is given as,

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

$$P = \frac{1}{2}(1.23)(7850)20^3$$

P = 38622 W

Example 2

A wind turbine travels with the speed is 10 m/s and has a blade length of 20 m. Determine wind power.

Solution:

Given:

Wind speed v =10 m/s,

Blade length l = 20 m,

air density ρ = 1.23 kg/m3,

area , $A = \pi r^2$

= π × 400

= 1256 m^2

The wind power formula is given as,

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

= 0.5 × 1.23 × 1256 × 1000

P = 772440 W.