CHAPTER - 4

WIND ENERGY

WIND ENERGY :-

Wind energy is the kinetic energy associated with movement of large masses of air. These motions result from aneven heating of the atmosphere by the sun.

* It is an indirect form of solar energy.
* It is a clean, cheap and eco-friendly renewable source. The main disadvantages are that it is a dispersed, erratic and location-specific source.

CLASSIFICATION OF WIND ENERGY

The origin of winds may be traced basically to uneven heating of the earth's surface due to the sun. This may lead to circulation of widespread winds on a global basis.

* Wind energy is mainly classified in to two types. They are

→ Global (or) planetary winds

→ Local winds.

GLOBAL (OR) PLANETARY WINDS

* The primary force for global winds is developed due to differential heating of the earth at equatorial and polar regions.
* In tropical regions there is a net gain of heat due to solar radiation, whereas in the polar regions there is net loss of heat.
* This means that the earth's atmosphere has to circulate to transport heat from tropic towards the poles.

* Oceans are responsible for about 30% of this global heat transfer.

* Spinning of the earth about its axis produces a coriolis force, which is responsible for deviation of air currents towards the west

* Between 30°N and 30°S, heated air at the equator rises and is replaced by cooler air coming from north and south. This known as Hadley circulation.

* Between 30°N(S) and 70°N(S) predominantly western winds are found. These winds are wavelike circulation, transferring cold air southward and warm air northward. This pattern is called Rossby circulation.

LOCAL WINDS :-

Localized uneven heating is responsible for local winds. Local winds are produced due to two mechanisms.

* The first is differential heating of land suface. During the day. Solar energy is readily converted to sensible thermal energy on the land suface and this quickly increases its temperature Whereas, on water bodies it is partly consumed in evaporating water and only partly absorbed to cause an increase in temperature. As a result, cool, heavier air blows from the water outwards land At night, the direction of wind is reversed as the land mass cools to sky more rapidly than the water.

* The second mechanism of local wind is differential heating of slopes on the hill slides and that of low lands. The slope heats up during the day and cools down during night more rapidly than the low land. This causes the heater air to rise along the slope during the day.

FACTORS AFFECTING THE DISTRIBUTION OF WIND ENERGY ON THE SURFACE OF THE EARTH

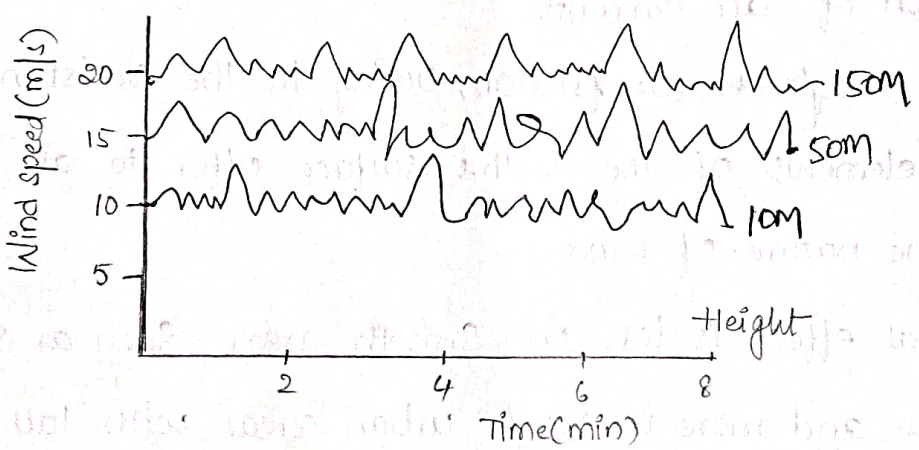
Several factors are responsible for distribution of wind energy on the suface of the earth.

* On the planetary level, great mountain masses influence the circulation of air currents.
* Surface roughness (or) friction, owing to the resistance that different elements of the earth's suface offer to air circulation affects the nature of wind.
* Frictional effect is less on smooth areas such as seas (or) large open areas and more in rough urban areas with tall buildings (or) trees.
* climatic disturbances such as downdraught from thunder clouds and precipitation also effects the local winds.
* Wind speed is also increases while passing through narrow mountain gaps, where it gets channelled.

WIND DATA :-

All countries have national meteorological services that record and publish weather related data including wind speed and direction. Wind speed is measured by an anemometer and wind direction is measured by a wind vane attached to a direction indicator.

* A cup anemometer consists of three (or) more cups mounted symmetrically about vertical axis. The speed of rotation indicates wind speed.
* Wind speed can also be recorded by measuring the wind pressure on a flat plate.



The main conclusions are

* Wind speed increases with height
* The turbulence is spread over a broad range of frequencies.
* Wind speed is fluctuating with time i.e., turbulences are present at the site.

VARIATION OF WIND SPEED WITH HEIGHT

Wind speed with height is called gradient height and is typically of about 2000m. Above the gradient height, known as free atmosphere, changes in wind speed are not affected by ground conditions.

* The layer of air from ground to gradient height is known as planetary boundary layer. The planetary boundary layer consists of Surface layer, which extends from the height of local obstructions to a height of approximately 100m and Ekman layer, which starts from 100m and extends upto gradient height.

* Wind speed with height can be represented by

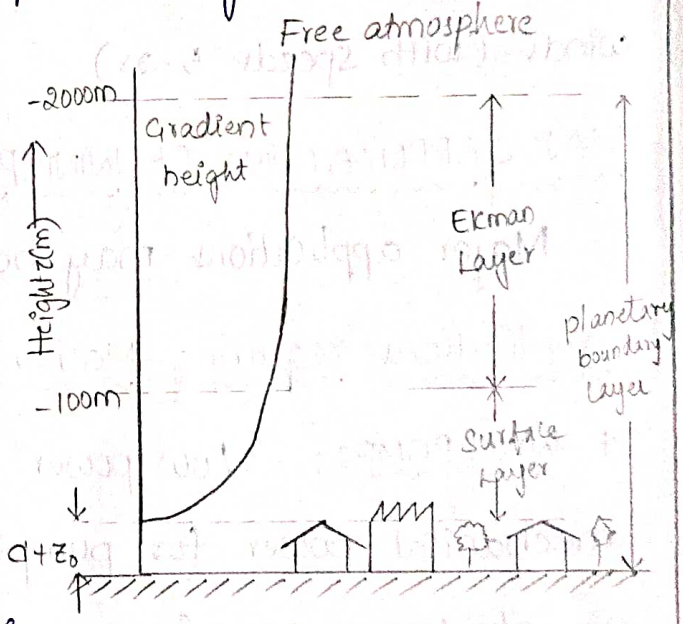
$$u_z = V \ln\left[\frac{z-d}{z_0}\right]$$

where V = Characteristic speed

d = Zero plane displacement

z_0 = roughness length

$z_0 + d$ = Height of local obstructions



* It is very important then to place the wind turbine well above the height of local obstructions so that the turbine disk receives a strong uniform wind flux across its area without erratic fluctuations.

* Wind speed u_z at a height 'z' relative to that available at Standard reference height H

$$u_z = u_H \left[z/H \right]^{\alpha}$$

Where u_H = mean speed at reference height H.

α depends on surface roughness. [0.14 for open sites]

VARIATION OF WIND SPEED WITH TIME

As wind speed fluctuates with time for electrical power generation, the minimum average wind required is 5 m/s.

* A site is not considered favorable for wind power generation if average wind speed remains less than this for prolonged periods, as there will be no generation during these periods.
* Also no generation is possible, if wind speed is very high i.e., 25 m/s and above. The best sites are those where favourable winds (with speeds 5-25)

MAJOR APPLICATIONS OF WIND POWER

Major applications may be grouped in three Categories.

Applications requiring Mechanical power

* WIND PUMPS :- Low power turbines are used for producing mechanical power for pumping water in remote areas. These are also known as wind pumps. Simple and reliable tradinal. reciprocating pumps (or) Centrifugal pumps are used. These wind pumps are used for supplying water for livestock, Smale-scale irrigation, low head pumping for aquatic breeding and domestic water supply.

Heating:- The direct dissipation of mechanical power produces heat with 100% efficiency using a paddle wheel and other turbulent fluid systems.

* Sea transport:- The old square rigged sailing ships were inefficient as they were operated by drag forces. Lift forces are much efficient and can sail faster than the wind. Large cargo ships requiring power in MW range, drives by improved efficient sails, are now being designed.

II. AS OFF GRID ELECTRICAL POWER SOURCE

* Applications of somewhat more powerful turbines of about 50kw are producing electrical power for navigation signal.
* For lifting water to a hill, aero generator is installed on the top of hill and electrical energy is transmitted to a pump fixed at lower level.
* Machines of low power with a rotor diameter of about 3m and 40-1000w rating can generate sufficient electrical energy for space heating and cooling of homes, water heating battery charging and for operating domestic appliances such as fans, lights etc.

III AS GRID-CONNECTED ELECTRICAL POWER SOURCE

Large aero generators in the range of few hundred kw to a few MW are planned for supplying power to a utility grid. Large arrays of aero generators, known as wind farms.

Characteristics of wind energy

1. It is readily available in nature & does not cause any pollution
2. It is clean & mostly available in many offshore, onshore & remote areas
3. The wind energy obtained is cost effective & reliable for power generation, pumping of water.
4. Desired winds are available only in few locations away from cities & forests.
5. Wind energy is unsteady, irregular, intermittent.
6. Direction of wind continuously changes.

Advantages & Disadvantages of wind powerplant :-

Advantages :-

1. There is no requirement of fuel supply
2. It consumes less time for its construction
3. It is non-polluting power system,
4. wind turbines occupies very small floor area.

Disadvantages :-

1. This system is noise in operation.
2. only limited amount of power is produced.
3. It involves very high initial cost.
4. The overall weight of the wind power system is high

Types of Wind turbines and their Construction

(1) ⑤

Wind turbines are broadly classified into two categories. When 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), and when it is perpendicular to the air stream (i.e., vertical), it is said to be a Vertical Axis Wind turbine (VAWT).

HORIZONTAL AXIS WIND TURBINE (HAWT)

Horizontal axis wind turbine's are emerged as the most Successful type of turbines. These are being used for commercial energy generation in many parts of the world

Main Components :-

The constructional details of the most common, three blade rotor, horizontal axis wind turbine is shown in figure.

* TURBINE BLADES :-

Turbine blades are made of high density wood (or) glass fibre and epoxy composites. They have an airfoil type of cross section The blades are slightly twisted from the outer tip to the root to reduce the tendency to stall. In addition to centrifugal force and fatigue due to Continuous vibrations, there are many extraneous forces arising from wind turbulence, gust, gravitational forces and directional changes in the wind. All these factors are to be taken care off at the designing stage. The diameter of a typical, MW range, modern rotor may be the of 100m.

Modern wind turbines have two (or) three blades. Two/three blades rotor HAWT are also known as propeller type wind turbines

Owing to their similarity with propellers of old aeroplanes. However, the rotor rpm is case of a wind turbine is very low as compared to that for propellers. The relative merits and demerits of two and three blade rotors are as follows.

* Compared to the two blade design, the three blade machine has smoother power output and balanced gyroscopic force
* There is no need to teeter the rotor, allowing the use of a simple rigid hub. The blades may be cross-linked for greater rigidity.
* Adding a third blade increases the power output by about 5% only, while the weight and cost of a rotor increases by 50% and additional 50% weight and cost.
* The two blade rotor is also simpler to erect, since it can be assembled on the ground and lifted to the shaft without complicated maneuvers during the lift.

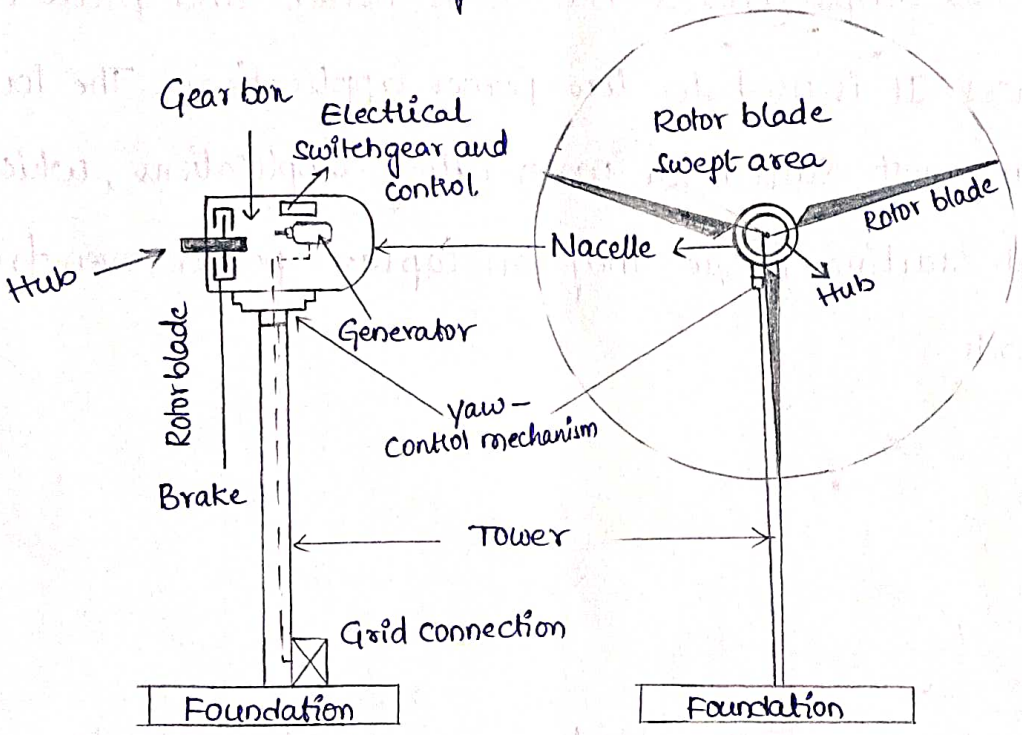
HUB :-

The central solid portion of the rotor wheel is known as HUB. All blades are attached to the Hub. The mechanism for pitch angle control is also provided inside the hub.

NACELLE :-

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

* It contains rotor brakes, gearbox, generator and electrical switchgear and control. Brakes are used to stop the rotor when power generation is not desired. The gearbox steps up the shaft rpm to suit the generator.
* protection and control functions are provided by switchgear and control block. The generated electrical power is conducted to ground terminals through a cable.



YAW-CONTROL MECHANISM :-

The mechanism to adjust the nacelle around the vertical axis to keep it facing the wind is provided at the base of nacelle.

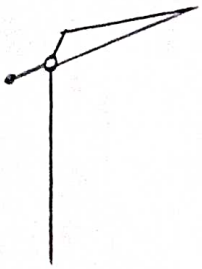
TOWER :-

The tower supports the nacelle and rotor. For medium and large sized turbines, the tower is slightly taller than the rotor diameter. In case of a small sized turbine, the tower is much

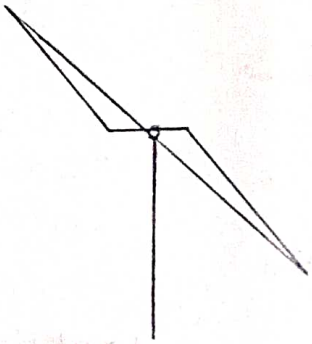
larger than the rotor diameter as the air erratic at lower heights Both steel and concrete towers are being used. The construction can be either tubular (or) lattice type.

TYPES OF ROTORS :-

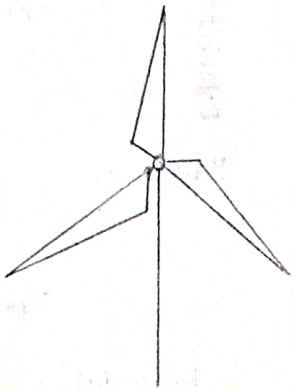
Large HAWT's have been manufactured with two and three blades. A single blade rotor, with a balancing counterweight is economical, has simple controls but it is noiser and produces unbalanced forces. It is used for low-power applications. The low speed rotors are most suited for water-lifting applications, which require a high starting torque. They can capture power even from very slow winds.



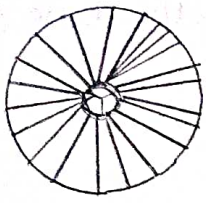
(a) Single blade rotor



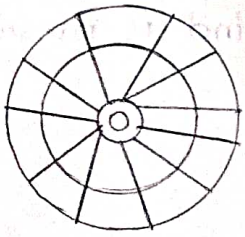
(b) Two-blade rotor



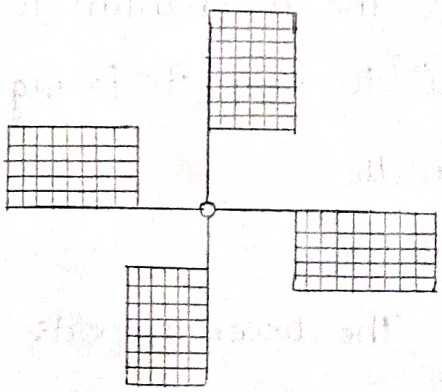
(c) Three-blade rotor.



d) Chalk multiblade rotor.

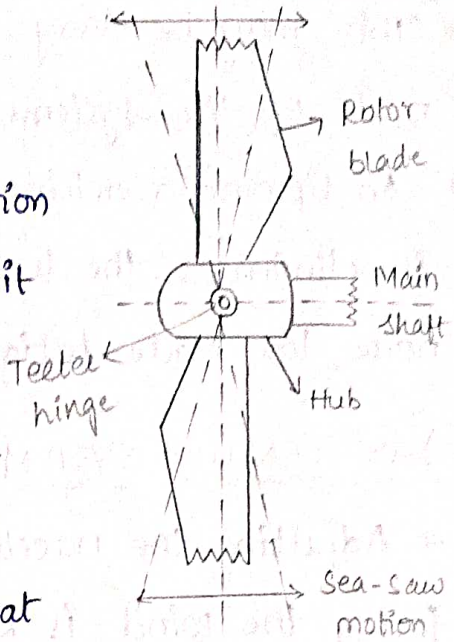


e) American multibladed rotor



(f) Dutch type rotor

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 a lower position.
* For one and two blade rotors, this causes cyclic load on a rigid hub leading to fatigue. This is greatly relieved by providing a teeter hinge that allows a see-saw motion to take place out of the plane of rotation. (i.e., Vertical plane). The rotor leans backwards to accomodate the extra force
* This also reduces blade loads near the root by approximately 40%. The use of a third blade has approximately the same effect. therefore, teetering is not required when the number of blades is three or more.

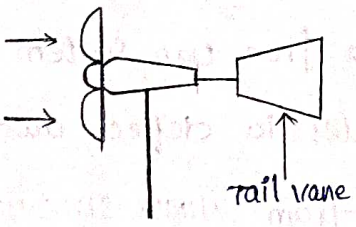
UPWIND AND DOWNWIND MACHINES

* In an upwind machine, the rotor is located upwind (in front) of the tower whereas in a downwind machine, the rotor is located downwind of the tower. Both types have certain benefits
* A downwind machine allows the use of a free yaw system (in low rating machines). It also allows the blades to deflect away from the tower when loaded. However, it suffers from WIND SHADOW effects of the tower on the blades as they pass through the tower's wake, in a region of Separated flow.
* For a high solidity tower with limited rotor overhang, the wind speed might be effectively reduced to zero causing a severe impulse load of periodic nature.

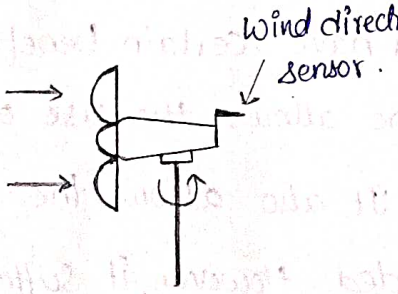
* This may be very dangerous as it may excite any natural mode of the systems if that lies near a rotor harmonics
* An Upwind machine on the other hand, produces higher power as it eliminates the tower shadow on the blades. This also results in lower noise, low blade fatigue and smoother power output.

YAW-CONTROL SYSTEM

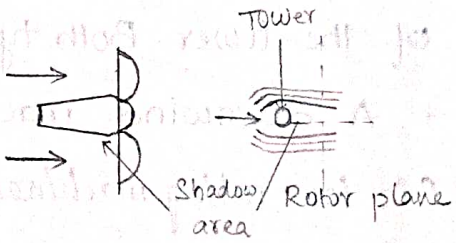
* Adjusting the nacelle about the vertical axis to bring the rotor facing the wind is known as Yaw Control. The yaw control system continuously orients the rotor in the direction of wind.
* For localities with a prevailing wind in one direction only, the rotor can be in a fixed orientation. Such a machine is said to be yaw fixed. Most of wind turbines are yaw active.
* In small wind turbines, a tail vane is used for passive yaw control In large turbines however, an active yaw control with power steering and wind direction sensor is used to maintain the orientation.



(a) upwind with tail vane passive yaw control

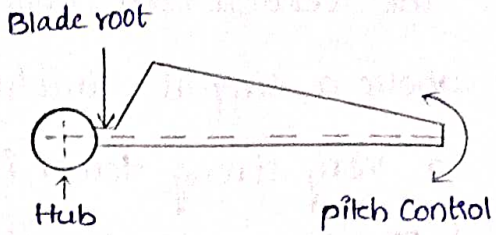


(b) upwind with active yaw control



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

PITCH CONTROL SYSTEM:



* The pitch of a blade is controlled by rotating it from its root, where it is connected to the hub. The pitch control mechanism is provided through the hub using a hydraulic jack in Nacelle.
* The control system continuously adjusts the pitch to obtain optimal performance. In modern machines, pitch control is incorporated by controlling only the outer 20% length of the blade, keeping the remaining part of the blade as fixed.

VERTICAL AXIS WIND TURBINE (VAWT)

VAWT's are in the development stage and many models are undergoing field trial. The main attractions of a VAWT are.

* It can accept wind from any direction, eliminating the need of yaw control
* The gearbox, generator, etc., are located at the ground, thus eliminating the heavy nacelle at the top of the tower, thus simplifying the design and installation of whole structure including the tower.
* The inspection and maintenance also gets easier, and
* It also reduces the overall cost.

MAIN COMPONENTS

The constructional details of a vertical axis wind turbine (Darrieus type rotor). The details of main components are as follows:

TOWER (OR) ROTOR SHAFT:-

* The tower is a hollow vertical rotor shaft, which rotates freely about

the vertical axis between the top and bottom bearings. It is installed above a support structure. In the absence of any load at the top, a very strong tower is not required, which greatly simplifies its design

*. The upper part of the tower is supported by guy ropes. The height of the tower of a large turbine is around 100m.

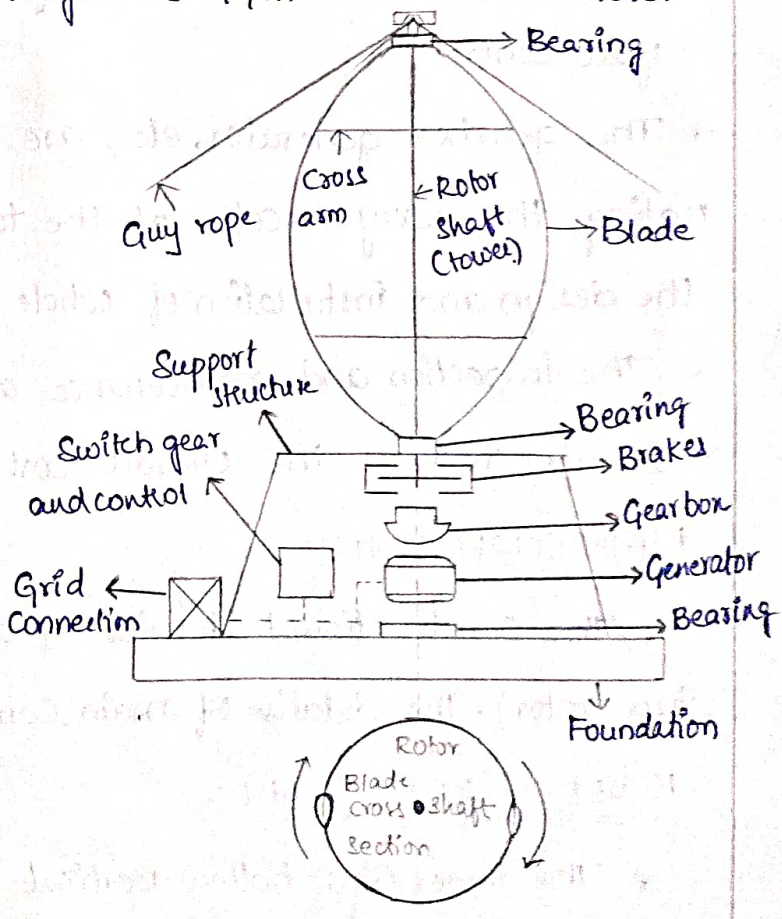
BLADES :-

* It has two or three thin, curved blades shaped like an egg beater in a profile, with blades curved in a form that minimizes the bending stress caused by centrifugal forces – the so called 'Troposkien' profile The blades have an airfoil cross section with constant chord length.

* The pitch of the blades cannot be changed. The diameter of rotor is slightly less than the tower height. The first large, darrieus type, Canadian machine has a rotor height as 94m and the diameter as 65m with a chord of 2.4m.

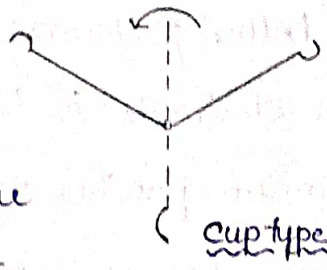
SUPPORT STRUCTURE :-

The support structure is provided at the ground to support the weight of the rotor. Gearbox, generator, brakes electrical switch-gear and controls are housed within this structure.



Types of Rotors :-

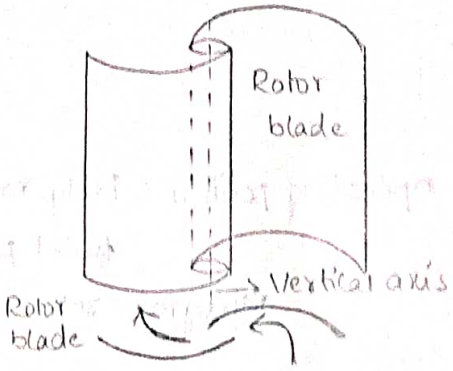
* Various types of rotors for VAWT's are shown in figures. The simplest being a three (or) four cup structure attached Symmetrically to a vertical shaft


Cup type rotor

* The drag force on the concave suface of the cup facing the wind is more than that on the convex suface. As, a result, the structure starts rotating.
* However it cannot carry a load and therefore cannot be used as power source and the apparatus is known as Cup anemometer

Savonious rotor :-

* The savonious (or) S-rotor consists of two half cylinders attached to a vertical axis and facing in opposite directions to form a two-vaned rotor
* It has high starting torque, low speed and low efficiency. These are used for Low power applications

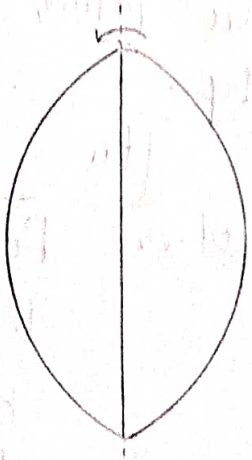


Savonious rotor

* A high starting torque particularly makes it suitable for pumping applications, using positive displacement pumps.

Darrieus Rotor :-

* The Darrieus rotor is used for large scale power generation. It runs at large tip speed ratio Along with centrifugal force, complicates the design of the blade
* One of the drawbacks of this rotor is that it is usually not self starting. Movement may be

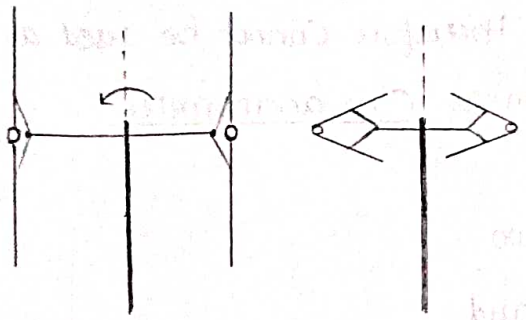

Darrieus rotor

initiated by using electrical generator as Rotor

* Hence at high speed wind it becomes difficult to control the output

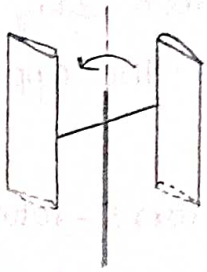
For better performance and safety of the blades, gearbox and generator, it is desirable to limit the output to a level much below to its maximum possible value.

Other types of rotors are :-



Operating position Fully reefed (or) furled position

Musgrove rotor



Blade pitch controllable

Evans rotor

⊛ Factors to be considered while selecting a site :-

→ The following factors to be considered

① High Annual average speed :-

→ The power in the wind mainly depends on the velocity.

$$P_w = KV^3$$

where P_w = power from wind

V = wind velocity

K = constant

② Availability of Anemometry data :-

→ The speed of wind without any errors, in order to measure

ensure effecient operation.

③ Availability of wind at the proposed site :-

→ Maximum energy in the wind is known with the help of $V_{(t)}$ curve.

④ wind structure at the proposed site :-

It is necessary to know the structure of the wind & is defined by V(t) curve.

⑤ Altitude of the proposed site :-

→ The winds have higher velocities at higher altitudes which in turn produces more power.

⑥ Terrain & aerodynamic :-

It is important to know about terrain of the site to be chosen, the wind must flow in horizontal direction.

⑦ Local Ecology :-

Local ecology should also be considered while choosing the site. If surface of the ground is rock, lower hub height is sufficient, if it is grass, the hub height is high.

⑧ Distance to roads or Railways :-

→ Transportation of machinery to the site should also be considered.

⑨ Nearness of site to load centres :-

→ To minimize transmission cost, losses the site must nearer to load centres, otherwise the cost is increases.

⑩ Nature of ground :-

→ The wind machines are erected from ground. So WECS are secured, if ground surface is rigid & stable.

⑪ Favourable land cost :-

→ Land cost should be low, otherwise it effect on the total cost

⑫ Other conditions :-

such as icing, blowing dust, should not be present at the site, which may effect the turbine blades.

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⑧ Methods for maximum power tracking systems :-

→ In order to obtain maximum power output from wind power system, under variable operating conditions, control schemes has to be employed.

① Constant tip speed ratio :- [TSR]

→ In this method, the wind turbine rotor is operated at its optimum tip speed ratio (TSR).

→ The optimum value is selected & stored as refrence TSR in computer system. The rotor operating at refrence TSR generates maximum power output.

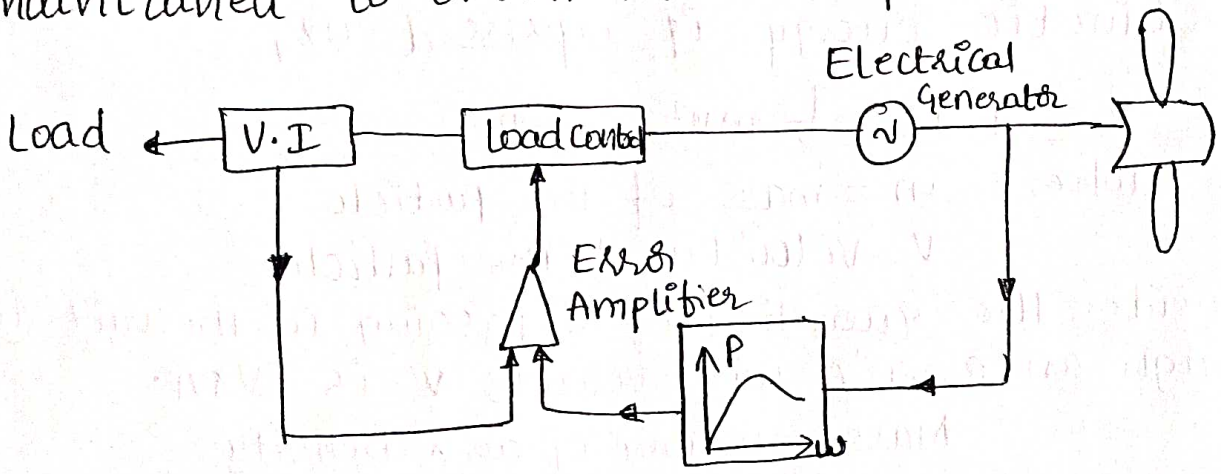
The speed of wind turbine is closely monitored, measured & compared with blade tip speed. Any variation in speed generates an error signal that is fed to control system.

→ which minimizes the error by changing the speed of turbine rotor.

→ It is difficult to store an optimum reference TSR with respect to varying environmental conditions.

⊛ **Peak power Tracking method :-**

→ In this method, power & speed are relatively maintained to obtain maximum power output.



→ The necessary condition is

$$\frac{dP}{d\omega} = 0$$

where

dP = change in power output

dω = change in speed.

→ The speed is slightly adjusted (i.e increased or decreased) & power output is measured simultaneously

Thus the ratio of power & speed is evaluated.

→ If the ratio is positive, the power output can be increased, thus the speed of rotor is increased further.

→ If the ratio is negative, the power output may reduce for an increase in speed.

(*) **Expression for kinetic energy of the wind:-**

→ The principle of wind machines is to convert kinetic energy of wind into mechanical energy.

→ The energy available in the wind is in the form of kinetic energy. The power is expressed as energy per unit time.

Kinetic energy is expressed as,

$$K.E = \frac{1}{2} mv^2 \quad \text{—①}$$

where m = mass of the particle

V = velocity of the particle

→ Consider, the quantity of air passing in the unit time through an area 'A' with velocity 'V' is $V \times A$.

Mass = volume of air × Density

$$m = V \times A \times \rho \quad \text{—②}$$

$$\therefore K.E = \frac{1}{2} \times \rho \times A \times V \times v^2 \text{ watts}$$

$$\boxed{K.E = \frac{1}{2} \times \rho \times A \times v^3}$$

, Area of section, $A = \frac{\pi}{4} D^2$

D = Diameter.

$$\therefore \text{Kinetic energy} = \frac{1}{2} \times \rho \times \frac{\pi}{4} \times D^2 \times v^3$$

$$\boxed{K.E = \frac{\pi}{8} \times \rho \times D^2 \times v^3 \text{ watts}}$$

Power coefficient :-

It is defined as the ratio of rotor output power to the maximum wind power available.

$$\text{Power coefficient } C_p = \frac{\text{Rotor output power } [P]}{\text{Maximum wind power available}}$$

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

Where ρ = Density of air

A = Swept area

v = velocity of the winds.

Tip speed ratio :-

It is defined as the ratio of the speed of tip of the rotor blade to the speed of incoming air

$$\lambda = \frac{\omega \times R}{u_0}$$

where ω = speed of rotation of the blade

R = Radius of rotor

u_0 = speed of the incoming wind.

Solidity :- It is defined as the ratio of the blade area to the blade swept area.

$$\text{Solidity } S = \frac{nb}{\pi D}$$

Where n = number of blades

b = Average breadth of a blade

D = Diameter of the circle described by a blade.

COMPARISION B/W HAWT AND VAWT

HAWT	VAWT
* It requires yaw control system to change the direction of hub towards wind direction.	* yaw control system is not required It accepts the wind from all directions.
* It requires strong tower to carry all the equipments.	* It does not require strong tower
* Rotor brakes generator, gear box all are mounted on the top of the towel.	* All the equipments are mounted at ground in support stucture
* Design is complicated	* Design is easy
* Cost is more	* Cost is less
* No guy ropes are required	* Guy ropes are required to support rotor
* pitch control is present	* pitch control is absent
* Noise is less compared to VAWT	* Noise is more
* Height of the tower is high	* Height of the tower is low
* These are mostly used for power generation	* These are mostly used for water pumpings as wind pumps

SPEED CONTROL STRATEGIES OF WIND TURBINE

Various options are available for speed control of a turbine. The particular strategies depends on the size of the turbines. use simple, low cost methods while large machines use more sophisticated methods incorporating pitch control along with power electronic circuit

* Various components of the entire system are designed to withstand

extreme speed under gusty winds.

* 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
* pitch control, in which the pitch of the rotor blades is controlled to regulate the speed.
* 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

* Low-speed region:-

In this region the turbine is kept in braked position till minimum wind speed (about 5 m/s), known as cut in speed. Below this speed, the operation of the turbine is not efficient

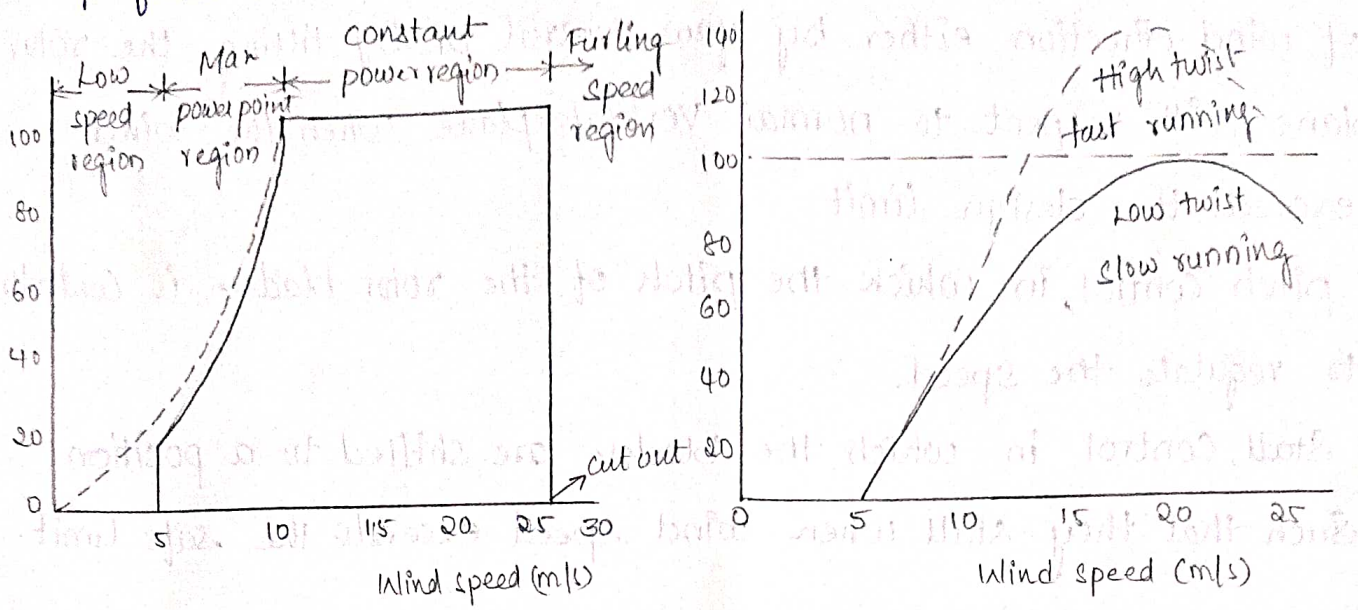
* Maximum power-coefficient region:-

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. The turbine is operated at maximum power output using pitch control.

* Constant power region:-

Large machines use pitch control to maintain turbine speed as constant. Such a machine is known as pitch regulated. In case of fixed blade rotor, the flow over the blade stalls.

The stall performance depends on the twist of the blade tip from the root and thickness of blade sections.

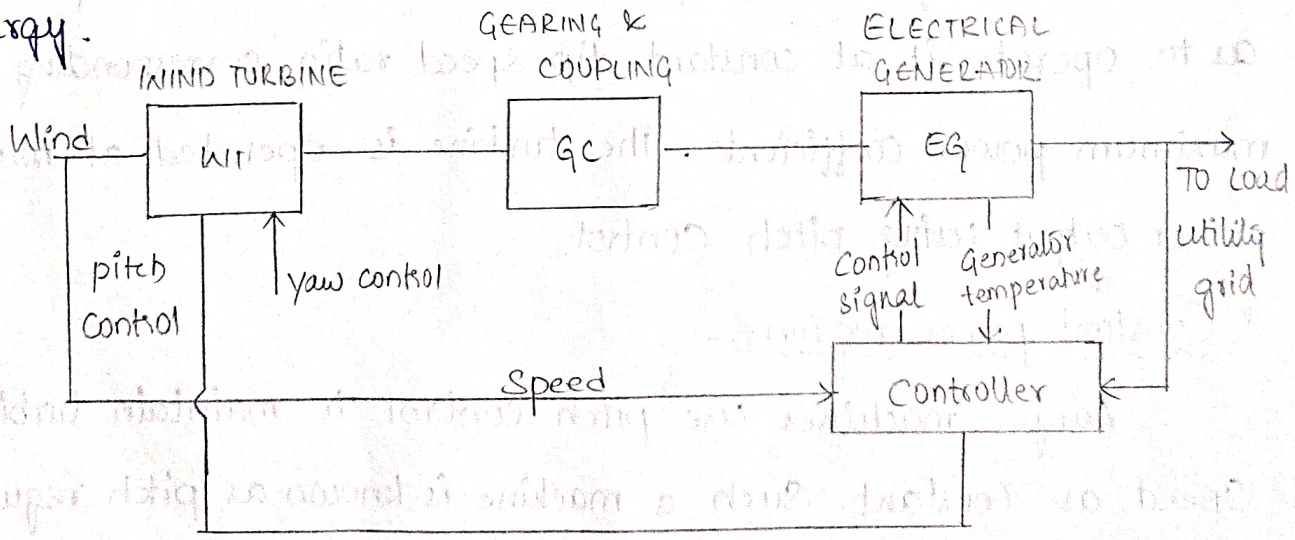


* Furling speed region :-

Beyond a certain maximum value of wind speed (around 25 m/s) the rotor is shut down and power generation is stopped to protect the blades, generator and other components of the system.

GENERATING SYSTEMS :-

Aero turbines convert wind energy into rotary mechanical energy.



The output of this generator is connected to the load or system grid. The controller senses the wind direction, wind speed, power output of the generator.

* The choice of an electrical generator and control method to be employed can be decided by consideration of following three factors.

→ The basis of operation i.e., either constant tip speed (or) constant tip speed ratio

→ The wind-power rating of the turbine and

→ The type of load demand e.g. battery connection.

Wind power ratings can be divided into three convenient grouping, small to 1kw, medium to 50kw, and large 200kw to mega watt frame size.

Electrical generators types applicable to each of these ratings are:

Small → permanent, magnet, dc generators

Medium → permanent magnet, d.c generator, Induction generator, Synchronous generator.

Large → Induction generator, Synchronous generator.

Schemes for Electric generation

Several schemes for electric generation have been developed. These schemes can be broadly classified under three categories:

* Constant-speed constant frequency system (CSCFS)
* Variable-speed constant frequency systems (VSCFS)
* Variable-speed variable frequency systems (VSVFS)

* Constant-speed Constant frequency Systems

Constant speed drive has been used for large generators Connected directly to the grid where constant frequency operation is essential.

(a) Synchronous Generator:-

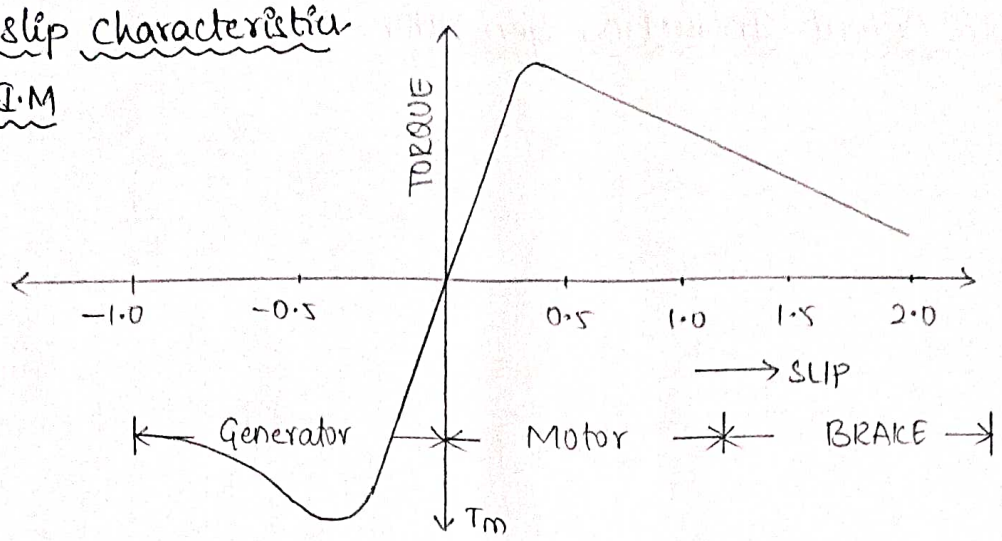
For such machines the requirement of constant speed is very rigid and only minor fluctuations about 1% for short durations could be allowed. Synchronisation of wind driven generator with power grids also will pose problems with gusty winds.

(b) Induction generator :-

If the stator of an Induction machine is connected to the power grid and if the rotor is driven above Synchronous speed N_s ($N_s = 120f/p$) the machine becomes a generator and delievers constant line frequency power to the grid.

Induction generators are basically simpler than Synchronous generators. They are easier to operate, control and maintain have no synchronisation problems.

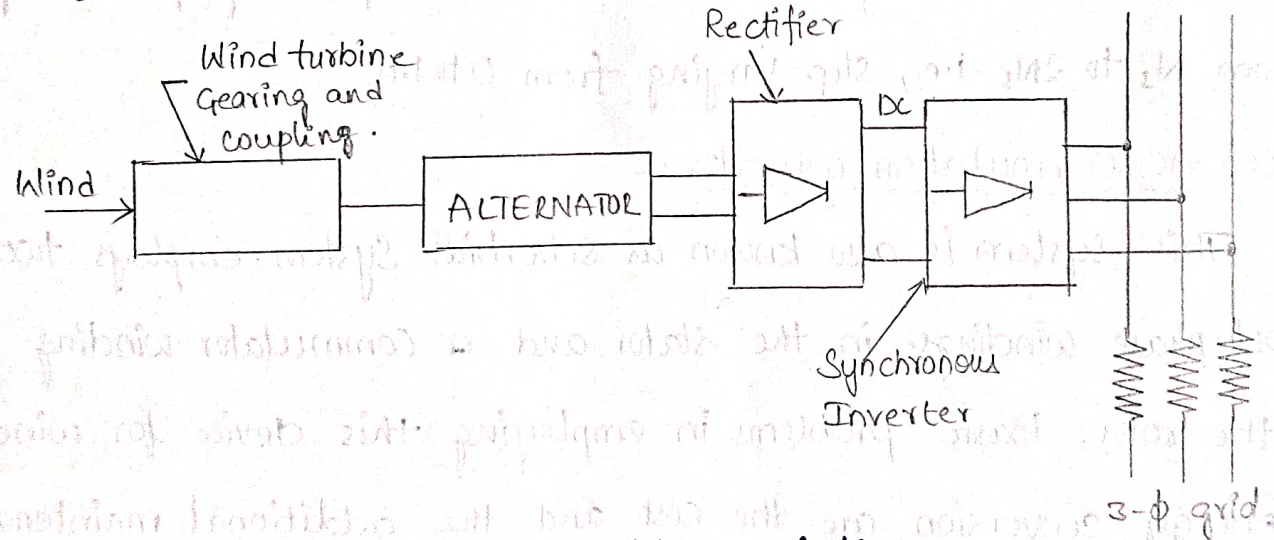
Torque-slip characteristics of I.M



* Variable Speed Constant frequency Scheme

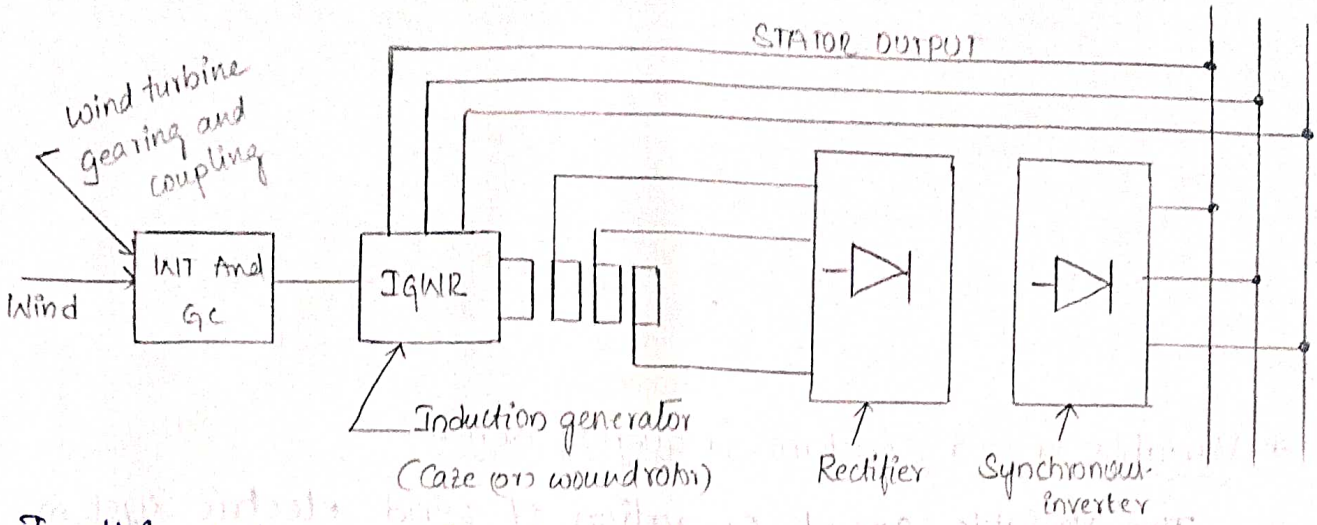
The variable speed operation of wind electric system yield higher outputs for both low and high wind speeds. The popular schemes to obtain constant frequency output are as follows:

(a) AC – DC – AC Link :-



They utilises an a.c source which periodically reverses polarity and causes the commutation to occur naturally. Since frequency is automatically fixed by the power line, they are also known as synchronous Inverters.

(b) Double Output Induction generator



In this system a slip ring Induction motor is used. Rotor power output at slip frequency is converted to line frequency power by rectification and inversion. output power is obtained both from stator and rotor hence this device is called double output induction generator. such an operation increases the operating speed range from N_s to $2N_s$ i.e., slip varying from 0 to 1.0.

(c) AC Commutation generator:-

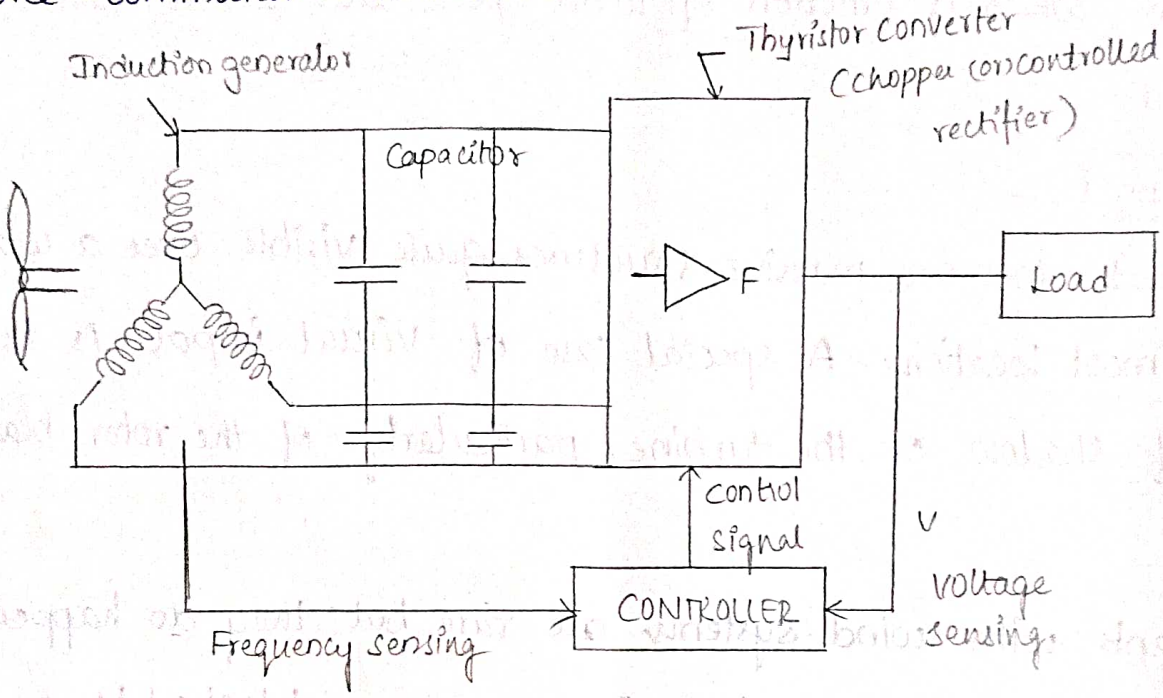
This system is also known as Scherbius System. employs two polyphase windings in the stator and a commutator winding on the rotor. Basic problems in employing this device for wind energy conversion are the cost and the additional maintenance

* Variable Speed Variable frequency Schemes:-

These systems are gaining importance for Stand alone wind power applications. The magnitude and frequency of the emf depends on the value of load impedance, prime mover speed and

excitation Capacitance.

The Varying output voltage Can be Converted to Constant d.c using choppers (or) Controlled rectifiers on Constant a.c using force-Commutated Inverters.



ENVIRONMENTAL ASPECTS :-

* Indirect Energy use and Emissions :-

Energy is required to produce material used to construct the wind turbine and its installation. This energy is paid back in a period of few months to about a year, what is known as energy payback period.

* Bird life :-

Large wind turbines pose a threat to bird life as a result of collision with tower (or) blades. Their testing and breeding patterns are also affected.

* Noise :- The disturbance caused by the noise produced by a wind turbine is one of the important factors that prevent

its siting close to inhabited areas. The acoustic noise is composed of (a) mechanical noise due to movement of mechanical parts in the nacelle, which can be reduced by good design and acoustic insulation, which is function of wind speed and which cannot be avoided.

* Visual impact:-

Wind turbines are massive structures quite visible over a wide area in most locations. A special case of visual impact is the effect of shadow of the turbine, particularly of the rotor blades

* Safety:-

Accidents with wind systems are rare but they do happen, as in other industrial activities. For example, a detached blade or its fragment may be thrown a considerable distance and can harm people and property

* Effects of Ecosystems:-

Large scale use of wind generation can reduce wind speed and cause stress to an ecosystem.

* Telecommunication Interference:-

Wind turbines present an obstacle for incident electro-magnetic waves. These waves can be reflected, scattered and dithered. Thus, they interference with telecommunication links and badly affect the quality of radio and TV reception

BETZ CRITERION:-

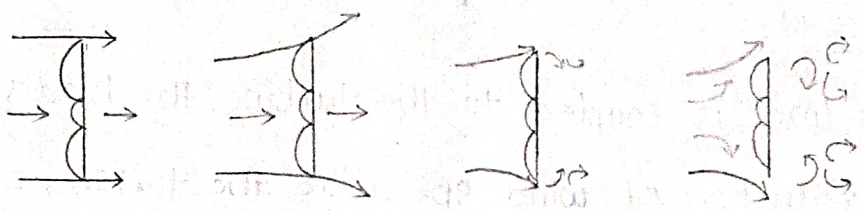
When no load is coupled to the turbine, the blades just freewheel. There is no reduction of wind speed at the turbines. therefore $u_1 = u_0$. and the value of a is zero. The turbine does not generate any power and $C_p = 0$. The air just passes through the turbine without any reduction of speed.

Now as load is applied, power is extracted, so C_p increases as u_1 decreases. Maximum value of C_p (i.e., $C_{p\,max} = 16/27 = 0.593$) occurs at $a = 1/3$. At this condition

$$u_1 = \frac{2}{3}u_0 \text{ and } u_2 = \frac{1}{3}u_0$$

That means, at maximum power extraction condition, the upstream wind speed is reduced to two third at the turbine and further reduced to one third down stream. The criterion for maximum power extraction i.e., $C_{p\,max} = 16/27$ is called the Betz criterion.

When $u_2 = 0$, $a = 0.5$ and the simple model breaks down as no wind is predicted to be leaving downstream. In practise, this is equivalent to the onset of turbulence downstream. power extraction decreases due to mismatch of rotational frequency and wind speed and partial stalling begins.

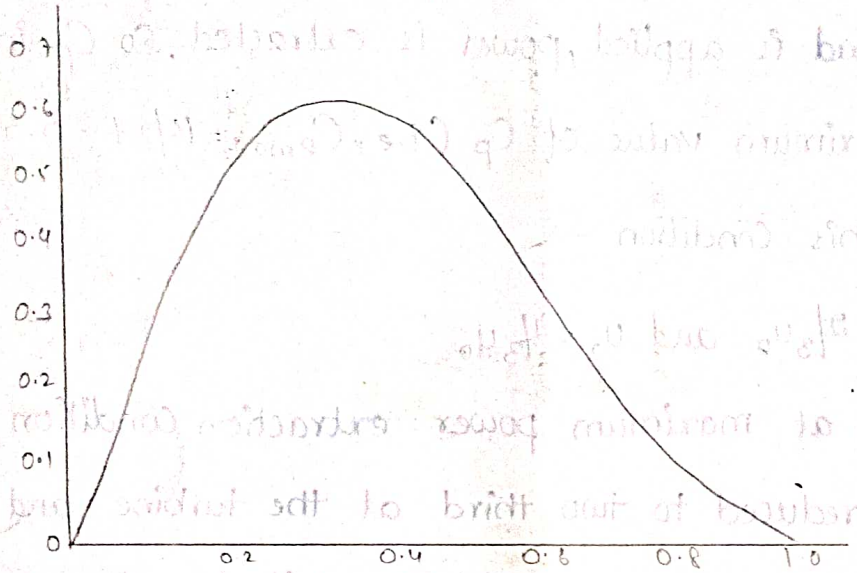


$u_1 = u_0$
$u_2 = u_0$
No power generation
$a = 0$

$u_1 = (2/3)u_0$
$u_2 = (1/3)u_0$
Max power generation
$a = 1/2$

$u_1 = (1/2)u_0$
$u_2 = 0$
Turbulent downstream
$a = 1/2$

$u_1 = 0$
Stall Condition
$a = 1$



In practise all of the kinetic energy in the wind cannot be converted to shaft power since the air must be able to flow away from the rotor area. The betz criterion, derived using the principles of conservation of momentum and conservation of energy suggests a maximum possible turbine efficiency of 59%. In practise power coefficients of 20-30% are more common