Centre of Excellence in Renewable Energy Education and Research,
New Campus, University of Lucknow,
Lucknow
M Sc. Renewable Energy
Semester II, First Year
Module REC-202: Wind Energy Conversion Systems

(Unit-3) Contents

Wind electric generators: Aero-generator classification, tower, rotor, gearbox, power regulation, safety mechanisms, Wind turbine design considerations; methodology.
Theoretical simulation of wind turbine characteristics; test methods.

Wind Electric Generators

In conventional DC machines, the field is on the stator and the armature is on the rotor. The stator comprises a number of poles which are excited either by permanent magnets or by DC field windings. If the machine is electrically excited, it tends to follow the shunt wound DC generator concept. An example of the DC wind generator system is illustrated in Fig. 3. It consists of a wind turbine, a DC generator, an insulated gate bipolar transistor (IGBT) inverter, a controller, a transformer and a power grid. For shunt wound DC generators, the field current (and thus magnetic field) increases with operational speed whilst the actual speed of the wind turbine is determined by the balance between the WT drive torque and the load torque. The rotor includes conductors wound on an armature which are connected to a split-slip ring commutator. Electrical power is extracted through brushes connecting the commutator which is used to rectify the generated AC power into DC output. Clearly, they require regular maintenance and are relatively costly due to the use of commutators and brushes.
In general, these DC WTGs are unusual in wind turbine applications except in low power demand situations where the load is physically close to the wind turbine, in heating applications or in battery charging.

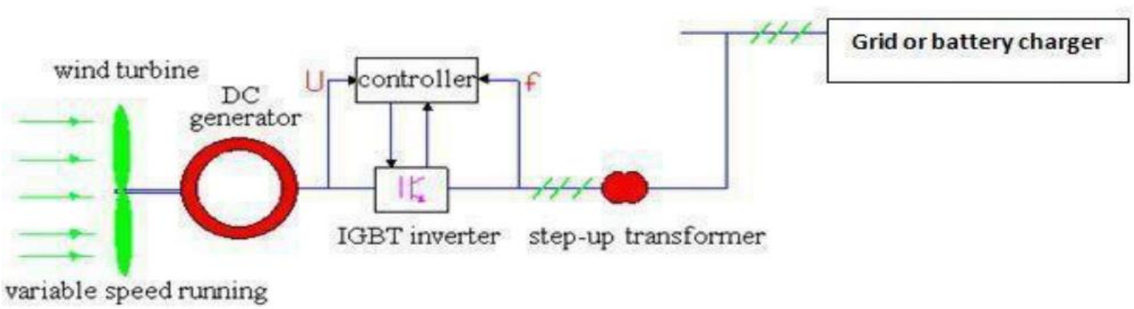
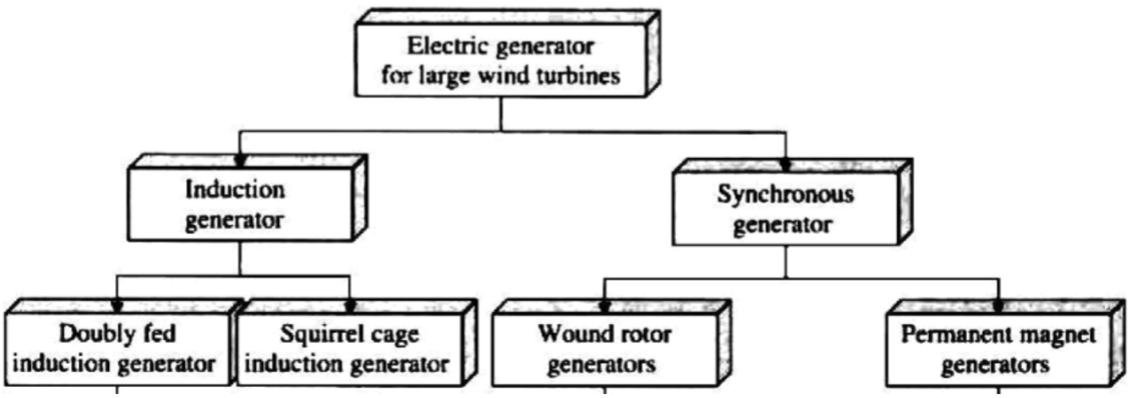


Fig 1: DC Generator

Induction and Synchronous Generator

Types of Generators used in Wind Turbine System



Any types of three-phase generator can connect with a wind turbine. Several different types of generators which are used in wind turbines are as follows. Asynchronous (induction) generator and synchronous generator. Squirrel cage induction generator (SCIG) and wound rotor induction generator (WRIG) are comes under asynchronous generators. Wound rotor synchronous generator (WRSG) and permanent magnet generator (PMSG) are comes under synchronous generator.

Asynchronous (Induction) Generator

Squirrel Cage Induction Generator (SCIG):

The fixed speed concept is used in this type of wind turbine. In this configuration the Squirrel Cage Induction Motor is directly connected to the wind turbine through a transformer is shown in the figure 2**.** A capacitor bank is here for reactive power compensation and soft starter is used for smooth grid connection.

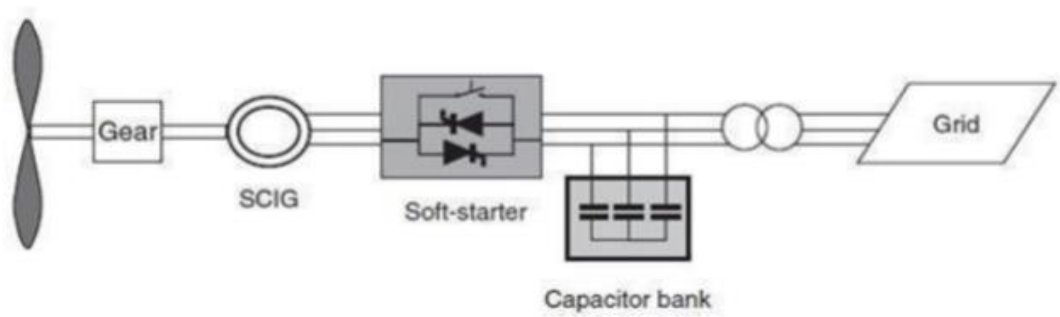


Fig 2: Asynchronous Generator

Wound rotor induction generator (WRIG):

The variable speed concept is used in this type. In this type of wind turbine wound rotor induction generator is directly connected to the grid as shown in the figure 3. The variable rotor resistance is for controlling slip and power output of the generator. The soft starter used here for reduce inrush current and reactive power compensator is used to eliminate the reactive power demand .The speed range is limited, poor control of active and reactive power, the slip power is dissipated in the variable resistance as losses are the disadvantages of this configuration.

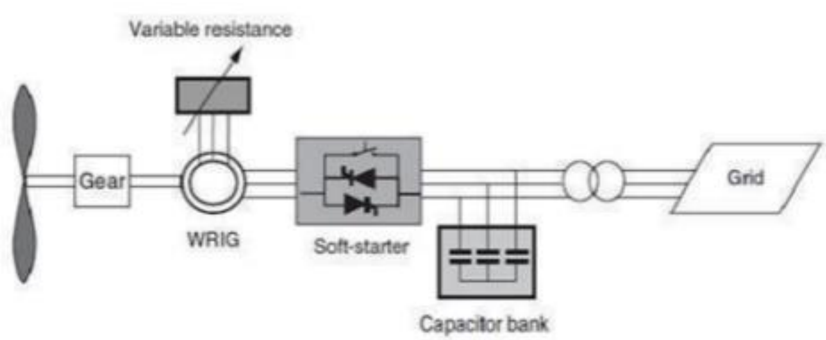


Fig 3: Wound rotor induction generator

Doubly Fed Induction Generator (DFIG):

In order to satisfy the modern grid codes, the grid turbine system has the capability of reactive power support. Doubly fed induction generator based wind turbine systems have more advantages than others. DFIG wind turbine deliver power through the stator and rotor of the generator the reactive power can provide in two sides. Hence use the term doubly. Reactive power can be supported either through grid side converter or through rotor side converter. The stator part of the turbine is directly connected to the grid and the rotor is interfaced through a crowbar and a power converter. The voltage to the stator part is applied from the grid and the voltage to the rotor is induced by the power converter. The power is delivered from the rotor through the power converter to the grid if the generator is operates above synchronous speed.

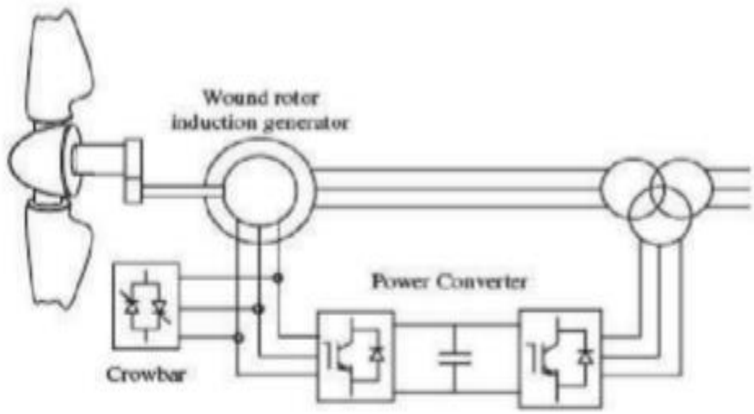


Fig 4: Doubly Fed Induction Generator wind turbine

If the generator is operates below synchronous speed, then the power is delivered from the grid through the power converter to the rotor. The power converter controls the active and reactive power flow, the DC voltage of link capacitor between the grid and DFIG wind turbine by feeding the pulse width modules (PWM) to the converters.

A crowbar is implemented between the generator and converter to prevent short circuit in the wind energy system. This may result in high current and high voltage. The RSC converter controls the flux of the DFIG wind turbine .which operates at the slip frequency that depends on the rotor speed of the generator. According to the maximum active and reactive power control capability of converter, the power rating of the RSC is determined.

Synchronous Generator

Wound Rotor Synchronous Generator (WRSG):

Turbine with wound rotor connected to the grid is shown in fig 5. This configuration neither require soft starter nor is a reactive power comparator its main advantage. The partial scale frequency converter used in the system will perform reactive power compensation as well as smooth grid connection. The wide range of dynamic speed control is depends on the size of frequency converter the main disadvantage is that in the case of grid fault it require additional protection and use slip rings, this makes electrical connection to the rotor.

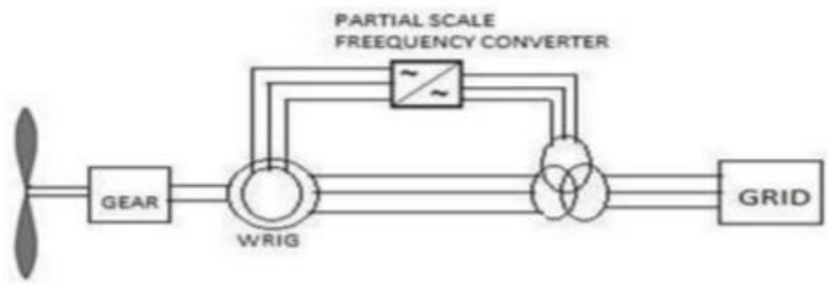


Fig 5: Wound Rotor Generator

Permanent Magnet Synchronous Generator (PMSG):

The generator is connected to the grid via full scale frequency converter. The frequency converter helps to control both the active and reactive power delivered by the generator to grid.

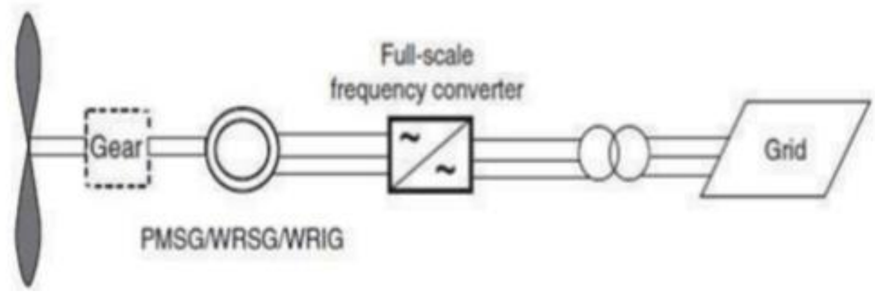


Fig 6: Permanent Magnet Generator

Rotor

The rotor is made up of the hub and blades.

Hub:

The hub connects to the generator shaft by a bearing and also connects to the blades by bearing to allow control of the pitch of the blades. The hub is typically made primarily out of cast iron with a glass fiber reinforced polyester (or similar material) casing called the spinner.

Blades:

The blades of modern turbines are aerofoils, which can reach over 50 m in length, comprising a main spar glued between two shell sections. Primary materials used in blades are carbon fibers and woven glass fibers infused with epoxy resins and polyurethane glue used to assemble the blade shell.

Nacelle

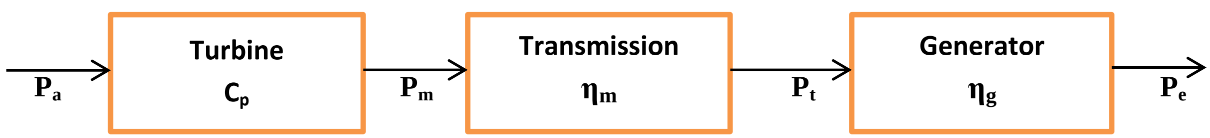
The nacelle houses the electricity generating equipment including gearbox (if geared), generator, foundation, cover, yaw system (a bearing system that allows the wind turbine to change direction to face the wind), and controls.

Gearing and Generator:

The gearbox converts the low-speed rotation delivered by the blades to a high-speed (1500 rpm) rotation for electricity generation. Typical materials for the gearbox are iron and steel. The generator also consists mainly of iron and steel. Some manufacturers use lighter permanent magnets made from rare earth metals (e.g., neodymium or dysprosium) while others use heavier induction generators. Although most wind turbines have gears, non-geared turbines are being built but must rely on heavier, low-speed generators.

Transmission and Generator Efficiencies

The shaft power output that we have been discussing is not normally used directly, but is usually coupled to a load through a transmission or gear box. The load may be a pump, compressor, grinder, electrical generator, and so on. For purposes of illustration, we will consider the load to be an electrical generator. The basic system is then as shown in Fig.



We start with the power in the wind, P_a. After this power passes through the turbine, we have a mechanical power P_m at the turbine angular velocity ω_m, which is then supplied to the transmission. The transmission output power P_t is given by the product of the turbine output power P_m and the transmission efficiency η_m:

$$\mathbf{P_t = \eta_m P_a} \quad \textbf{Watt} \qquad \textbf{eq.....1}$$

Similarly, the generator output power P_e is given by the product of the transmission output power and the generator efficiency η_g:

$$\mathbf{Pe = \eta_g P_t} \quad \textbf{Watt} \qquad \textbf{eq.....2}$$

Equations 1 and 2 can be condensed to a single equation relating electrical power output to wind power input:

$$\mathbf{Pe = C_p \eta_g \eta_m P_a} \quad \textbf{Watt}$$

Foundation and Cover:

The nacelle foundation provides the floor of the nacelle and is often made from cast iron. The cover to the nacelle is typically made from a fiberglass, consisting of woven glass fibers, polyethylene, and styrene.

Tower:

Because wind speeds increase with height, the turbine is mounted on a tower. In general, the higher the tower, the more power the wind system can produce. The tower also raises the turbine above the air turbulence that can exist close to the ground because of obstructions such as hills, buildings, and trees. A general rule of thumb is to install a wind turbine on a tower with the bottom of the rotor blades at least 30 feet (9 meters) above any obstacle that is within 300 feet (90 meters) of the tower. Relatively small investments in increased tower height can yield very high rates of return in power production.

There are two types of towers: self-supporting (free-standing) and guyed. Guyed towers, which are the least expensive, can consist of lattice sections, pipe, or tubing (depending on the design); supporting guy wires; and the foundation. They 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 space to accommodate them. Although tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller lightweight turbines (usually 5 kW or smaller). Tilt-down towers can also be lowered to the ground during hurricanes and other hazardous weather conditions. Aluminum towers are prone to cracking and should be avoided. Most turbine manufacturers provide wind energy system packages that include a range of tower options.

Foundation:

The foundation of wind turbines can change significantly, depending on the installation location. Onshore foundation designs include: tensionless pier, a cast-in-place concrete ring around 3-5 m in diameter and up to 10 m deep; anchor deep, a 2 m thick concrete ring supported by up to 20 steel anchors up to 15 m deep; and gravity spread, a broad steel-reinforced concrete disk up to 20 m in diameter. Offshore designs include: gravity-based, using mass to prevent the turbine from tipping over; mono-pile, consisting of a single, hollow steel pile driven into the sea bed; tripod, consisting of a braced Y-frame and three, smaller piles into the sea bed; and floating, consisting of a floating ballast submerged and moored to the sea bed.

Rotor Selection- Wind Turbine Rotor Design Considerations:

There are several parameters involved in the design of an efficient economical wind turbine. Generally, efficient design of the blade is known to maximize the lift and minimize the drag on the blade. Now, minimization of the drag means that the aerofoil should face the relative wind in such a way that minimum possible area is exposed to the drag force of the wind. Furthermore the angle of this relative wind to the blades is determined by the relative magnitudes of the wind speed and the blade velocity.

The wind velocity basically stays constant throughout the swept area but the blade velocity increases from the inner edge to the tip. Which means the relative angle of the wind with respect to the blade is ever-changing. Now the various parameters which determine the design of the wind turbine are noted below:

Diameter of the Rotor:

Since the power generated is directly proportional to the square of the diameter of the rotor, it becomes a valuable parameter. It's basically determined by the relation between the optimum powers required to be generated by the mean wind speed of the area. Power generated,

$$\mathbf{P=\eta_e \eta_m C_p P_o}$$

Choice of the number of blades:

The choice of the number of blades of a wind rotor is critical to its construction as well as operation. Greater number of blades is known to create turbulence in the system, and a lesser number wouldn't be capture the optimum amount of wind energy. Hence the number of blades should be determined by both constraints and after proper study of its dependence on the TSR. Now, let $\mathbf{t_a}$ be the time taken by one blade to move into the position previously occupied by the previous blade, so for an n-bladed rotor rotating at an angular velocity, $\boldsymbol{\omega}$ we have the following relation:

$$t_a = \frac{2\pi}{n\omega}$$

Again let $\mathbf{t_b}$ be the time taken by the disturbed wind, generated by the interference of the blades to move away and normal air to be reestablished. Now this will basically depend on the wind speed, on how fast or how slow the wind flow is. Hence it depends on the wind speed $\boldsymbol{V}_{\infty}$ & the length of the strongly perturbed wind stream, say **d** Here we have:

$$\boldsymbol{t_b} = \frac{\boldsymbol{d}}{\boldsymbol{V}}$$

For maximum power extraction, t_a & t_b should be equal, hence

$$\boldsymbol{t_a} = \boldsymbol{t_b}$$

$$\frac{2\pi}{n\omega} = \frac{d}{V}$$

$$\boldsymbol{d} = \frac{\boldsymbol{2\pi V}}{\boldsymbol{n\omega}}$$

So, **d** has to be determined empirically.

Choice of the Pitch Angle:

The pitch angle is given by, α=I-i, where I is the angle between the speed of the wind stream and the speed of the blades. Now as I varies along the length of the blade, α, should also vary to ensure an optimal angle of incidence at all points of the blade. Thus the desirable twist along the blade can be calculated easily. The pitch angle such as tan Ø or C_d/C_l should be minimum at all points of the rotor. Its minimum point will represent the optimal pitch angle.

Power Regulation:

Wind turbines are designed to produce electrical energy as cheaply as possible. Wind turbines are therefore generally designed to yield of maximum output at wind speeds around 15 meters per second. (30 knots or 33 mph).

It does not pay to design turbines that maximize their output at stronger winds, because such strong winds are rare. In case of stronger wind is necessary to waste part of the excess energy of the wind in order to avoid the damaging wind turbine. All wind turbines are therefore designed with some sort of power control. There are two different ways of doing this safely on modern wind turbines.

Pitch Controlled Wind Turbines

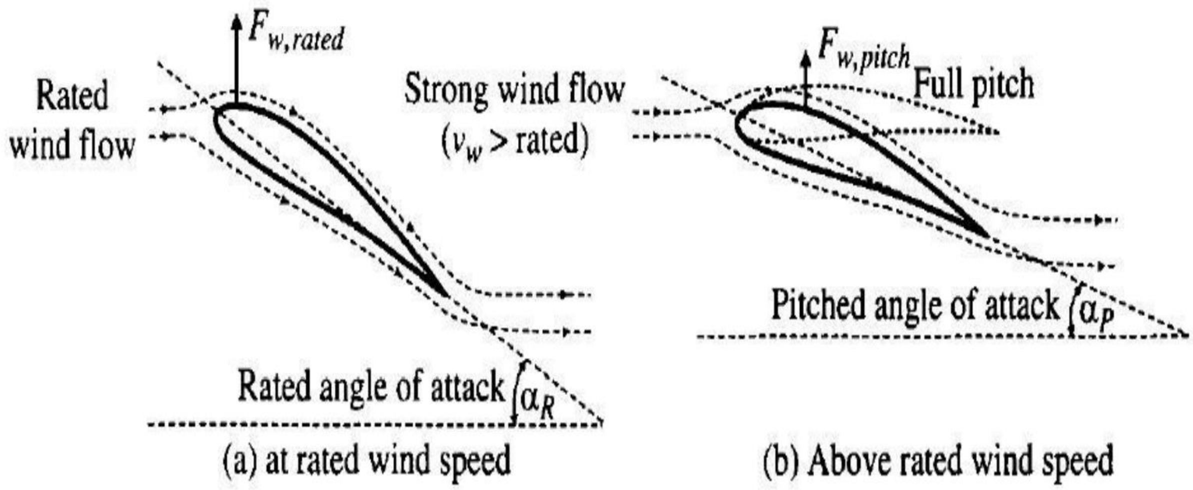


Fig. Schematic of Pitch Controlled Wind Turbines

On a pitch controlled wind turbine the turbine's electronic controller checks the power output of the turbine several times per second. When the power output becomes too high, it sends an order to the blade pitch mechanism which immediately pitches (turns) the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again.

Stall Controlled Wind Turbines

(Passive) stall controlled wind turbines have the rotor blades bolted into the hub at a fixed angle. The geometry of the rotor blade profile however has been aerodynamically designed to ensure that the moment of the wind speed becomes too high; it creates turbulence on the side of the rotor blade which is not facing the wind as shown in the picture on the previous page. This stall prevents the lifting force of the rotor blade from acting on the rotor.

If you have read the section on aerodynamics and aerodynamics stall , you will realize that as the actual wind speed in the area increases, the angle of attack of the rotor blade will increase, until at some point it starts to stall.

Active Stall Controlled Wind Turbines

An increasing number of larger wind turbines (1 MW and up) are being developed with an active stall power control mechanism.

Technically the active stall machines resemble pitch controlled machines, since they have patchable blades. In order to get a reasonably large torque (turning force) at low wind speeds, the machines will usually be programmed to pitch their blades much like a pitch controlled machine at low wind speeds. (Often they use only a few fixed steps depending upon the wind speed).

When the machine reaches its rated power, however, this will notice an important difference from the pitch controlled machines: If the generator is about to be overloaded, the machine will pitch its blades in the opposite direction from what a pitch controlled machine does. In other words, it will increase the angle of attack the rotor blades in order to make the blades go into a deeper stall, thus wasting the excess energy in the wind.

Yaw Control:

Turbines whether upwind or downwind, are generally stable in yaw in the sense that if the nacelle is free to yaw, the turbine will naturally remain pointing into the wind. However, it may not point exactly into wind, in which case some active control of the nacelle angle may be needed to maximize the energy capture.

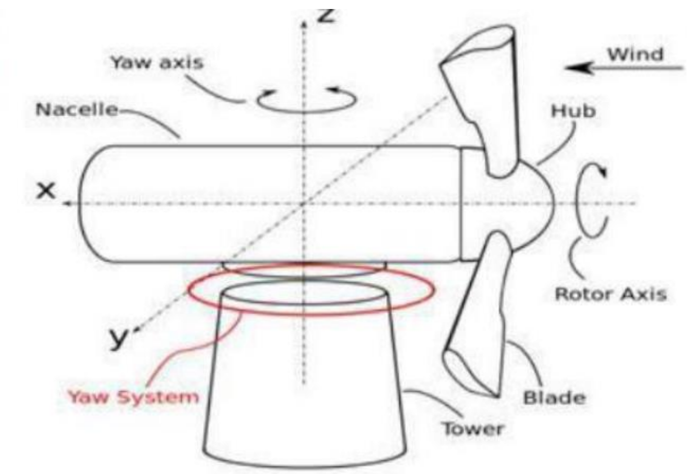


Fig. 2.6 Schematic of Yaw Control

Since a yaw drive is usually required anyway, e.g. for start-up and for unwinding the pendant cable, it may as well are used for active yaw tracking. Free yaw has the advantage that it does not generate any yaw moments at the yaw bearing. However, it is usually necessary to have at least some yaw damping, in which case there will be a yaw moment at the bearing. In practice, most turbines are used active yaw control.

Note:

1. Study Material on Power Safety Mechanisms will be provided Soon.
2. Please Follow Electrical Engineering [Textbook/ Class Notes (Semeter-1)] for detail information about Generator: Synchronous and Induction Generator.