UNIT -2: (Part: 2) WIND ENERGY-FUNDAMENTALS AND APPLICATIONS

Introduction to Wind Energy:

In the continuous search of clean, safe and renewable energy sources, wind power is certainly one of the most attractive solutions. Wind power was used earlier for several centuries for propelling ships, driving windmills, pumping water, irrigating fields and numerous other purposes. The exploitation of plenty of cheap fossil fuels and development of internal combination engines have led to the wind power being gradually replaced by other energy, sources during the first half of 20th century. The oil crisis of 1973 together with environmental consciousness has however renewed the interest in the wind power all over the world, Wind energy is one of the important renewable.

During 1970s and 1980s data regarding wind energy resources has been collected from various sites. During 1980s various types of prototype wind turbine generators have been built. By late 1980s commercial production of wind turbine generators has commenced.

Several wind farms have been installed particularly in Canada, Denmark, Netherlands, Sweden, U.K., U.S.A., Germany, India etc. By 1990's wind-energy to electrical energy has become economically competitive in areas of favourable wind (e.g. Gujarat, Tamil Nadu) and wind-electric energy systems are now on the forefront of renewable energy utilization projects sponsored by the Department of Nonconventional Renewable Energy (DNRE). Several wind turbine generators have been installed throughout the world.

Unit ratings of wind-turbine generators cover a wide range from 0.5 kW to 14 kW. The broad classification is as follows.

-- Very small	0.5 to 1 kW
-- Small	1 to 15 kW
-- Medium	15 to 200 kW
-- Large	250 to 1000 kW
-- Very large	1000 kW to 6000 kW

Single wind turbine generators rated 14 MW are under development (1990). In India, wind farms are operating in Tamil Nadu and Gujarat since 1989. Several new projects totaling 500 MW are at various stages of execution.

Wind energy is a manifestation of the solar energy.

Wind is the air-in-motion. Energy in the wind is converted into rotary mechanical energy by the wind-turbine. The rotary mechanical energy is used for several applications such as

-- Pumping water

-- Grinding flour

-- Driving generator rotors to produce electrical energy.

Energy Chains of Wind Energy are:

Wind Energy → **Mechanical energy at wind turbine shaft** → **Mechanical energy utilization**

Wind Energy → **Mechanical energy at wind turbine shaft** → **Electrical energy by generator** → **Electrical energy for utilization**

The direct use of mechanical energy is useful for pumping water, grinding grains, operating, wood-saw etc.

The electrical energy can be used by stand-alone loads or by the loads connected to the distribution system.

Several types of wind-turbines have been developed, installed and are being operated successfully. These are classified into two main categories:

-- Horizontal shaft wind turbine

-- Vertical shaft wind turbine

Wind-turbine generators have become commercially successful products and are being encouraged by the departments of Non-conventional and Renewable Energy. Horizontal shaft wind-turbine generator units are more popular. The generator-turbine unit is mounted on a tall tower.

Vertical shaft wind turbine units are mounted on ground level. They are generally in very large size (4 MW and above) and are also commercially successful in some countries.

Wind farms are located in geographical areas which have continuous, steady, favourable wind in the speed range between 6 m/s to 30 m/s. Annual average wind speed of 10 m/s are considered to be very suitable.

A wind farm has several wind-turbine-generator units. A typical wind farm may have 5 to 50 wind-turbine generator units of small or medium size.

Large wind-turbine-generator units (WTGU) are generally built as single units (without wind-farm).

The electrical generators with the wind-turbine units are of two types.

-- 50 Hz A.C. synchronous generators with constant speed connected to the grid. Power Control and gear are necessary.

-- Variable frequency A.C. Induction generators with variable speed. An electronic frequency

Changer converts variable frequency (0 to 20 Hz) output to the commercial frequency Supply (50 Hz or 60 Hz).

Following options are available for wind-electric energy conversion plants.

(1) As stand-alone generators with battery storage support.

(2) In parallel with the electrical grid as energy displacement plants. Battery storage is not necessary.

(3) Wind-Diesel hybrid for remote stand-alone systems.

India's potential for useful wind energy plants is about 25,000 MW. This may constitute about 10 per cent of the National installed capacity by about 2010 AD. Wind farms with unit ratings of 15 kW to 200 kW have been installed in Gujarat and Tamil Nadu. At present, the total installed capacity is 45 MW and projects of 155 MW are under installation (1994). By 1996-end, wind-electric energy capacity in India may well cross 500 MW target.

Wind energy is considered to be a very clean, cheap important renewable energy source particularly for rural areas, farms, remote on-shore and off-shore installation away from main electrical grid.

Entity	Symbol	Units
Wind velocity	V	m/s
Area of stream	A	m^2
Air mass	m	kg
Air mass flow, rate	M_d	Kg/s
Air mass density		Kg/m^2
Conversion factor for wind speed to power unit	K	m/s
Kinetic energy in wind	KE_w	J
Electrical power	P_e	W
Electrical energy	E	J

Wind Power Density (P_w):

Wind is flowing air-mass. Let **V** be wind velocity or wind speed. The air has mass density $\mathbf{m_d}$. Flowing air has kinetic energy $\mathbf{KE_w}$,

Power density ($\mathbf{P_w}$) of wind is proportional to $\mathbf{V^3}$.

For simplified analysis, we begin with the basic power equation.

$$P_w = k\,V^3 \qquad ...W/m^2 \qquad \text{........1}$$

Where,

$\mathbf{P_w}$ = Wind power density, W/m^2 (the m^2, represents area of wind stream crossing wind-turbine blade swept area)

k = Conversion factor for wind power

from dimensional analysis, the dimensions of **k** are

$$[\boldsymbol{k}] = [\frac{\boldsymbol{W/m^2}}{\boldsymbol{m^3/s^3}}] = [\frac{\boldsymbol{Ws^3}}{\boldsymbol{m^5}}] = \boldsymbol{Ws^3m^{-5}}$$

The value of k in SI units is **k= 0.63836**

When P_w is in W/ and V is in m/s.

Thus, in SI units

$P_w = 0.6386\ V^3$ ...W/m^2 2

Fig-8.3 shows a typical P-V characteristic of wind.

Power by wind-turbine

P= P_w A .... Watts 3

Actual characteristic varies with site, height, and is not constant.

For each site and height, measurements are carried out).

P_w = Wind power density W/m^2

A = Swept area, m^2

Energy in Wind, energy in time integral of power and energy in '**n**' hours is given by

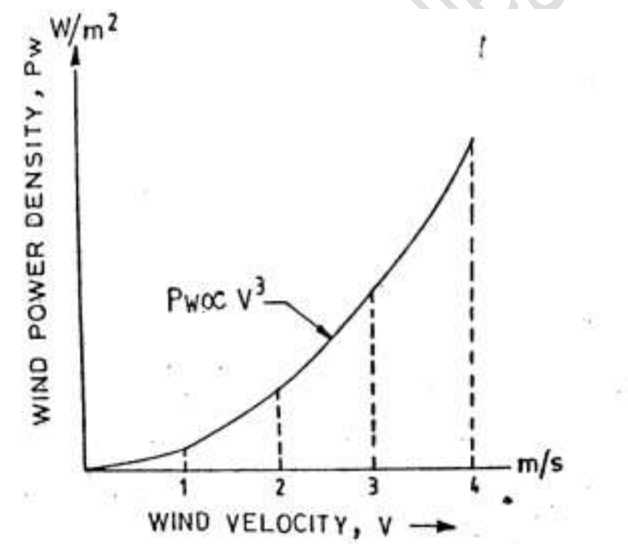


Fig. 8.3. Power-Velocity characteristic of wind.
(Actual characteristic varies with site, height, and is not constant.
For each site and height, measurements are carried out).

$$\boldsymbol{E = \int_0^n Pdh} \quad \ldots\ldots .Wh$$ 4

Where,

E= Energy, Wh

P = P_w **A** =Watts

Area under the Power versus Hours curves gives the energy

$$\boldsymbol{E = \int Pdh} \quad \ldots Wh$$ 5

Area under P-H curve of the wind gives energy in the wind through swept area A of turbine blades.

Area under the P-H curve of the wind-turbine gives the energy output of the wind-turbine.

Efficiency Factor of Wind Turbine:

Efficiency of a wind-turbine is given by the ratio for same interval of time.

$$\eta = \frac{\textbf{Energy output by wind turbine}}{\textbf{Energy in the wind}} = \frac{P_0}{P_I} \quad \text{.........6}$$

Fig-8.4 illustrates Power versus Hours characteristic called Daily power Curves for the following.

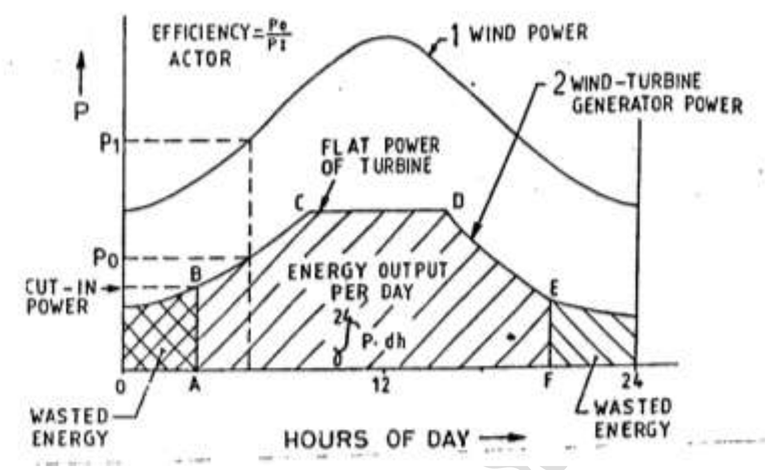


Fig - 8.4 Daily wind power curves (1) and curve of wind-turbine generator output power (2) Area under curve 2 gives energy delivered by WTG unit cross-hatched area

1. Wind power for certain cross sectional area at certain height from ground,
2. Power output of wind-turbine generator unit. Operating point moves along A, B, C, D, E

At point B, the wind power is X whereas the wind-turbine generator unit power is Y. At point A, wind-turbine is cut in and at point B wind-turbine is cut out. Area ABCDEF represents daily energy output of the wind turbine generator unit.

Power in a Wind Stream: A wind stream has total power P, which is equal to the time rate of kinetic energy KE_w

$P_t = m\, KE_w$

$$= \bar{m}\frac{{v_i}^2}{2} \quad \text{........7}$$

Where,

$\bar{m}$ = Air mass flow rate, kg/s

V_i = Incoming wind velocity, m/s

P_t = Total power in wind stream, W

The air mass flow $\bar{m}$ is given by

$\bar{m} = \rho A V_i$ 8

Where, ρ = Wind density of incoming wind, kg/m^3

= **1.226** kg/m^2, for **1** atm and **15**°C

A= Cross Sectional area of the wind stream, m^2

Substituting equation-8 in equation-7,

$P_t = \frac{\rho A V_i^3}{2}$ .... W 9

Thus, the total power (P_t) in the wind stream is

-- Directly proportional to wind density

-- Directly proportional to area of stream A

-- Proportional to V_i^3

Fig. 8.5 gives the graph of P_t versus **A.** At standard pressure 1atm, and temperature 15°C, the Air density is 1.226 kg/m^3.

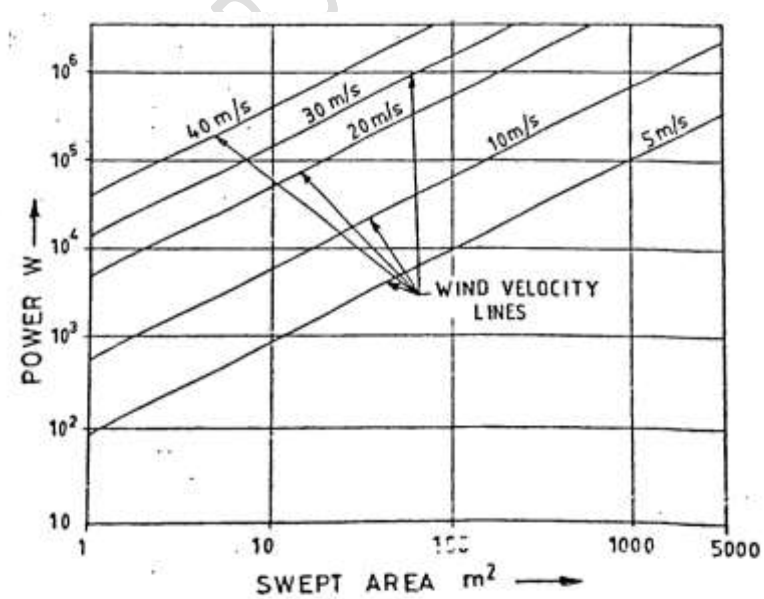


Fig- 8.5 Total Power P_t in wind stream for various wind velocities (**V**) and swept areas (**A**).

From Equation- 9 we conclude the following:

-- A wind turbine rotor should have blades of very long length, so that swept area $\boldsymbol{A} = (\boldsymbol{\pi D^2/4})$ is adequate.

-- Several wind-turbines are necessary to get more **P**.

-- Wind turbine should be located at place having favourable wind speed throughout the year (V= 10 m/s is considered to be ideal).

Wind Turbine Efficiency:

The swept area (**A**) of a wind-turbine propeller is considered in calculating the power P of the wind-turbine. In practice the wind spills through the gap between the blades resulting in spillage loss. Therefore the real power (**P**) delivered by a wind-turbine is less than the total power in the wind stream.

$$\mathbf{P} = \eta_a P_t \qquad .....10$$

P = Real power by turbine, W

P_t = Total Power in wind stream, W

η_a = Actual Efficiency of wind turbine.

η_{max} = Maximum possible theoretical efficiency assuming no spillage, friction, etc.

The actual efficiencies of various types of wind-turbine vary between 10 to 45 percent depending upon the ratio of blade-tip speed to wind speed, type of wind-turbine, spillage factor, etc. ($\boldsymbol{\eta_a = 0.5\ \eta_{max}}$ **to** $\boldsymbol{0.6\ \eta_{max}}$).

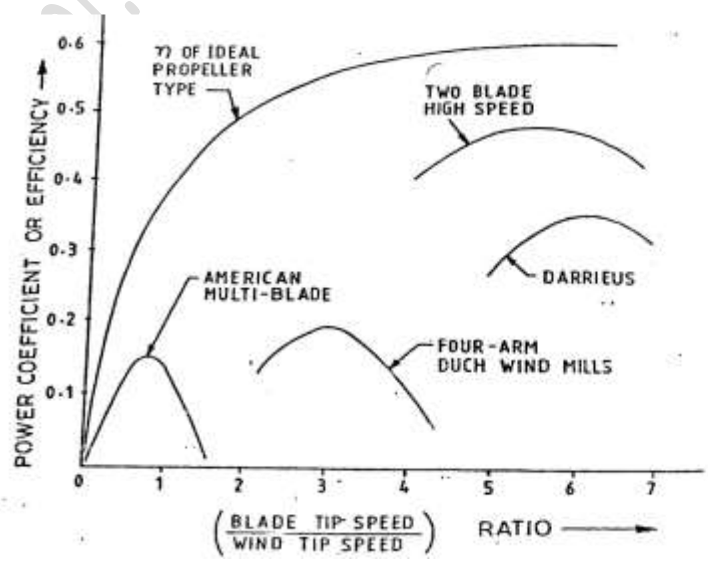


Fig – 8.6 Power coefficients for various types of wind turbines for practical blade tip speed ratios

Table 8.6 Efficiency of Various Types of Wind Turbines

Type of Wind Turbine	Ratio: $\frac{\text{Blade Tip Speed}}{\text{Wind speed}}$	Actual Efficiency (η_a)
-- Ideal propeller type	1 to 4	0.4 to 0.55
-- High-speed 2 blade propeller type	4 to 7	0.4 to 0.45
-- Darrieus	4.5 to 7	0.25 to 0.35
-- Multiblade	0.25 to 1.4	0.02 to 0.15

Power of a Wind Turbine for given incoming wind Velocity V_i:

A propeller type horizontal axis, wind-turbine is considered because it 18 most common.

Let, **a-b**= thickness of turbine blades indirection of wind stream, m

a = inlet plane

b = exit plane

V_i = incoming wind velocity, m/s

V_e = Wind velocity at exit from blades, m/s

i = incoming-end subscript

e = exit end subscript

P_i = incoming wind pressure,

P_e = Wind pressure at exit from blades, WW

v = Specific volume = **1/ρ**

Assuming no energy loss and no change in air density,

Incoming wind energy = Exit wind energy

$$P_i v + \frac{V_i^2}{2} = P_a v + \frac{V_a^2}{2} \qquad \text{......11}$$

Or

$$P_i + \rho\frac{V_i^2}{2} = P_a + \rho\frac{V_a^2}{2} \qquad \text{......12}$$

Where, P_i, P_a and V_i, V_a are pressures and volumes respectively and are the specific volume and specific density.

The specific volume and specific density both considered constant, **V= 1/e**.

Similarly, for the exit end, we get

$$P_e + \rho\frac{V_e^2}{2} = P_b + \rho\frac{V_b^2}{2} \qquad \text{.......13}$$

The wind velocity decreases from inlet plane 'a' to exit plane 'b' as kinetic energy is converted into mechanical work. The incoming velocity V decreases gradually as it approaches the turbine to **V_a** and as it leaves it to **V_e**. Thus **V_i** >**V_a** and **V_b**>**V_e**, and therefore, from Equations 12 and 13, **Pa**>P_i and P_b<P_e; that is, the wind pressure rises as it approaches, and reduces as it leaves the wheel.

From equation-12,

$$\boldsymbol{P_a = P_i + \rho \frac{V_i^2 - V_a^2}{2}} \qquad \text{.......13a}$$

Similarly from equation-13,

$$\boldsymbol{P_b = P_e + \rho \frac{V_e^2 - V_a^2}{2}} \qquad \text{.......13b}$$

By subtracting equation-13b from equation-13a one can get,

$$\boldsymbol{P_a - P_b = \left[P_i + \rho \frac{V_i^2 - V_a^2}{2}\right] - \left[P_e + \rho \frac{V_e^2 - V_a^2}{2}\right]} \qquad \text{.....14}$$

At exit-end away from the turbine at e, the wind pressure returns to original wind pressure. Thus,

$$\boldsymbol{P_e = P_i} \qquad \text{......15}$$

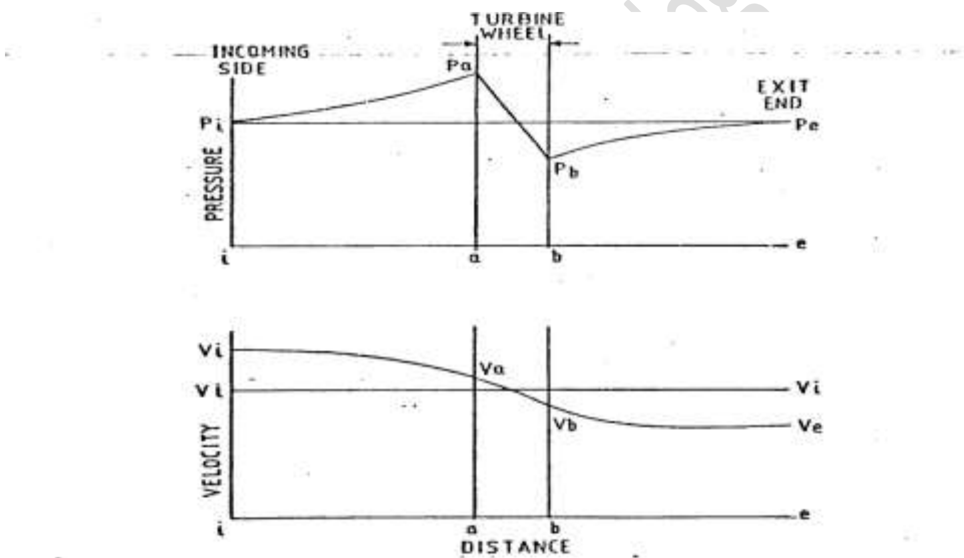


Fig- 8.7 Curves of pressure and velocity of wind passing through a propeller of a horizontal axis wind turbine.

Subscript, i- Incoming, e = Exit, P = Power, V=Velocity, a, b = points at rotor at inlet and exit respectively.

Velocity within the turbine, $\mathbf{V_t}$, does not change because the blade width a-b is thin compared with the total distance.

$$\boldsymbol{V_t \approx V_a \approx V_b} \qquad \text{.........16}$$

Combining Equation-14 and-16 gives,

$$\boldsymbol{P_a - P_b = \rho \left[\frac{V_i^2 - V_e^2}{2}\right]} \qquad \text{........17}$$

The axial force $\boldsymbol{F_x}$, in the direction of the wind stream, on a turbine propeller projected area, perpendicular to the stream A, is given by

$$\boldsymbol{F_x = (P_a - P_b)A = \rho A \left[\frac{V_i^2 - V_e^2}{2}\right]} \quad \text{……..18}$$

This force is also equal to the change in momentum of the wind $\Delta(\boldsymbol{\bar{m}V})$where is the mass flow rate given by

$$\boldsymbol{\bar{m} = \rho A V_t} \quad \text{…..19}$$

Therefore,

$$\boldsymbol{F_x = \rho A V_t (V_i - V_e)} \quad \text{….20}$$

Equating equations 18 and 20 we get,

$$\boldsymbol{V_t = \frac{1}{2}(V_i + V_e)} \quad \text{……. 21}$$

Let us now consider the total thermodynamic system bounded by i and e. The changes in potential energy are, as above, zero. Likewise, the changes in internal energy (T_i-T_e) and flow energy ($P_i v = P_e v$) are also zero and no heat is added or rejected. The general energy equation now reduces to the steady-flow work W and kinetic energy terms

$$\mathbf{W = KE_i - KE_e} = \frac{V_i^2 - V_e^2}{2} \quad \text{………22}$$

The power P is the rate of work. Using Equation-19

$$\mathrm{P} = \bar{m}\frac{V_i^2 - V_e^2}{2} = \frac{1}{2}\boldsymbol{\rho A V_t (V_i^2 - V_e^2)} \quad \text{…..23}$$

Substituting value of $\mathbf{V_t}$ from equation- 21, in equation-23 we get,

$$\mathrm{P} = \frac{1}{4}\boldsymbol{\rho A (V_i + V_e)(V_i^2 - V_e^2)} \quad \text{…..24}$$

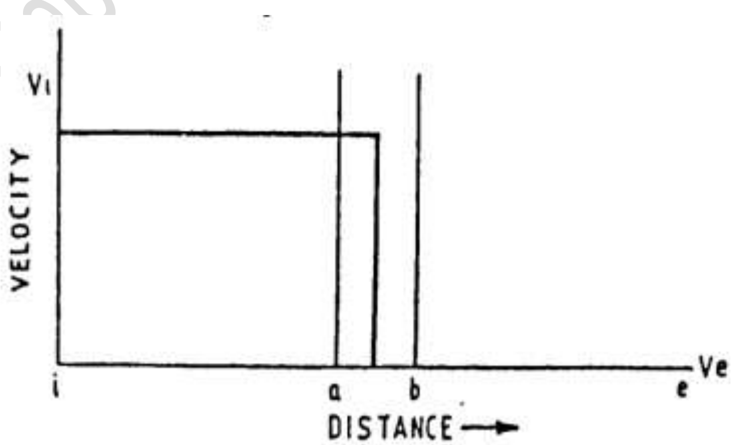


Fig - 8.8 Total conversion of incoming wind kinetic energy to work (corresponds to Fig. 8.7)

Equation -24 reduces to Equation-9 for P_t, when $V_t = V_i$ and $V_e = 0$; that is, the wind comes to a complete rest after leaving the turbine (see figure-8.7). This is practically impossible because the wind cannot accumulate at turbine exit. It can be seen from Equation-24, where V_e is positive in one term and negative in the other, that too low or too high a value for V_e results in reduced power. There is thus an optimum exit velocity $V_{e.opt}$ that results in maximum power P_{max}, which is obtained by differentiating P in Equation-24 with respect to V_e for a given V_i and equating the derivative to zero, i.e. $dP/dV_e = 0$, which gives

$$3V_e^2 + 2V_iV_e - V_i^2 = 0$$

This is solved for a positive V_e to give $V_{e.opt}$

$$V_{e.opt} = \frac{1}{3}V_i \qquad \text{.......25}$$

Combining with Equation-24 gives P_{max}

$$P_{max} = \frac{8}{27}\rho A V_i^3 \qquad \text{.....26}$$

The ideal, or maximum, theoretical efficiency η_{max} (also called the power coefficient) of a wind-turbine is the ratio of the maximum power obtained from the wind. Equation-16 to the total power of the wind, Equation-9), or

$$\eta_{max} = \frac{P_{max}}{P_t} = \frac{8}{27} \times 2 = \frac{16}{27} = 0.56 \qquad \text{........27}$$

Where, η_{max} = Maximum possible efficiency of a wind-turbine (propeller type).

P_{max} = Maximum power from wind-turbine.

P_t = Total power in the wind stream.

The maximum efficiency of c propeller type wind-turbine is only 59 percent. Out of total power in the wind stream only 59 percent power is useful.

Actual efficiency η_a is even less than maximum possible (theoretical) efficiency (η_{max}) by factor 0.5 to 0.7 due to friction, spillage, etc.

$$\eta_a = 0.5 \text{ to } 0.7 \text{ times } \eta_{max}$$
$$\cong 0.6\eta_{max} = 0.6 \times 0.59$$
$$= 0.354$$

Actual efficiency is only 35 percent.

Types of wind turbine - Generator Units:

A wind turbine-generator unit consists of the following major Subassemblies.

-- A wind turbine with vertical axis or horizontal axis.

-- Gear chain.

-- An electrical generator (Synchronous or asynchronous (induction).

-- Associated civil works, electrical and mechanical auxiliaries, control panels etc.

The wind turbine-generator units convert wind power into electrical power, The ratings of a wind turbine units range between 15 kW to 14 MW.

The propeller type horizontal axis wind turbine has a central shaft with a hub and a propeller (wheel). The shaft is mounted on two bearings. The propeller (wheel) has a few blades with aerofoil design.

The wind passes through the propeller and gives a circumferential force (Torque) and axial thrust.

The torque is responsible for converting wind power to rotary mechanical power.

The mechanical design of the wind turbine generator unit, nacelle, tower etc. should be strong enough to withstand the axial thrust during worst winds.

The wind turbine, gears and generator together form a Unit. Several identical units are installed in a wind farm. The total electrical power produced by the wind farm is fed into the distribution network or stand-alone electrical load.

Horizontal axis wind turbine generator units (HAWT) are very widely manufactured. The three blade version is the most popular all over the world for unit ratings from 15 kW to 3 MW.

Vertical Axis Wind Turbine Generator Units (VAWT) is built commercially by a few manufacturers. Two types of designs are commercially successful.

1. Darrius Wind Turbine with o configuration.
2. VAWT with H configuration.

Very large Vertical Axis Darrius Wind Turbines with unit rating 4 MW have been successfully built. Large Vertical Axis Darrius Wind Turbines with unit rating of 10 MW and 14 MW are under development. Table -9.1 gives the summary of various types of wind turbine generator units.

The rotor blades of horizontal and vertical wind turbines are designed on aerodynamic principle. The profile is similar to that, of fan blades. The root of each blade is fixed on to the hub. The blade is in a plane perpendicular to the axis of the hub. The profile has a gradual inclination against the plane of blades such that the wind glides over the profile and pushes the blade in desired direction.

Table - 9.1 Horizontal Axis Wind Turbines

Type and Configuration	Remarks
1. Propeller Type Horizontal Axis	-- 3 Blade Propeller type design, most successful configuration all over the world. -- Very wide range of ratings -- Small, medium, large machines 15 kW to 3 MW unit -- rating. -- Single Blade designs for small and medium size. -- Double and Triple blade design for medium and large sizes. -- Wind turbines, Gear, Generator are with common axis, -- mounted in 'nacelle' installed on a tall tower. -- Blade pitch control controls speed power. -- Teethering control for mono-blade and twin-blade -- turbines. -- Yaw control positions the nacelle. -- Several small units installed in a wind farm. -- Electrical generators operate in parallel -- $\frac{Blade\ tip\ speed}{Wind\ speed} = 2\ to\ 0.44$ Efficiency factor (ideal maximum) = 0.58 (Practical) = 0.4 to 0.44
2. Space Frame Rotor Mans forth Design	-- Very large sizes and unit ratings: 3MW to 14MW -- Large Framed space structure (like a Giant wheel), supports the blades in two parallel vertical planes in symmetrical radial fashion. -- Commercial success uncertain -- A few prototypes of lower ratings have been built -- successfully Prospects uncertain
3. Wind Mill type Multi blade Design	-- Several blades arranged symmetrically around a central rotatable hub -- Blades with increasing width and with a slant -- Design evolved from traditional wind mills -- Used for pumping -- Not used for power plants
4. Bicycle Wheel Multi-blade design	-- Simple symmetrical construction -- Several blades arranged radially like the spokes of a bicycle wheel but with certain width and slant -- Used for pumping sets -- Not used for power plants

Characteristic of wind turbine generator:

Teethering control. This is provided for mono-blade and twin blade horizontal axis wind turbines. It is not necessary for three blade version. Wind speed (V) increases with height above ground. Force on the blade is proportional to V^3.

At higher wind speeds the forces on blade in upper position are significantly higher from force on the blade in lower position. Due to this difference in force, while orienting the nacelle, the single blade and twin blade rotors experience. Severe vibrations during orientation of nacelle several failures have occurred in earlier designs. To avoid this teethering control is provided. The axis of the wind turbine gets positioned such that the propeller blades revolve in slanting plane at higher velocities. The angle of slant of propeller plane reduces with reduced wind speed and increases with increasing wind speed.

Mono-Blade Horizontal Axis Wind Turbine (HAWT): Some European manufacturers are marketing the Mono-blade horizontal axis wind turbine generator units of lower power range (15 kW to 50 kW).

Table 9.2 Mono-Blade HAWT

The advantages:
- --- Simple and Lighter construction
----- Favourable price.
- ---- Easy to install and maintain.
- ---- Yaw positioning by simple wind-vanes. No need of complex hydraulic mechanism.

Disadvantages:
------ Teething control necessary for higher loads.
------ Not suitable for higher power ratings.

Applications:
------ Field irrigation.
------ Sea-water desalination plants
------ Electric power Supply for farms and remote loads

The mono-blade wind turbines have lighter rotor and are therefore favourably priced. Smallest mono-blade designs are of 15 kW to 30kW unit rating. These may be used in wind parks or individually for water pumping, battery recharging, power supply system for remote installations.

Mono-blade wind turbine can be equipped with synchronous generator or an asynchronous generator. It can be operated as a standalone unit or with grid connections. Mono-blade wind turbine blades are generally pitch controlled. The downwind designs are preferred.

Wind vanes are used for orientation to the direction of wind.

Due to light weight, the installation and dismantling are easy.

Blade lengths are in the range of 15m to 25 m. Most heights are range of 30 m and 60 m.

Mono-blade design experience minimum stresses on the bearing and gears. Designs are aerodynamically optimised with high tip speed/wind speed ratio. Blades are made of metal, glass reinforced plastics, laminated wood, composite carbon fiber/fiberglass etc. to obtain light, economical and strong design. Service life is of about 30 years.

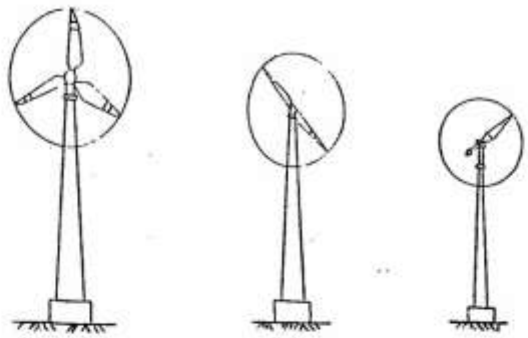


Fig-9.1 Mono-blade, twin-blade, three-blade horizontal axis propeller type wind turbine-generator units

Single blade designs seem to have lesser scope in higher ratings. Two blade and three blade designs are preferred for harnessing more power.

Twin-Blade Horizontal Axis Wind Turbine Generator units:

Such units are built in large unit sizes of unit ratings such as 1 MW 2 MW and 3 MW.

Such high capacity units are installed singly and feed power into the distribution the network: Some of the largest wind turbine generator units are twin-blade horizontal axis wind turbine.

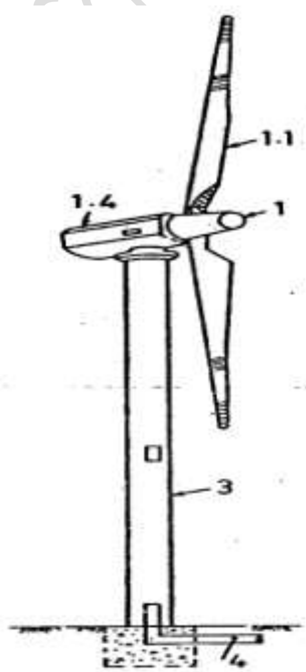


Fig- 9.2 A twin – blade horizontal axis propeller type wind-turbine generator unit

1. Hub, 1.1 Blades, 1.4 Nacelles, 3. Tower, 4. Power cable and control cables

Cost of a two blade turbine is lesser than that of an equivalent three blade turbine.

Weight of two blade rotor is lesser than of an equivalent three blade turbine.

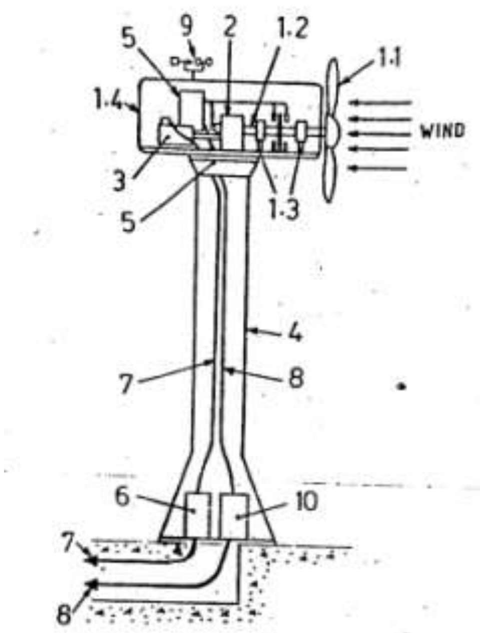
Two blade turbine needs teethering control. The reason for this is as follow:
The wind speed increases with the height. When rotor is vertical, the blade in upper position experiences a greater force than the blade in lower position. A pivot within the hub allows the rotor to lean backwards to accommodate the extra force. Without such teethering arrangement, additional fatigue on the main shaft could seriously affect the life of a two blade wind turbine.

Three Blades, Horizontal Axis Wind Turbine (HAWT):

Several 3 blade propeller type wind turbines have been installed in India and other countries in the world.

A wind farm with total installed capacity of 25 MW equipped with 75 numbers of 330 kW units is located in Alta mount Pass, California, USA. Machines commenced commercial power generation in 1-1-1986. The technical features of a 330 kW and 750 kW unit design are described below.

Figure- 9.4 shows cross section of a typical, 3 blade, horizontal shaft propeller type wind turbine generator unit having the following parts:



1. Wind turbine (Aero-turbine)
1.1. Blade
1.2. Shaft
1.3. Bearings
1.4. Nacelle
2. Gear box and mechanical transmission
3. Generator
4. Tower
5. Control and protection panel
6. Control cables
7. Power cables
8. Power switchgear

Fig - 9.4 cross section of a typical wind turbine generator unit

A wind farm with total installed capacity of 25 MW equipped with 75 numbers of 330 kW units is located in Alta mount Pass, California, USA. Machines commenced commercial power generation in 1-1-1986. The technical features of a 330 kW and 750 kW unit design are described below.

The rotor has three blades (1.1) assembled on a hub. The blade tips have a pitch control (0-30˚C) for controlling shaft speed. The shaft is mounted on bearings (1.3). The gear 'chain changes the speed from turbine shaft speed to generator shaft speed. The blades are long and are mounted on a hub with aerodynamic profile.

The generator may be a 3-phase synchronous generator or a 3 phase induction generator. Three phase synchronous generator is operated in synchronism with the grid frequency and has a constant speed.

The synchronous generator has a tendency to remain in synchronism. Constant rotor speed is ensured by pitch control and gear ratio.

Induction generator has nearly constant turbine speed with a small margin of slip-speed. Induction generator takes excitation current rent from the grid supply and needs power factor improvement by capacitors.

The generator, turbine, bearings, etc. are mounted in a Nacelle (1.4). The nacelle is positioned automatically to the direction of the wind by means of the yaw control and hydraulic mechanism. In small wind turbines, wind vanes are provided on the nacelle to achieve the automatic positioning of the turbine axis in line with the wind direction.

The nacelle is mounted on a tall tower (4). The required height of the tower increases with the power rating of the wind turbine. For smaller wind turbine generators, the tower is a galvanized steel structure with bolted and welded members. For large wind turbine generators the tower is of reinforced cement concrete construction.

The control and protection panel (6) and power control switchgear (10) are mounted on ground level.

Power cables (8) carry the generated power to the substation bus via the power switchgear (10). Control cables (7) for are data transmission of control, protection and monitoring data from the Master control Room of the wind farm to the wind turbine control panel. The important controls are:

1. Positioning of Nacelle (Yaw Control): The axis is oriented, such that the turbine blades are in the plane perpendicular to the wind, either in upward wind direction (Wind from front side of blades passing through the blades towards the nacelle) or in downward wind direction (from nacelle towards the blades).

2. Blade-tip Pitch Control (see fig. 9.5): The blade tips are adjusted automatically (0 to 30°) to provide feathering action. Thereby the power and speed of the wind turbine shaft is adjusted to match with the generator speed and electrical power output.

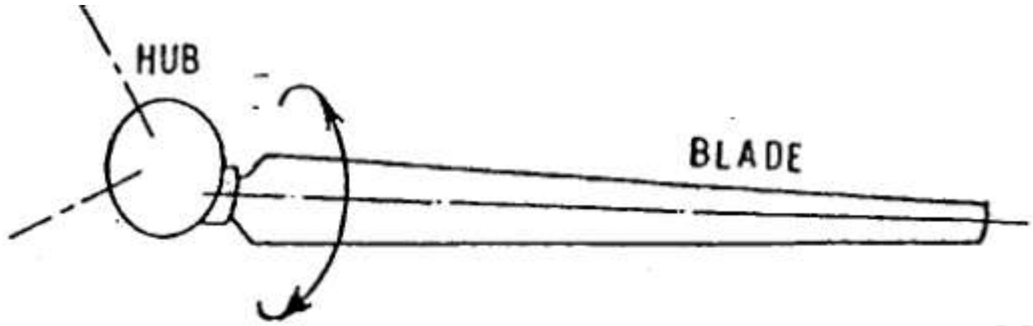


Fig-9.5. Pitch control

Electrical Protection and Control: The generator electrical output is fed into the grid. Microprocessor based electrical protection and control monitors and controls several electrical and mechanical parameters and sends appropriate control demands to the control systems. The electrical protection systems include:

-- Overload protection
-- Short Circuit protection
-- Earth fault protection
-- Under frequency protection
-- Protection against prolonged monitoring
-- Under voltage protection
-- Over voltage protection
-- Loss of synchronism protection
-- Over frequency protection
-- Lightning protection

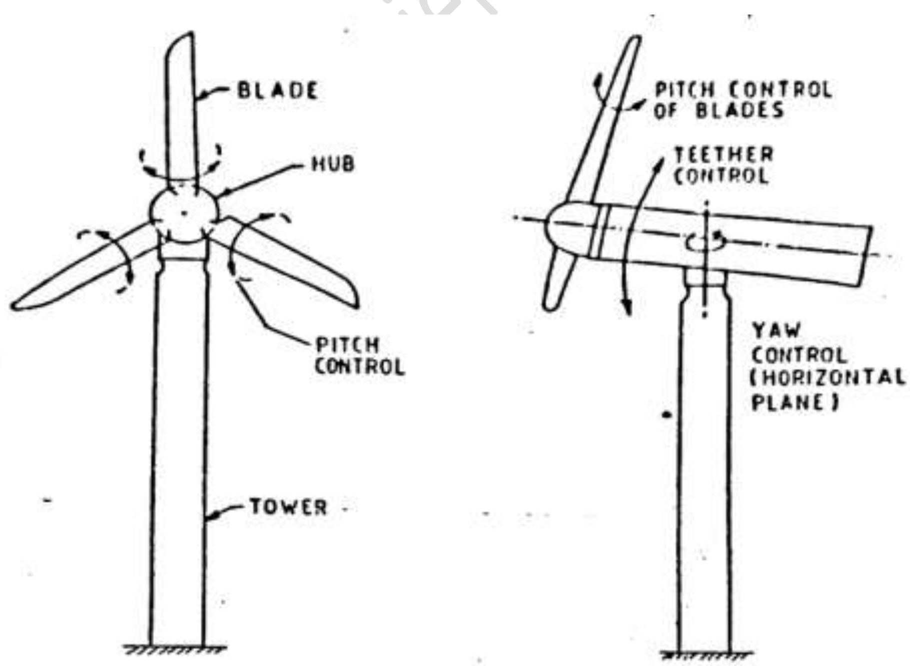


Figure: 9.6 Control in wind turbines
- Pitch control - Yaw control - Teether control

Table: 9.3 Specifications of 3 blade wind turbine generator

	330kW unit	**750kW unit**
Rotor		
Rotor type	3-blade upwind	3-blade upwind
Rotor diameter	31 meter	45 meter
Rotor speed	37 rev/min	30 rev/min
Blade material	Wood epoxy laminate	Wood epoxy laminate
Aerodynamic control	Variable pitch blade tips (0-30°)	Variable pitch blade tips (0-30°)
Maximum chord	1.75 m	2.6 m
Tip chord	0.8 m	0.8 m
Blade twist	14.0°	13.0°
Rotor weight	5.4 t	14.6 t
Transmission		
Gear box type	3-stage parallel shaft	2-stage epicyclic
Gear type	Helical	Spur
Gear ratio	48.8:1	40:1
Generator type	Induction or synchronous	Induction
Generator rating	330kW	750kW
Rated voltage & frequency	460V & 60Hz	4.16 kV & 60Hz
Rated speed	1800 rev/min	1200 rev/min
Nacelle weight	17.0 t	40.0 t
Tower		
Tower type	Tubular steel with base	Tubular steel, conical
Tower diameter	1.8 m	2.5 m
Base diameter	4.0 m	7.0 m
Rotor centerline height	25.0 m	36.0 m
Yaw system	Geared hydraulic motor	Geared hydraulic motor
Tower weight	22.3 t	29.4 t

Table 9.4 Specifications of a 2.5 MW, 2 Blade Wind Turbine Generator Unit

Performance	Rated power	2.5 MW	
	Wind velocity /hr	At 10 m height	At hub
	Cut – in	14 m height	22
	Rated	32 m height	44
	Cut – out	58 m height	72
	Max. design limit	192 m height	200
Wind – Turbine	Diameter	91 m	
	Number of blades	Two	
	Location, rotation	Upwind, counter clockwise	
	Revolution per minute	17.5	
	Cone, tilt, twist angles	0°, 2°,8°	
	Tip length, each	45 ft. 13.7 m	
	Material	Steel	
Tower	Height	58.5 m	
	Hub – height	61 m	
	Type	Flared shell	
	Access	Power man lift	

Controls	Power regulation	Rotor – tip pitch control, hydraulic
	Yaw	Internal toothing gear
	Yaw motor	Hydraulic , 0.25 Deg/s
	Supervisory	Microprocessor
Generator	Rating power factor	3125 kVA, 0.8
	Voltage, frequency	4160 (three - phase), 60 Hz USA standard
	Revolution per minute	1800
	Gear box	Three – stage planetary
	Gear set – up ratio	103
Mass	Rotor	81,670 kg
	Rotor and Nacelle	165,150 kg
	Tower	115,700 kg

QUESTIONS

Part-1: Multiple Choice Questions:

1. Energy in the wind is converted into rotary mechanical energy by the________________.
   (a) wind-turbine (b) pumping (c) generator (d) spring
2. The horizontal shaft wind-turbine generator unit is mounted on a______________.
   (a) Ground level (b) tall tower (c) On river bank (d) On mountain
3. The vertical shaft wind turbine units are mounted on ground level.
   (a) tall tower (b) On river bank (c) Ground level (d) On mountain
4. Large wind-turbine-generator units (WTGU) are generally built as________________.
   (a) Wind farm (b) multi units (c) double units (d) single units
5. The maximum efficiency of c propeller type wind-turbine is only_________ percent.
   (a) 59 (b) 50 (c) 48 (d) 35
6. The ideal or maximum theoretical efficiency η_{max} also called the __________ of a wind-turbine.
   (a) Power efficiency (b) power coefficient (c) efficiency (d) Ripple factor
7. Energy in the wind is converted into rotary mechanical energy by the ______________
   (a) pitch control (b) Blade (c) wind turbine (d) Tower
8. India's potential for useful wind plants is about_____________
   (a) 50000MW (b) 15000MW (c) 25000kW (d) 25000 MW
9. The wind turbine, gears and generator together form a___________.
   (a) Unit (b) propeller (c) tower (d) Wind mill
10. Force on a blade is proportional to ____________.
    (a) V^2 (b) V^3 (c) V^4 (d) V^n

Part-2: Short answer questions:

i. Give the energy chains of wind energy.
ii. Write available options for wind-electric energy conversion plants.
iii. Prepare a table for efficiency of various types of wind turbines.
iv. Describe in short- characteristic of the wind turbine generator.
v. Enlist the advantages, disadvantages and applications of Mono-blade horizontal axis

wind turbine.

vi. Define efficiency factor of wind turbine.

Part-3: Long answer questions:

1. What is wind energy? Discuss wind power density with suitable derivations.
2. Discuss: power in wind stream and wind power turbine efficiency.
3. Explain power of a wind turbine for given incoming win velocity.
4. Describe types of wind turbine generator units.
5. Write a note on Mono-blade horizontal axis wind turbine.
6. Discuss three blade horizontal axis wind turbine.

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