CHAPTER 5

WIND ENERGY

5.1. INTRODUCTION

Wind is air set in motion by small amount of insolation reaching the upper atmosphere of earth.

It contains kinetic energy (K.E.) which can easily be converted to electrical energy. Nature generates about 1.67 × 105 kWh of wind energy annually over land area of earth and 10 times this figure over the entire globe.

- This wind energy, which is an indirect source of energy, can be used to run a wind mill which in turn drives a generator to produce electricity.
- Although wind mills have been used for more than a dozen centuries for grinding grain and pumping water, interest in large scale power generation has developed over the past 50 years. A largest wind generator built in the past was 800 kW unit operated in France from 1958-60. The flexible 3 blades propeller was about 35 m in diameter and produced the rated power in a 60 km/hour wind with a rotation speed of 47 r.p.m.
- In India the interest in the wind mills was shown in the last fifties and early sixties. Apart from importing a few from outside, new designs were also developed, but these were not sustained. It is only in last 20-25 years that development work is going on in many institutions. An important reason for this lack of interest in wind energy must

- be that wind, in India is relatively low and vary appreciably with seasons. These low and seasonal winds imply a high cost of exploitation of wind energy. In our country high wind speeds are however available in coastal areas of Sourashtra, Western Rajasthan and some parts of central India. In these areas there could be a possibility of using medium and large sized wind mills for generation of electricity.

5.2. UTILISATION ASPECTS OF WIND ENERGY

Utilisation aspects of wind energy fall into the following three broad categories:

1. Isolated continuous duty systems which need suitable energy storage and reconversion systems.
2. Fuel-supplement systems in conjunction with power grid or isolated conventional generating units.
   - This utilisation aspect of wind energy is the most predominant in use as it saves fuel and is fast growing particularly in energy deficient grids.
3. Small rural systems which can use energy when wind is available.
   - This category has application in developing countries with large isolated rural areas.

5.3. CHARACTERISTICS OF WIND

The main characteristics of wind are:

- Wind speed increases roughly as 1/7 th power of height. Typical tower heights are about 20–30 m.
- Energy-pattern factor. It is the ratio of the actual energy in varying wind to energy calculated from the cube of mean wind speed. This factor is always greater than unity which means the energy estimates based on mean (hourly) speed are pessimistic.

5.4. ADVANTAGES AND DISADVANTAGES OF WIND ENERGY

Following are the advantages and disadvantages of wind energy:

Advantages:

1. It is a renewable energy source.
2. Wind power systems being non-polluting have no adverse effect on the environment.
3. Fuel provision and transport are not required in wind energy conversion systems.
4. Economically competitive.
5. Ideal choice for rural and remote areas and areas which lack other energy sources.

Disadvantages:

1. Owing to its irregularity, the wind energy needs storage.

2. Availability of energy is fluctuating in nature.

3. The overall weight of a wind power system is relatively high.

4. Wind energy conversion systems are noisy in operation.

5. Large areas are required for installation/operation of wind energy systems.

6. Present systems are neither maintenance free, nor practically reliable.

7. Low energy density.

8. Favourable winds are available only in a few geographical locations, away from cities, forests.

9. Wind turbine design, manufacture and installation have proved to be most complex due to several variables and extreme stresses.

10. Requires energy storage batteries and/or stand by diesel generators for supply of continuous power to load.

11. Wind farms require flat, vacant land free from forests.

12. Only in kW and a few MW range; it does not meet the energy needs of large cities and industry.

5.5. ENVIRONMENT IMPACTS OF WIND ENERGY

The possible environment impacts of wind energy are:

1. Wind energy creates noise pollution because of mechanical (gear box) aerodynamic noise.
2. The wind turbine produces electromagnetic interference when placed between radio, television etc. stations, as it reflects some electromagnetic radiations.
3. It produces visual shining because of reflection and refraction which depends upon turbine size, number of turbines in wind farm, design etc.
4. Safety consideration for life because of accidental braking of blade.
5. Fatal collisions of birds caused by rotating turbine blides.

5.6. SOURCES/ORIGINS OF WIND

Following are the two sources/origins of wind (a natural phenomenon):

1. Local winds. 2. Planetary winds.

1. Local winds. These winds are caused by unequal heating and cooling of ground surfaces and ocean/lake surfaces during day and night. During the day warmer air over land rises upwards and colder air from lakes, ocean, forest areas, and shadow areas flows towards warmer zones.

2. Planetary winds. These winds are caused by daily rotation of earth around its polar axis and unequal temperature between polar regions and equatorial regions. The strength and direction of these planetary winds change with the seasons as the solar input varies.

- Despite the wind’s intermittent nature, wind patterns at any particular site remain remarkably constant year by year.
- Average wind speeds are greater in hilly and coastal areas than they are available in land. The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.

- Wind speeds increases with height. They have traditionally been measured at a standard height of 10 meters where they are found to be 20-25 percent greater than close to the surface. At a height of 60 m they may be 30-60 percent higher because of the reduction in the drag effect of the surface of the earth.

5.7. WIND AVAILABILITY AND MEASUREMENT

Wind energy can only be economical in areas of good wind availability. Wind energy differs with region and season and also, possibly to an even greater degree with local terrain and vegetation. Although wind speeds generally increases with height, varying speeds are found over different kinds of terrain. Observations of wind speed are carried out at meteorological stations, airports and lighthouses and are recorded regularly with ten minute mean values being taken every three hours at a height of 10 m. But airports, sometimes are in valleys and many wind speed meters are situated low and combinations of various other factors mean that reading can be misleading. It is difficult, therefore, to determine the real wind speed of a certain place without actual in-situ measurements.

The World Meteorological Organisation (WMO) has accepted the following four methods of wind recording:

(i) Human observation and log book.

(ii) Mechanical cup-counter anemometers.

(iii) Data logger.

(iv) Continuous record of velocity and direction.

Table 5.1 Wind power potential

State	*Gross potential (MW)* *(a)*	*Technical potential (MW)* *(b)*
Andhra Pradesh	8275	1750
Gujarat	9675	1780
Karnataka	6620	1120
Kerala	875	605
Madhya Pradesh	5500	825
Maharashtra	3650	3020
Orissa	1700	680
Rajasthan	5400	895
Tamil Nadu	3050	1750
West Bengal	450	450
Total	**45195**	**12875**

Table 5.2. State-Wise Wind Power Capacity Addition (As on 31.12.2004)

State	*Demonstration projects (MW) (a)*	*Private sector projects (MW) (b)*	*MW (Total) capacity (MW) (a) + (b)*
Andhra Pradesh	5.4	95.9	101.3
Gujarat	17.3	202.6	219.9
Karnataka	7.1	268.9	276.0
Kerala	2.0	0.0	2.0
Madhya Pradesh	0.6	27.0	27.6
Maharashtra	8.4	402.8	411.2
Rajasthan	6.4	256.8	263.2
Tamil Nadu	19.4	1658.0	1677.4
West Bengal	1.1	0.0	1.1
Others	0.5	0.0	0.5
Total	**68.2**	**2912.0**	**2980.2**

Characteristics of a good wind power site:

A good wind power site should have the following characteristics:

1. High annual wind speed.

2. An open plain or an open shore line.

3. A mountain gap.

4. The top of a smooth, well rounded hill with gentle slopes lying on a flat plain or located on an island in a lake or sea.

5. There should be no full obstructions within a radius of 3 km.

5.9. WIND ENERGY PATTERN FACTOR (EPF)

The energy pattern factor (EPF) is the ratio of power from speed distribution to the power from coverage speed of the turbine blades.

i.e.
$$EPF = \frac{\text{Power from speed distribution}}{\text{Power from average speed}}$$

Generally, EPF lies between 2 to 5.

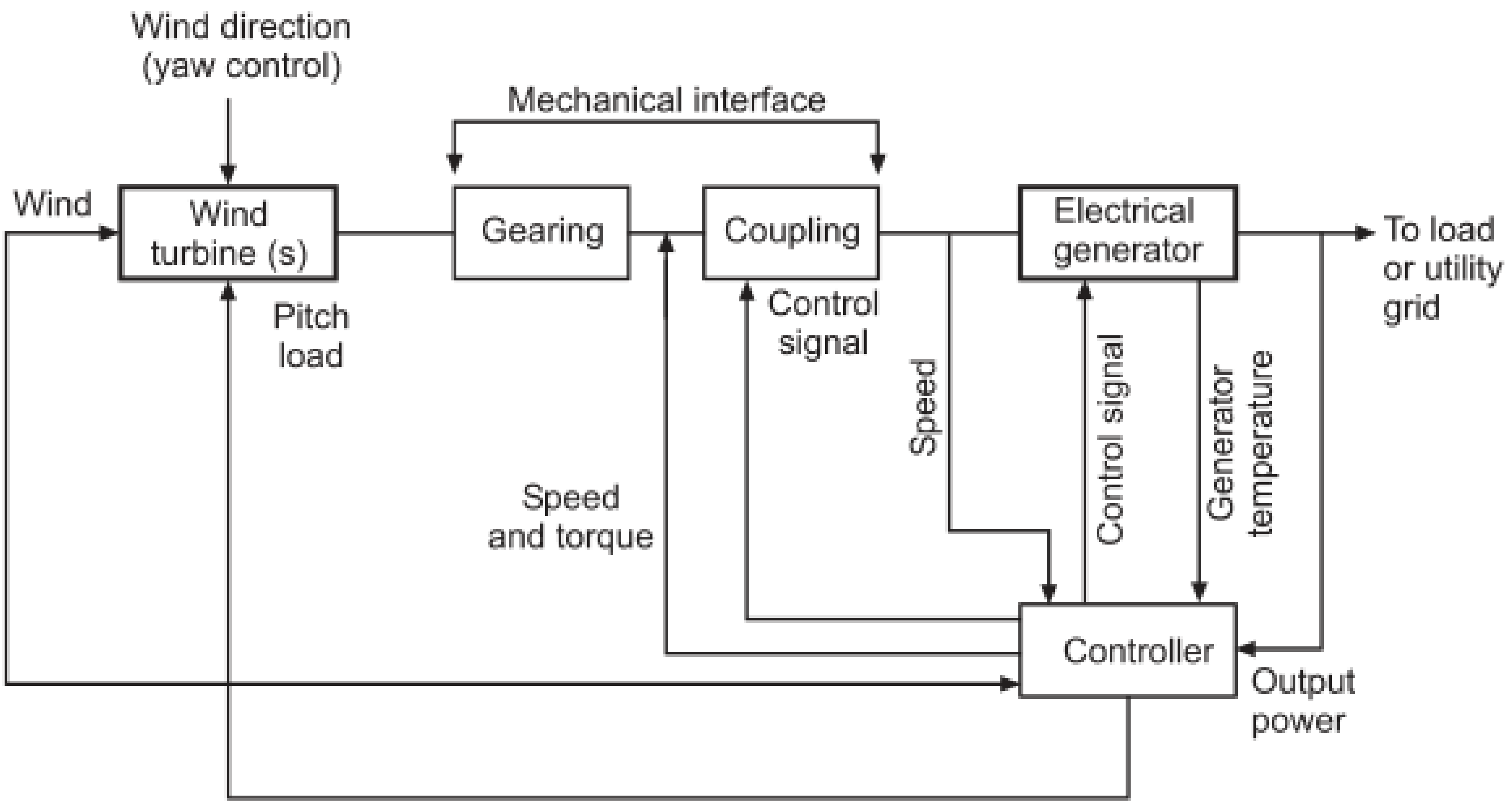
5.10. BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM (WECS)

Fig. 5.2 shows the block diagram of basic components of a wind energy conversion systems.

— Wind turbines (Aeroturbines) convert the energy of moving air into rotary mechanical energy. These turbines requires pitch and yaw controls for proper operation.

— A mechanical interface consisting of a step up gear and a suitable coupling transmits the rotary mechanical to an electrical generator. The output of this generator is connected to the road or power grid as the application demands.

— A controller serves purposes of sensing: (i) Wind speed, (ii) Wind direction, shafts speed and torques at one or more points, (iii) Output power and generator temperature as necessary, (iv) Appropriate control signals for matching the electrical output to the wind energy input, and (v) Protect the system from extreme conditions brought about by strong winds, electrical faults etc.



Basic components of a wind energy conversion system (WECS).

5.11. ADVANTAGES AND DISADVANTAGES OF WIND ENERGY CONVERSION SYSTEMS (WECS)

The advantages and disadvantages of wind energy conversion systems as follows:

Advantages:

1. Wind energy, a renewable energy source, can be tapped free of fuel cost.
2. The wind turbine generation (WTG) produces electricity which is environmentally friendly.
3. Wind power generation is cost effective.
4. It is economically competitive with other modes of power generation.
5. Quite reliable.
6. Electric power can be supplied to remote inaccessible areas.

Disadvantages:

1. As the wind speed is variable, wind energy is irregular, unsteady and erratic.
2. Wind turbine design is complex.
3. Wind energy systems require storage batteries which contribute to environmental pollution.

4. Wind energy systems are capital intensive and need government support.

5. Wind energy has low energy density and normally available at only selected geographical locations away from cities and load centers.

6. For wind farms (which are located in open areas away from load centres), the connection to state grid is necessary.

7. ‘Large units’ have less cost per kWh, but require capital intensive technology. In contrast ‘small units’ are more reliable but have higher capital cost per kWh.

5.12. CONSIDERATIONS FOR SELECTION OF SITE FOR WIND ENERGY CONVERSION SYSTEMS (WECS)

Following factors should be given due considerations while selecting the site for WECS:

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

5.13. TERMS AND DEFINITIONS

1. **Aerodynamics.** It is the branch of science which *deals with air and gases in motion and their mechanical effects.*
2. **Airfoil or aerofoil.** A *streamlined air surface designed for air* to flow around it in order to produce *low drag* and *high lift forces*.
3. **Angle of attack.** It is the angle between the relative air flow and the closed of the air foil (Fig 5.3).

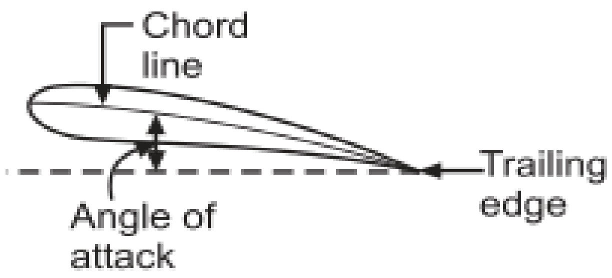


Fig 5.3. Angle of attack

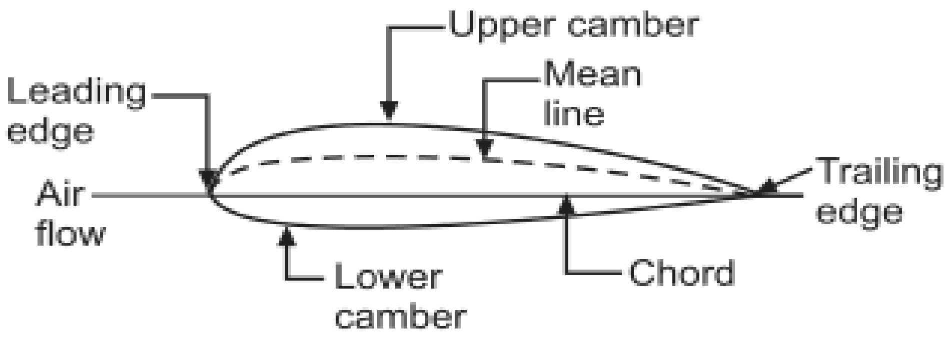


Fig 5.4. Air foil showing edges, camber and chord.

4. **Blade.** An important part of a wind turbine that *extracts wind energy*.
5. **Leading edge.** It is the front edge of the blade that *faces towards the direction of flow* (Fig. 5.4).
6. **Trailing edge.** It is the rear edge of the blade that *faces away from the direction of wind flow* (Fig. 5.4).
7. **Mean line.** A line that is *equidistant* from the upper and lower surfaces of the air foil (Fig. 5.4).

8. **Camber.** It is the *maximum distance between the mean line and the chord line, which measures the curvature of the airfoil*.

9. **Rotor.** It is the *primary part* of the wind turbine that *extracts energy* from the wind. It *constitutes the blade-and-hub assembly*.

10. **Hubs.** Blades are fixed to a hubs which is a *central solid part of the turbine*.

11. **Pitch angle.** It is the *angle between the direction of wind and the direction perpendicular to the planes of blades*.

12. **Pitch control.** It is the *control of pitch angle by turning the blades or blade tips* [Fig. 5.5 (*a*)].

13. **Yaw control.** It is the *control for orienting (steering) the axis of wind turbine in the direction of wind* [Fig. 5.5 (*b*)].

14. **Teethering.** It is see-saw like swinging motion with hesitation between two alternatives. The *plane of wind turbine wheel is swung in inclined position at higher wind speeds by teethering control* [Fig. 5.5 (*b*)].

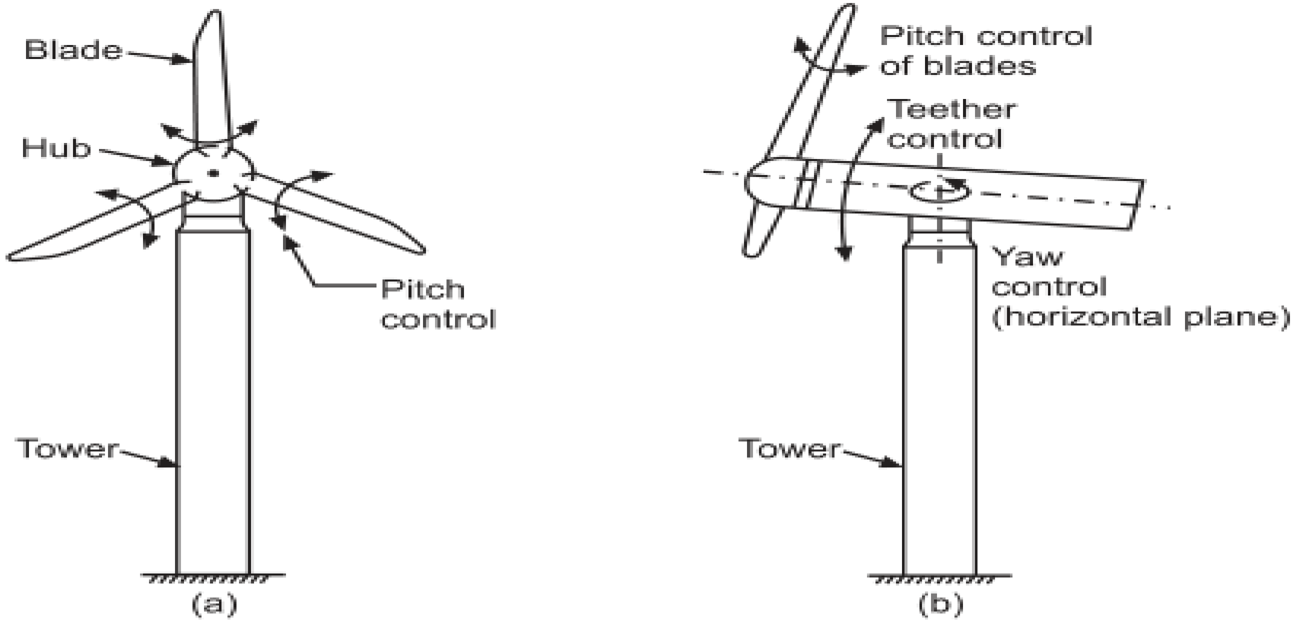


Fig. 5.5. Controls in wind–turbines: Pitch control; Yaw control; Teether control.

15. **Solidity.** *It is ratio of blade area to the swept area* (area covered by the rotating rotor).

16. **Drag force.** It is the force component which is *in line with the velocity of wind*.

17. **Lift force.** It is the force component *perpendicular to drag force*.

18. **Windmill.** It is the *machinery driven by the wind acting upon sails* used chiefly in flat districts for grinding of corn, pumping of water etc.

    Wind turbine (Aeroturbine, wind machine). It is a machine which *converts wind power into rotary mechanical power*. A wind turbine has aerofoil blades mounted on the rotor. The wind drives the rotor and produces rotary mechanical energy.

    Wind turbine generator unit. It is an *assemblage* of a wind turbine, gear chain, electrical generator, associated civil works and auxiliaries.

    Wind farm (wind energy park). It is a *zone comprising several turbine-generator units, electrical and mechanical auxiliaries, substation, control room* etc.

    Wind farms are located in areas having *continuous favourable wind*. Such locations are on-shore or off-shore away from cities and forests.

    Nacelle. It is an *assemblage* comprising of the wind turbine, gears, generator, bearings, control gear etc. *mounted in a housing*.

19. **Wind speeds for turbines:**

(*i*) ***Cut-in-speed.*** It is the *wind speed at which wind–turbine starts delivering shaft power*. For a typical horizontal shaft propeller turbine it may be *around 7 m/s*.

(*ii*) ***Mean wind speed.*** $$U_{wm} = \frac{U_{w_1} + U_{w_2} + \ldots U_{w_n}}{n}$$

(*iii*) ***Rated wind speed.*** *It is the velocity at which the wind–turbine generator delivers rated power.*

(*iv*) ***Cut-out wind velocity (furling wind velocity).*** It is the *speed at which power conversion is cut out.*

5.14. LIFT AND DRAG–THE BASIS FOR WIND ENERGY CONVERSION

The extraction of power, and hence energy, from the wind depends on creating certain forces and applying them to rotate (or to translate) a mechanism.

Following are the two primary mechanisms for producing forces from the wind: Refer to Fig. 5.6

(i) Lift force (FL), (ii) Drag force (FD).

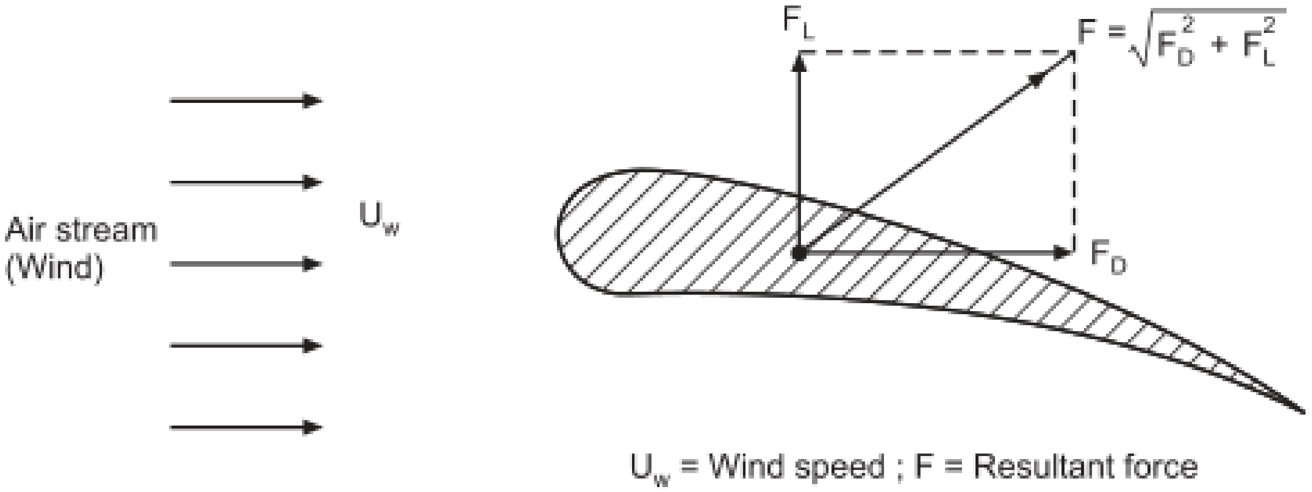


Fig. 5.6. Lift and drag on an airfoil.

Lift force. The component of force at right angles to the direction of air stream on the airfoil is called the lift force (FL) .

Drag force. The component of force in the direction of stream is called drag force (FD).

— When air stream approaches the airfoil along the axis of symmetry, the force acting on the body is only the drag force, in the direction of flow and there is no lift force. The production of lift force requires asymmetry of flow while drag force exists always. It is possible to create drag without lift but impossible to create lift without drag.

'Lift forces' are produced by changing the velocity of air stream flowing over either side of the lifting surface–speeding up the air flow causes the pressure to drop, while slowing the air stream down leads to increase in pressure. In other words, any change in velocity generates a pressure difference across the lifting surface. The pressure difference produces a force that begins to act on the high pressure side and moves towards the low pressure side of the lifting surface which is called an airfoil.

— A good airfoil has high lift/drag ratio (LDR); in some cases it can generate lift forces perpendicular to air stream direction, 30 times as great as the drag force parallel to the flow.

- The lift increases as the angle formed at the junction of the airfoil and the air stream (the angle of attack) becomes less and less acute, upto the point where the angle of the air flow on low pressure side becomes excessive. When this happens, the air flow breaks away from the low pressure side, a lot of the turbulence ensues, the lift decreases and the drag increases quite substantially; this phenomenon is known as stalling.

  For 'efficient operation' a wind turbine blade needs to function with as much lift and as little drag as possible because the drag dissipates energy.

  The design of each wind turbine specifies the angle at which the airfoils should be set to achieve the maximum LDR.
- Besides air foils, following are other two mechanisms for creating lift:

(i) Magnus effect. This effect is caused by spinning a cylinder in air stream at a high speed of rotation. The spinning slows down the air speed on the side where the cylinder is moving into wind and increases it on the other side; the result is similar to an airfoil. This principle has been put to practical use in one or two cases but is generally not applied.

(ii) Blowing air through narrow slots in a cylinder. In this mechanism, air is blown through narrow slots in cylinder, so that it energies tangentially; this is known as "Thwaites slot". This also creates a rotation (or circulation) of the airflow, which in turn generates lift. Because the LDR of airfoils is generally much better than those of rotating and slotted cylinders the latter techniques probably have little practical potential.

5.15. EXTRACTION OF WIND ENERGY

Energy from wind stream is extracted by a wind turbine, by converting the kinetic energy (K.E.) of the wind to rotational motion required to operate an electric generate.

In order to compute the mathematical relationships, let us make the following assumptions:

1. The flow of wind is ‘incompressible’, and hence the air stream diverges as it passes through the turbines
2. The mass flow rate of wind is ‘constant’ at far upstream, at the rotor and at far down stream.

5.16. CLASSIFICATION AND DESCRIPTION OF WIND MILLS/MACHINES

5.16.1. Classification of Wind Mills/Machines

The wind mills machines are classified as follows:

1. Based on the type of rotor:

(i) Propeller type (horizontal axis)

(ii) Multiblade type (horizontal axis)

(iii) Savonius type (vertical axis)

(iv) Darrieus type (vertical axis).

2. Based on orientation of the axis of rotor:

(i) Horizontal axis

(ii) Vertical axis.

Thanks