Chapter Two
Wind Energy

2.1 Introduction

Fig. (2.1): Dutch farm windmill

Wind energy has been harnessed since early centuries to drive windmills, pump water and propel sailboats. Vertical axis windmills for grinding grain were reported in Persia in the 10th century and in China in the 13th century. Windmills and water mills were the largest power sources before the invention of the steam engine. Windmills were widely used in Netherlands to grind grains. Numerous designs were used, ranging from the small post mills to the taller mills whose tops are capable of rotating to keep the blades perpendicular to wind direction. Water pumping windmills were widely used in the United States by the early settlers since 1850. All old windmills were fabricated from wood. By 1900, most windmills were made of metal. All these types are called Farm Windmills to distinguish them from the modern windmills that are used to generate electricity. The first wind turbine used to generate electricity was built by Charles F. Brush in 1888 in Cleveland, Ohio, USA. The turbine rotor diameter was 17 m and generated average electric power of 12 kW that was supplied to his house for about 20 years. The DC dynamo generator turned 50 times for every one revolution of the wind turbine. The rotor was composed of 144 individual vanes made of cedar wood. However, Charles turbine was inefficient compared with modern turbines of the same size which are capable now to produce more that 100 kW of electric power. Farm windmills are generally slow in motion because they contain large number of vanes. Modern wind turbines contain two or three vanes and rotate faster than farm windmills, so they are capable to produce electricity more efficiently.

Fig. (2.2): American farm windmill

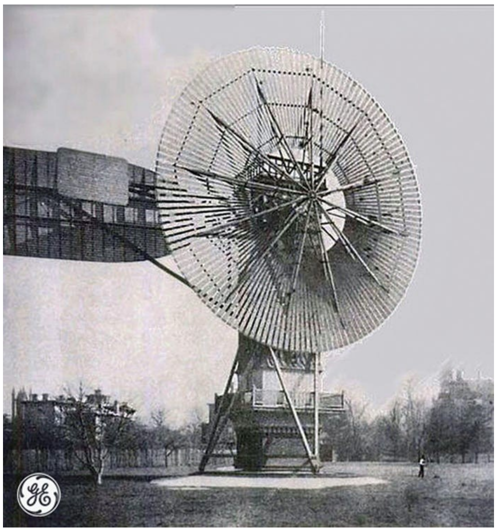

Fig. (2.3): Charles wind turbine; the first turbine to generate electricity in 1888.

2.2 Classification of wind turbines

Wind turbines can be classified mainly into two categories:−

- **Horizontal axis machines**:− at which the rotation axis is horizontal, (Fig. 2.4).
- **Vertical axis machines**:− at which the rotation axis is vertical, (Fig. 2.5)

Most of the wind turbine used today is of horizontal axis type with **three blades** and sometimes **two−bladed**. Most of turbines are of **upwind** variety where the blades are in front of the **nacelle**. The **downwind** variety has the advantage that it automatically faces into the wind but the disadvantage is that the **tower** blocks some of the incoming wind as well as creating increased cyclic stressing of the blades as they pass behind the tower (Fig. 2.6).

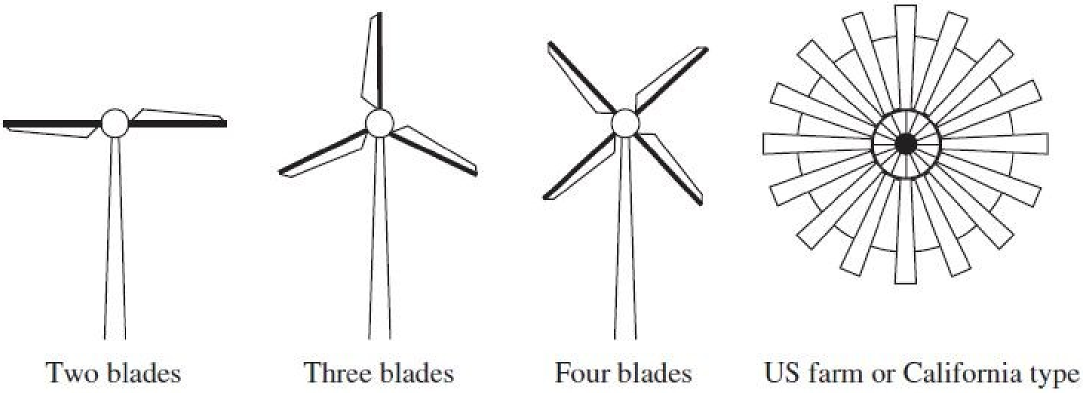

Fig. (2.4): Horizontal axis wind turbines.

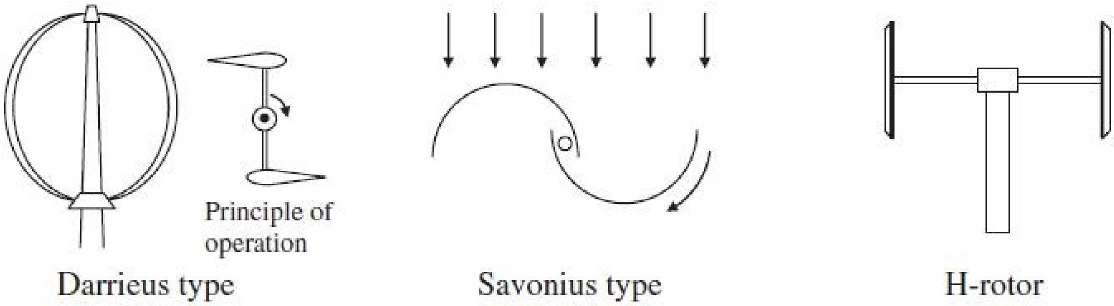

Fig. (2.5): Vertical axis wind turbines.

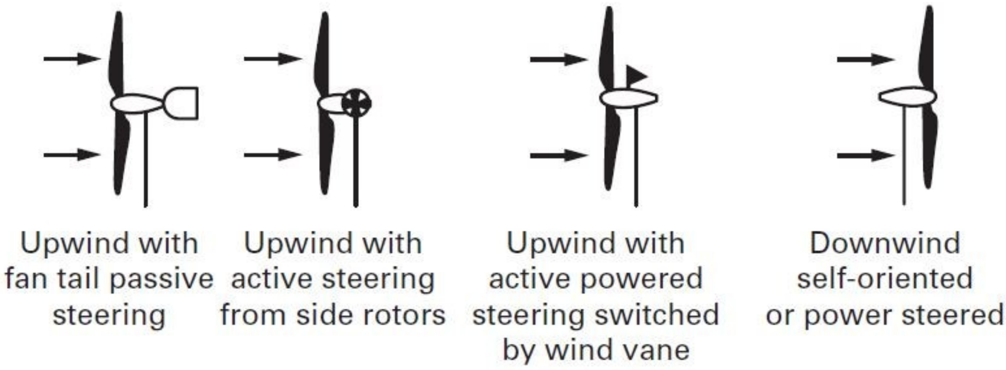

Fig. (2.6): Upwind and downwind configurations and steering methods.

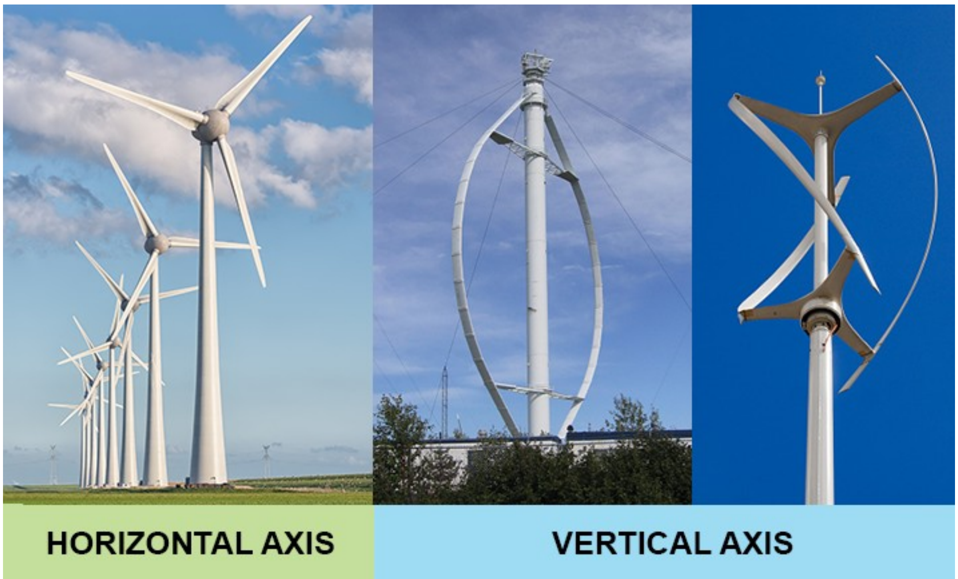

Fig. (2.7): Horizontal versus vertical axis wind turbines.

2.3 Advantages and disadvantages of horizontal and vertical axis wind turbines

2.3.1 Horizontal axis wind turbines

Advantages:

a) Produce higher power because it is installed on the top of a high tower and therefore receives winds of higher velocities than on the ground.

b) The blades are more efficient in converting wind speed to a rotational motion because they operate perpendicular to wind direction and can be optimized for maximum power conversion.

Disadvantages:

a) High initial construction and installation costs due to the high tower, large blades and heavy gearbox and electric generator that must be placed at the top of the tower.

b) Require yaw device to keep the rotor perpendicular to wind.

c) Maintenance is more difficult because all moving parts are at the tower top.

d) Inappropriate inside cities or narrow spaces.

2.3.2 Vertical axis wind turbines

Advantages

a) Do not require to face the wind because it can operate at and wind direction.

b) Capable of operating at minimal wind speeds. Long curved propellers are designed to be pushed by a small amount of wind.

c) Do not have to be placed at a very high place or a tower. Therefore, it is suitable for cities and narrow spaces.

d) Require less maintenance cost because all moving parts are near the ground.

e) Less expensive during fabrication and installation.

Disadvantages

a) Produce less power and are less efficient than horizontal axis machines.

2.4 Parts of a typical horizontal axis wind turbine

Any wind turbine of horizontal axis configuration consists of the following parts:

a) Rotor blades: which are usually two or three long and slim blades with a section of an aerofoil to ensure smooth flow of air around them and maximize the force that drives the rotor, (Fig. 2.8).

b) Hub: it is the central part at which all blades are connected.

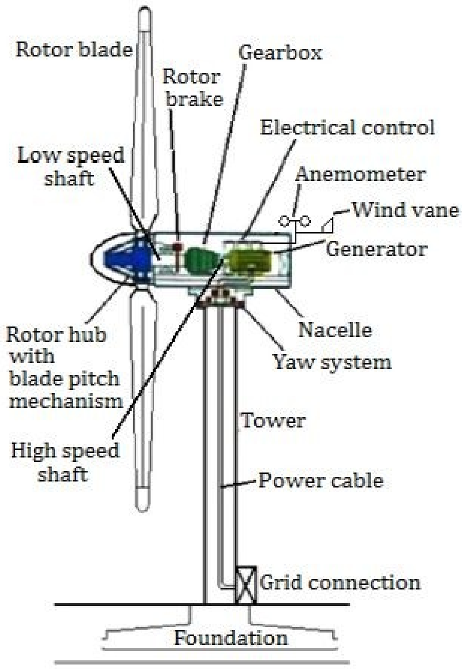

Fig. (2.8): Parts of a typical horizontal axis wind turbine.

c) Nacelle: which is a semi−cylindrical part holding the rotor and containing all moving parts that converts the rotational motion into electrical energy. The nacelle takes a smooth curved shape to minimize wind drag and turbulence. The nacelle is placed after the rotor in upwind turbines and before the rotor in downwind type. Downwind turbines are, in principle, self-orienting, but are more affected by the tower, which produces wind shadow and extra turbulence in the blade path. Perturbations of this kind cause cyclic stresses on the structure, additional noise and output fluctuations.

d) Tower: the rotor is mounted at the top of a high tower in order to provide the space for rotation and also to intercept winds of higher velocities that are generally increasing with altitude.

e) Yaw device: the rotor of the horizontal axis turbine must be adjusted to be always perpendicular to wind direction. The horizontal motion of the rotor to follow the wind is called (yawing). For small and medium size turbines of less than 10 m rotor diameter use a tail or rudder to keep the rotor perpendicular to wind. For larger wind turbines electrical motors are used to control yaw.

2.5 Parts of a typical vertical axis wind turbine

The vertical axis wind turbine is composed of the following parts, (Fig. 2.9):

a) Rotor blades: the blades in vertical axis turbine can take a variety of shapes as illustrated in (Fig. 2.5). the most common type is Darrieus turbine (Fig. 2.8) in which each blade is connected at its two ends to a vertical central shaft via two hubs. This central shaft drives the electric generator. Two or more blades are used in Darrieus turbine.

b) Upper and lower hubs: the blade in Darrieus turbine is connected to the central shaft via two hubs, upper and lower.

c) Central shaft: which is mounted in a vertical direction and drives the electric generator. In large machines the generator is placed at the middle of the central shaft so that the shaft may be of lighter weight and less cost.

d) Power box: which is generally located near the ground at the base of the central shaft. It contains the gear box and the electric generator.

e) Guy wires: Some vertical axis wind turbines require wires or cables to further support the tower and provide more robust design.

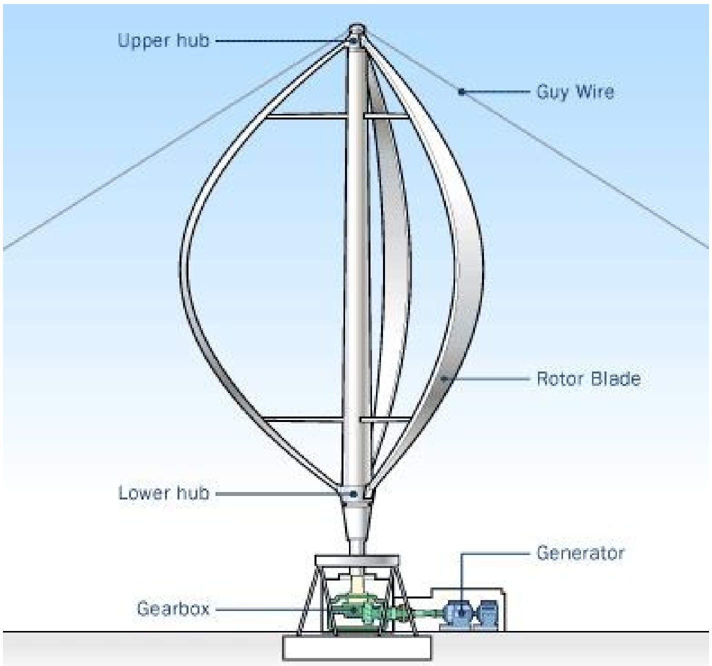

Fig. (2.9): Parts of vertical axis wind turbine (Darrieus type).

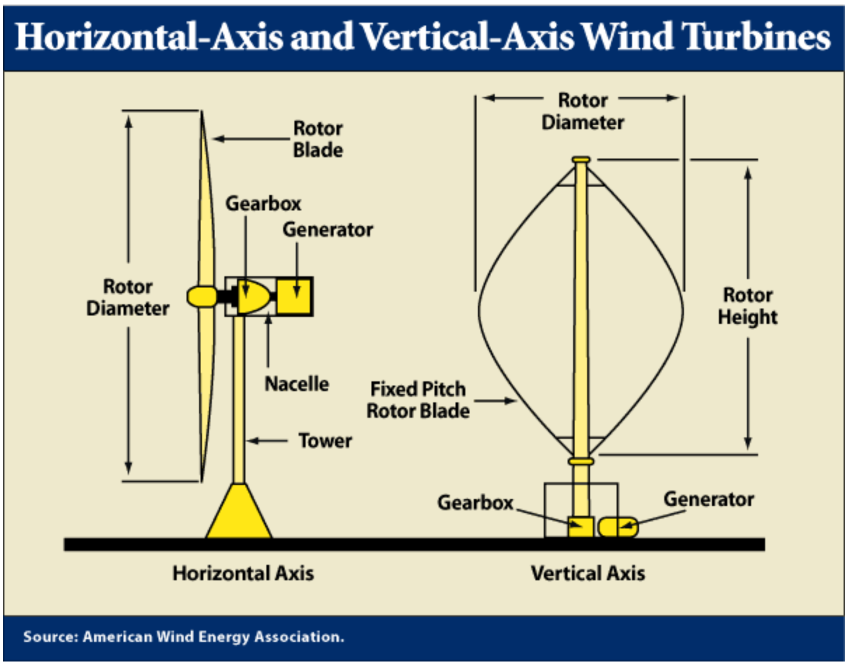

Fig. (2.10): Comparison between horizontal and vertical axis wind turbines.

2.6 Parts of the nacelle compartment

The nacelle in the horizontal axis type and the power box in the vertical axis type encloses most of the main parts of the wind turbine (other than the rotor and hub). These parts can be illustrated in (Fig. 2.11):

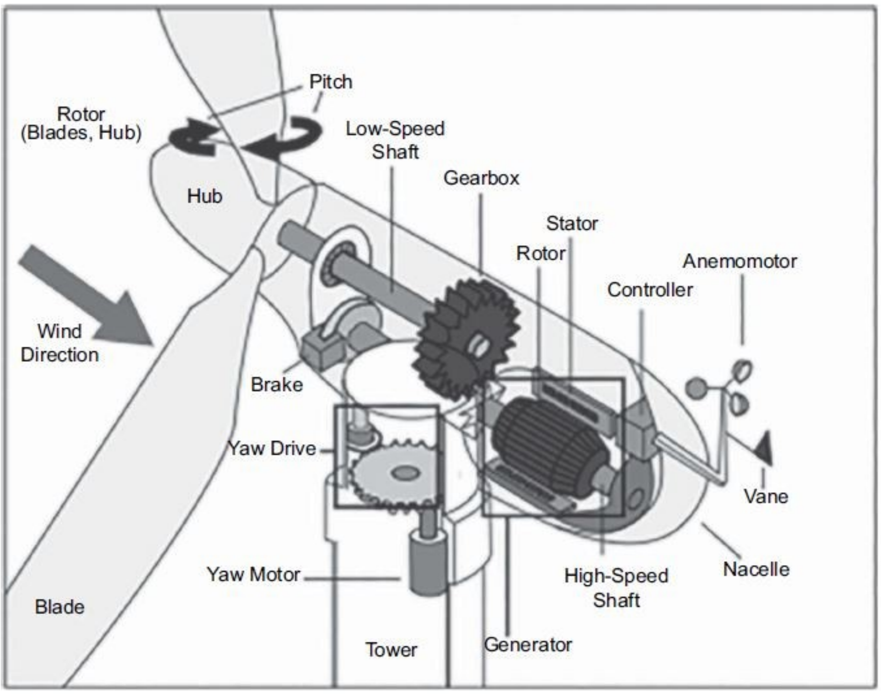

Fig. (2.11): Basic components of the nacelle compartment.