MODULE II

WIND ENERGY

Introduction:

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power generation capacity. Obviously, sites with steady high wind produce more energy over the year.

Two distinctly different configurations are available for turbine design, the horizontal-axis configuration (Figure 3.1) and the vertical-axis configuration. The horizontal-axis machine has been the standard in Denmark from the beginning of the wind power industry. Therefore, it is often called the Danish wind turbine. The vertical-axis machine has the shape of an egg beater and is often called the Darrieus rotor after its inventor. It has been used in the past because of its specific structural advantage. However, most modern wind turbines use a horizontal axis design. Except for the rotor, most other components are the same in both designs, with some differences in their placements.

2.1 SPEED AND POWER RELATIONS

The kinetic energy in air of mass m moving with speed V is given by the following in joules:

$$\text{kinetic energy} = \frac{1}{2} m V^2 \tag{1}$$

The power in moving air is the flow rate of kinetic energy per second in watts:

$$\text{power} = \frac{1}{2} (\text{mass flow per second}) V^2 \tag{2}$$

If

P= mechanical power in the moving air (watts),

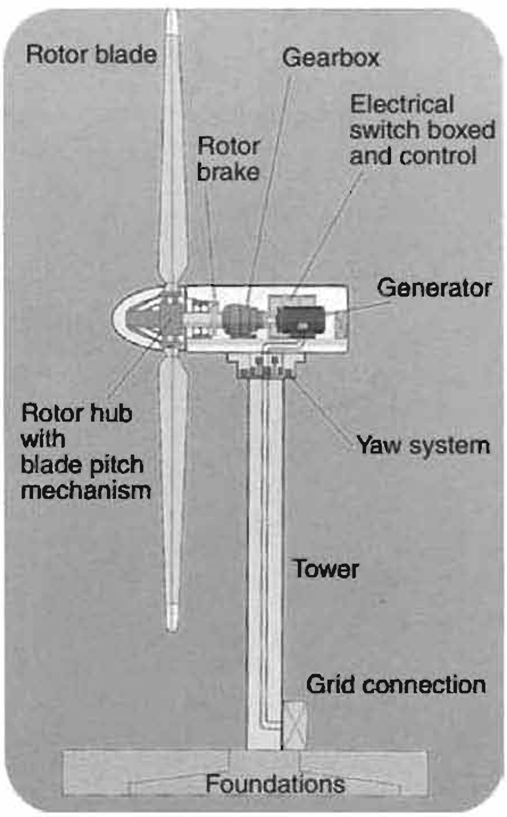
ρ = air density (kg/m^3),

A= area swept by the rotor blades (m^2), and

V= velocity of the air (m/sec),

then the volumetric flow rate is AV, the mass flow rate of the air in kilograms per second is ρAV, and the mechanical power coming in the upstream wind is given by the following in watts:

$$P = \frac{1}{2}(\rho AV)V^2 = \frac{1}{2}\rho AV^3 \quad (3)$$



Horizontal-axis wind turbine showing major components.

Two potential wind sites are compared in terms of the specific wind power expressed in watts per square meter of area swept by the rotating blades. It is also referred to as the power density of the site, and is given by the following expression in watts per square meter of the rotor-swept area:

$$\text{specific power of the site} = \frac{1}{2}\rho V^3 \quad (4)$$

This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed. The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed.

2.2 POWER EXTRACTED FROM THE WIND

The actual power extracted by the rotor blades is the difference between the upstream and downstream wind powers. Using Equation 3.2, this is given by the following equation in units of watts:

$$P_o = \frac{1}{2}(\text{mass flow per second})\left\{V^2 - V_o^2\right\} \tag{5}$$

where

P_o= mechanical power extracted by the rotor, i.e., the turbine output power,

V= upstream wind velocity at the entrance of the rotor blades, and

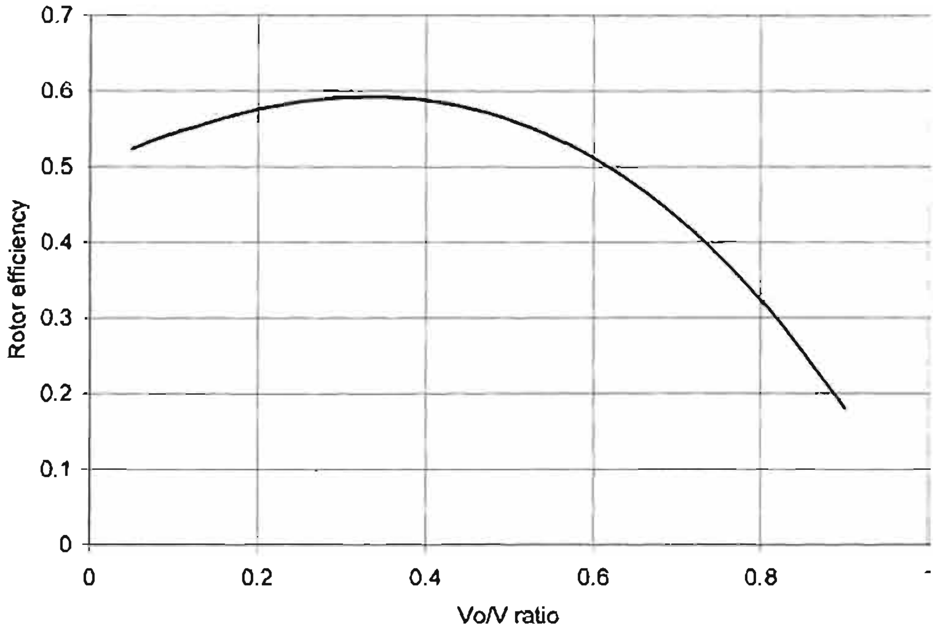
V_o= downstream wind velocity at the exit of the rotor blades.

Let us leave the aerodynamics of the blades to the many excellent books available on the subject, and take a macroscopic view of the airflow around the blades. Macroscopically, the air velocity is discontinuous from V to V_o at the "plane" of the rotor blades, with an "average" of ½(V + V_o). Multiplying the air density by the average velocity, therefore, gives the mass flow rate of air through the rotating blades, which is as follows:

$$\text{mass flow rate} = \rho A \frac{V + V_o}{2} \tag{6}$$

The mechanical power extracted by the rotor, which drives the electrical generator, is therefore:

$$P_o = \frac{1}{2}\left[\rho A \frac{(V + V_o)}{2}\right](V^2 - V_o^2) \tag{7}$$



Rotor efficiency vs. V_o/V ratio has a single maximum.

The preceding expression is algebraically rearranged in the following form:

$$P_o = \frac{1}{2}\rho A V^3 \frac{\left(1+\frac{V_o}{V}\right)\left[1-\left(\frac{V_o}{V}\right)^2\right]}{2} \tag{8}$$

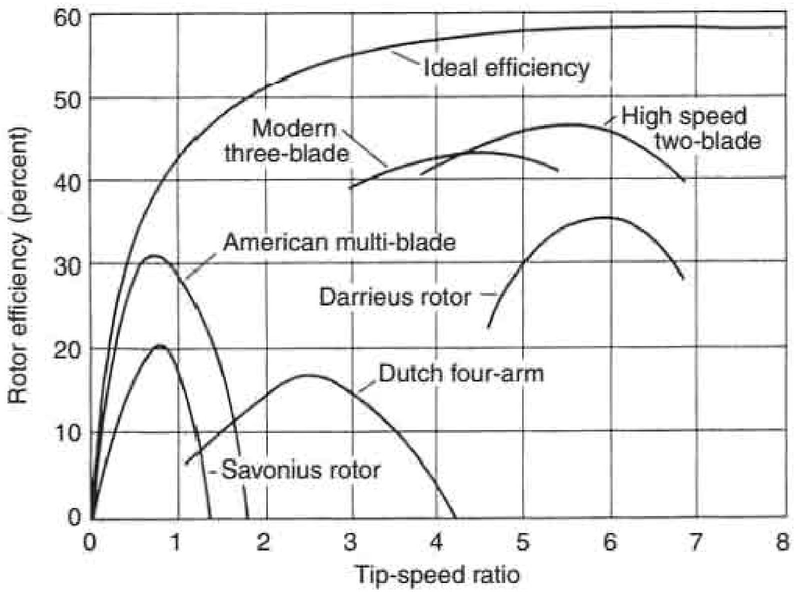
The power extracted by the blades is customarily expressed as a fraction of the upstream wind power in watts as follows:

$$P_o = \frac{1}{2}\rho A V^3 C_p \tag{9}$$

Where

$$C_p = \frac{\left(1+\frac{V_o}{V}\right)\left[1-\left(\frac{V_o}{V}\right)^2\right]}{2} \tag{10}$$

Comparing Equation 3 and Equation 9, we can say that C_p is the fraction of the upstream wind power that is extracted by the rotor blades and fed to the electrical generator. The remaining power is dissipated in the downstream wind. The factor C_p is called the power coefficient of the rotor or the rotor efficiency.



Rotor efficiency vs. V_0/V ratio for rotors with different numbers of blades.

2.3 WIND SPEED DISTRIBUTION

Having a cubic relation with power, wind speed is the most critical data needed to appraise the power potential of a candidate site. The wind is never steady at any site. It is influenced by the weather system, the local land terrain, and its height above the ground surface. Wind speed varies by the minute, hour, day, season, and even by the year. Therefore, the annual mean speed needs to be averaged over 10 yr or more. Such a long-term average gives a greater confidence in assessing the energy-capture potential of a site. However, long-term measurements are expensive and most projects cannot wait that long. In such situations, the short-term data, for example, over 1 yr, is compared with long-term data from a nearby site to predict the long-term annual wind speed at the site under consideration. This is known as the measure, correlate, and predict (mcp) technique.

Because wind is driven by the sun and the seasons, the wind pattern generally repeats over a period of 1 yr. The wind site is usually described by the speed data averaged over calendar months. Sometimes, the monthly data is aggregated over the year for brevity in reporting the overall "windiness" of various sites. Wind speed variations over the period can be described by a probability distribution function.

2.3.1 WEIBULL PROBABILITY DISTRIBUTION