## 2.4 Wind Energy and the Environment

In this section, both the positive and negative aspects of wind energy will be discussed.

### 2.4.1 Positive environmental benefits of Wind energy

It must be stressed that wind energy involves no combustion or nuclear reaction, so it is pollution free. It is renewable and plentiful and free, and what is more it is available everywhere, especially in remote areas and often it is windier in mountains and near costal areas. There are significant environmental benefits obtained from using a renewable energy device attributed to preventing the release of Green house gases associated with fossil fuels. The general equation for estimating the reduction in emitted gas is:

Gas-emission reduction (in tonnes) $= A \times 0.8 \times h \times kG$

Where

A is the rated capacity of the development in kW

h is the number of operational hours per year, = 8000 h

kG is the specific emitted gas constant.

Hence the following equations are used to predict environmental benefits from based on 1 kWe system:

$CO_2$ emission reduction (in tonnes) $= 1 \times 0.8 \times 8000 \times 862/10^6$
$= 5.5$

$SO_2$ emission reduction (in tonnes) $= 1 \times 0.8 \times 8000 \times 9.9/10^6$
$= 0.063$

$NO_2$ emission reduction (in tonnes) $= 1 \times 0.8 \times 8000 \times 862/10^6$

farms.

Even with these mitigation methods, there will be some proposed locations where wind turbines will cause disruptive radar interference. In such cases, wind projects would likely be unable to proceed at the proposed site.

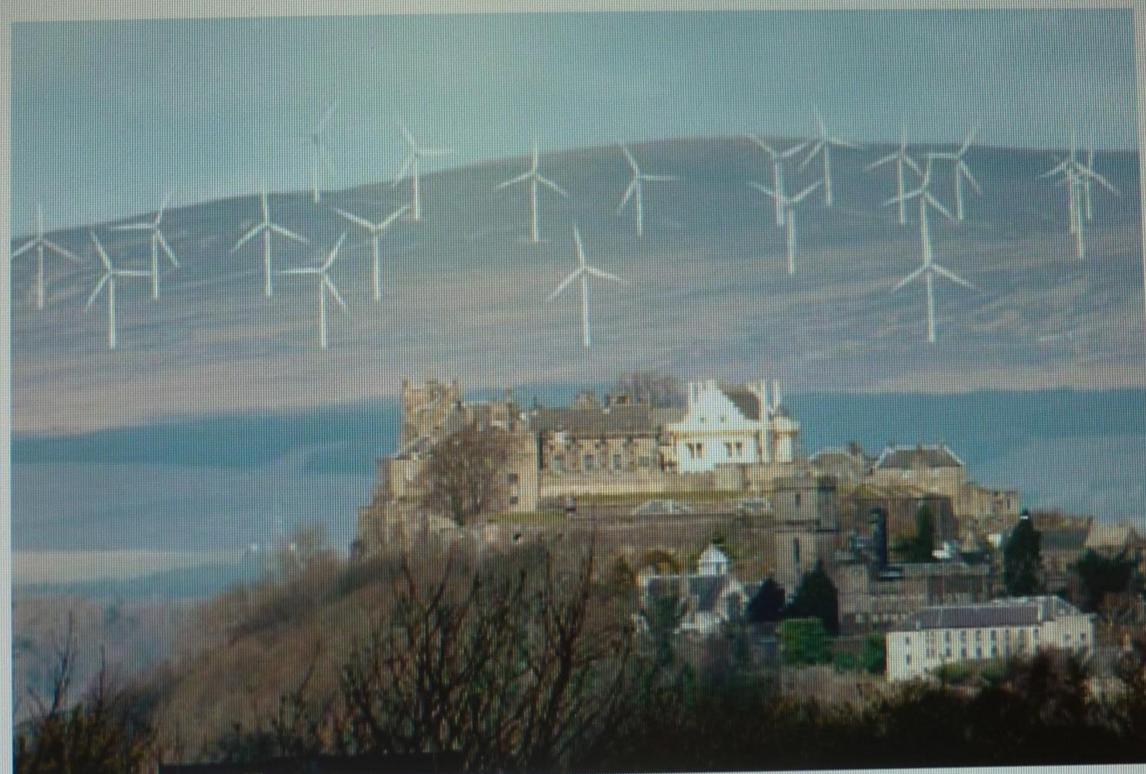

Figure 2.5 "Not" a perfect place to site a wind farm.

$V_f = A.dL/dt$

but since dL/dt is the fluid velocity (V, m/s) we can write: $V_f = V \times A$

The mass flow rate (m, kg/s) is given by the product of density and volume flow rate. Between any two points within the control volume, the fluid mass flow rate can be shown to remain constant:

or $$\rho_1 A_1 V_1 = \rho_2 A_2 V_2 \qquad (1)$$

## 3.2 Conservation of Energy:

Conservation of energy necessitates that the total energy of the fluid remains constant, however, there can be transformation from one form to another.

There are three forms of non-thermal energy for a fluid at any given point:-

The *kinetic energy* due to the motion of the fluid.
The *potential energy* due to the positional elevation above a datum.
The *pressure energy*, due to the absolute pressure of the fluid at that point.

If all energy terms are written in the form of the *head* (potential energy), ie in metres of the fluid, then conservation of energy principle requires that:

$$\left(\frac{p}{\rho g} + \frac{V^2}{2g} + z\right)_1 = \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z\right)_2 \qquad (2a)$$

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This equation is known as the *Bernoulli equation* and is valid if the two points of interest 1 & 2 are very close to each other and there is no loss of energy.

In a real situation, the flow will suffer a loss of energy due to friction ($h_L$) and obstruction between stations 1 & 2, hence

$$\left(\frac{p}{\rho g}+\frac{V^2}{2g}+z\right)_1=\left(\frac{p}{\rho g}+\frac{V^2}{2g}+z\right)_2+h_L \qquad (2b)$$

This is known as Darcy formula.

The value of the friction factor (f) depends mainly on two parameters namely the value of the Reynolds number and the surface roughness.

*The Reynolds number is defined in terms of the density, velocity of flow, diameter and the dynamic viscosity as follows:*

$$\mathrm{Re} = \frac{\rho . V . D}{\mu} \tag{4}$$

For *laminar* flow (ie Re < 2000),

$$f = \frac{16}{\mathrm{Re}} \tag{5a}$$

While for a *smooth* pipe with *turbulent* (i.e. Re > 4000) flow,

$$f = \frac{0.079}{\mathrm{Re}^{0.25}} \tag{5b}$$

For Re > 2000 and Re < 4000, this region is known as the critical zone and the value of the friction factor is certain.

Hence the power becomes:

$$P_{kin} = \frac{1}{2} x\rho * A * V_a * [V_1^2 - V_2^2] \tag{9}$$

Since the rotor speed is the average speed (Va) between inlet and outlet:

$$V_a = \frac{1}{2}[V_1 + V_2] \tag{10}$$

Hence, the power is

$$\begin{aligned} P_{kin} &= (1/2) * \rho * A * (V_1+V_2)/2) * [(V_1)^2 - (V_2)^2] \\ &= (1/4) * \rho * A * [V_1^3 - V_2^3 - V_1 * V_2^2 + V_1^2 * V_2)] \\ &= (1/4) * \rho * A * V_1^3 * [1 - (V_2/V_1)^3 - (V_2/V_1)^2 + (V_2/V_1)] \end{aligned} \tag{11}$$

To find the maximum power extracted by the rotor, differentiate equation 11 with respect to $V_2$ and equate it to zero

$$dP_{kin} / dV_2 = 1/4 * \rho * A * (-3 * V_2^2 - 2 * V_1 * V_2 + V_1^2) = 0 \tag{12}$$

Since the area of the rotor (A) and the density of the air (r) cannot be zero, the expression in the bracket of equation 12 has to be zero. Hence, the quadratic equation becomes:

Equation 14 clearly shows that:

- The power is proportional to the density ($\rho$) of the air which varies slightly with altitude and temperature
- The power is proportional to the area (A) swept by the blades and thus to the square of the radius (R) of the rotor; and
- the power varies with the cube of the wind speed ($V^3$). This means that the **power increases eightfold if the wind speed is doubled**. Hence, one has to pay particular attention in site selection.

## 3.3.2 Distinction between rated and actual power output of the turbine

The world's largest wind turbine generator has a rotor blade diameter of 126 metres and is located on offshore, at sea-level and so we know the air density is 1.2 kg/m$^3$. The turbine is rated at 5MW in 30mph (14m/s) winds,

Rotor Swept area $A = (\pi.\ 126^2)/4 = 12469\ m^2$

Wind Power $= 0.5 \times A \times \rho \times V^3$

$= 0.5 \times 12469 \times 1.2 \times (14)^3 = 20.5$ MW

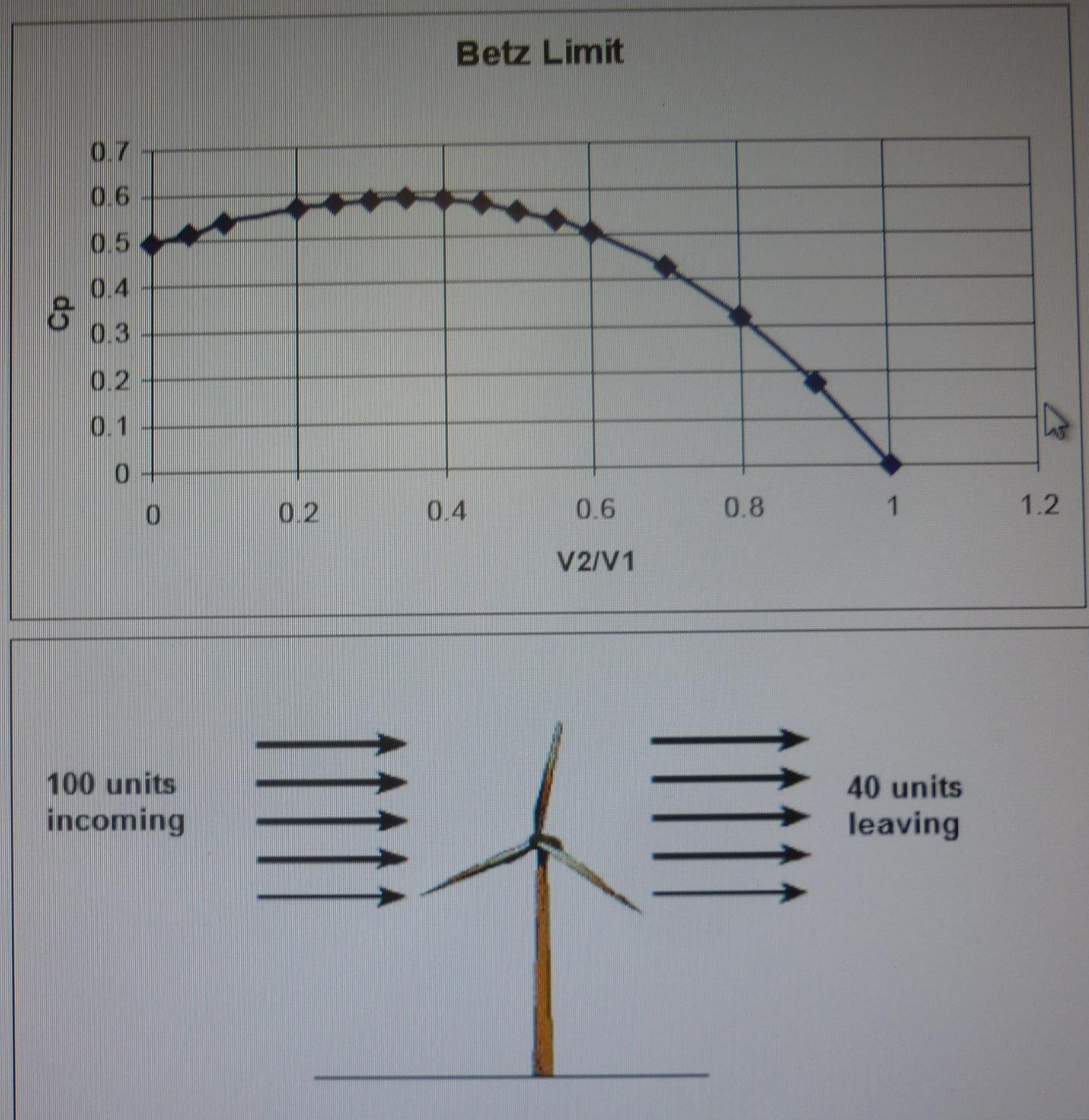



**Figure 3.3** Betz Limit on wind energy efficiency and its Implications.

# 4 Wind Turbines types and components

## 4.1 Types of Wind Turbines

There are mainly two types of wind turbine: horizontal axis and vertical axis. The horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) are classified or differentiated by the axis of rotation the rotor shafts.

**Horizontal Axis Wind Turbines** - Horizontal axis wind turbines, also known as HAWT type turbines have a horizontal rotor shaft and an electrical generator which is both located at the top of a tower.

**Vertical Axis Wind Turbines** - abbreviated as VAWTs, are designed with a vertical rotor shaft, a generator and gearbox which are placed at the bottom of the turbine, and a uniquely shaped rotor blade that is designed to harvest the power of the wind no matter which direction is it blowing.

The first is the Darrieus wind turbine, which is designed to look like a modified egg beater. These turbines have very good efficiency, but poor reliability due to the massive amount of torque which they exert on the frame. Furthermore, they also require a small generator to get them started.

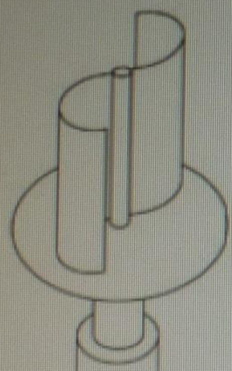
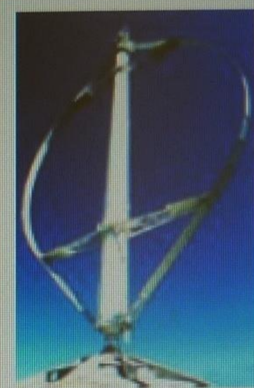
| **Savonius VAWT** | **Helical VAWT** | **Darrieus VAWT** | **3-blades HAWT** | **2 blades HAWT** |
|---|---|---|---|---|
|  |  |  |  |  |

**Figure 4.1** Wind Turbines, Some types

http://www.educypedia.be/education/

## 4.2 Components of a Wind Turbine

Wind turbine usually has six main components: the rotor, the gearbox, the generator, the control and protection system, the tower and the foundation. These main components can be seen in figure 4.2.

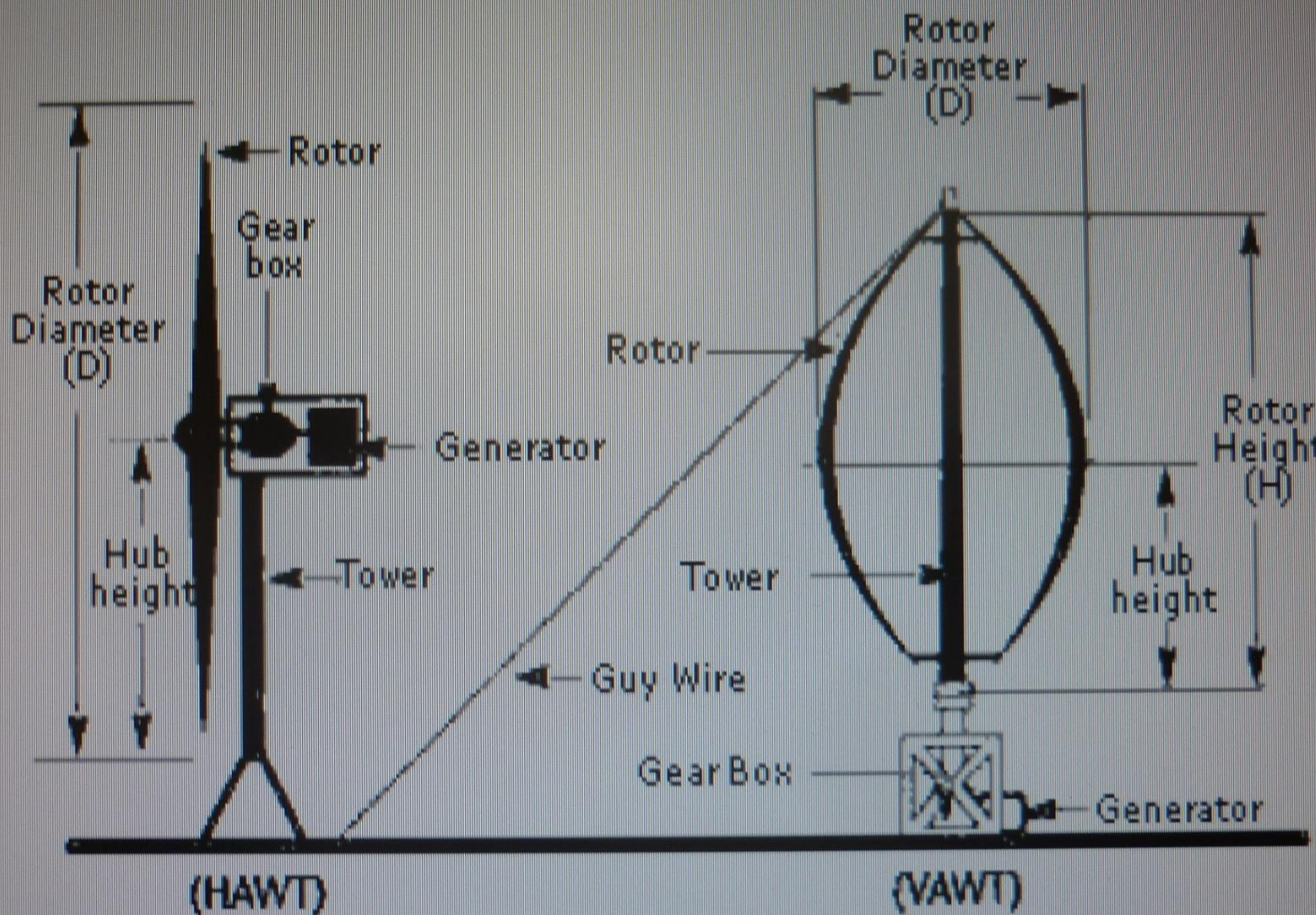



**Figure 4.2** Wind Turbine components

Courtesy of National Instruments Corporation, USA.

**Rotor** - The rotor is an elegant aerofoil shaped blades which take the wind and aerodynamically converts its kinetic energy into mechanical energy through a connected shaft.

**Gearbox** - The gearbox alters the rotational velocity of the shaft to suit the generator.

**Generator** - The generator is a device that produces electricity when mechanical work is given to the system.

**Control and Protection System** - The protection system is like a safety feature that makes sure that the turbine will not be working under dangerous condition. This includes a brake system triggered by the signal of higher wind speeds to stop the rotor from movement under excessive wind gusts.

**Tower** - The tower is the main shaft that connects the rotor to the foundation. It also raises the rotor high in the air where we can find stronger winds. With horizontal axis wind turbines, the tower houses the stairs to allow for maintenance and inspection.

**Foundation** - The foundation or the base supports the entire wind turbine and make sure that it is well fixed onto the ground or the roof for small household wind turbines. This is usually consists of a solid concrete assembly around the tower to maintain its structural integrity.

In addition to the main components of a wind turbine, a wind energy generation system is shown in Figure 4.2, incorporating a charge controller, Battery and inverter so that the electricity is converted for use by house appliances and lights.

house appliances and lights.

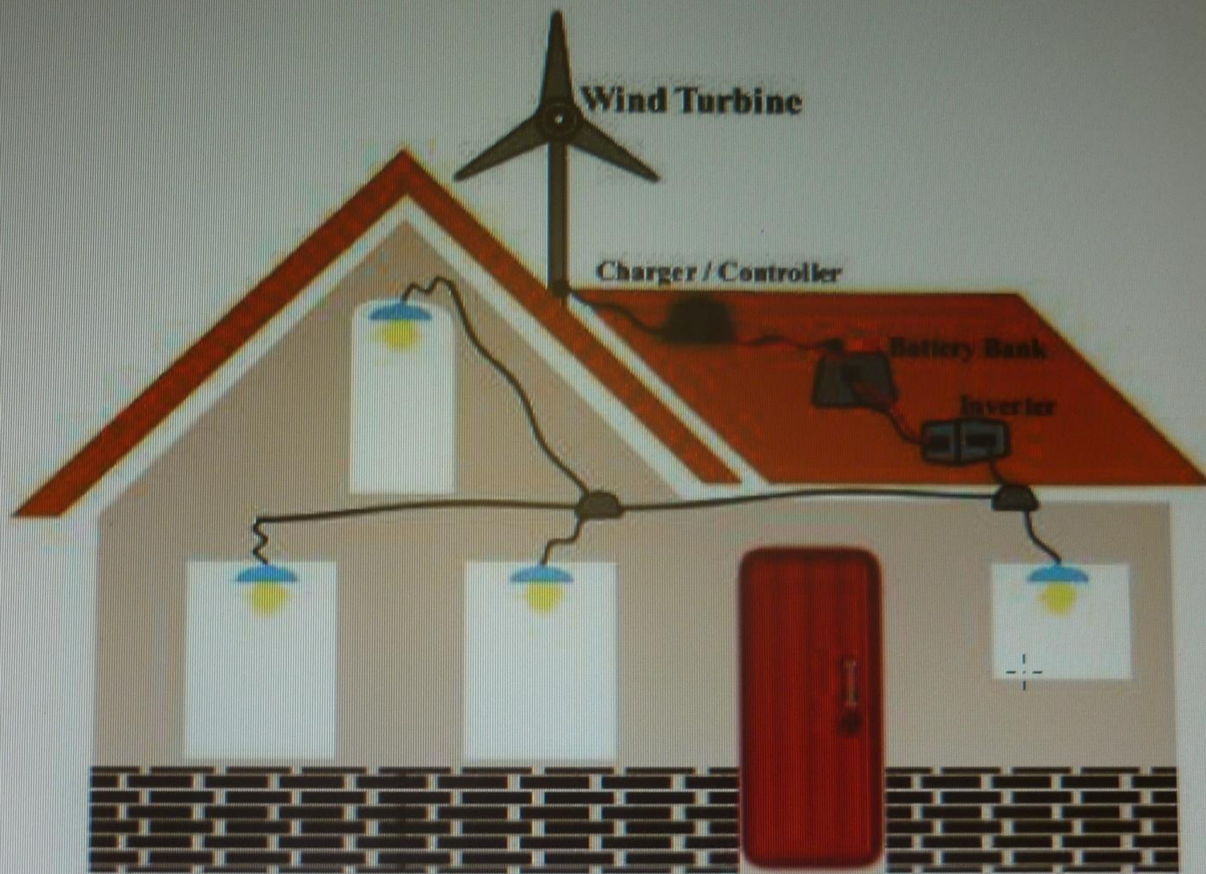



**Figure 4.3** Wind Energy System

http://www.inverter-china.com/

The optimum tip speed ratio depends on the number of blades in the wind turbine rotor. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind. A two-bladed rotor has an optimum tip speed ratio of around 6, a three-bladed rotor around 5, and a four-bladed rotor around 3. Figure 4.4 show some of the common Wind turbines and their respective efficiency against tip speed ratio (tsr).

## 5.2 Velocity and flow measured by Anemometers

Wind speed is the most important factor directly proportional to the power output of a wind turbine.

Various types of anemometer are used to measure the velocity, usually of air.

### 5.2.1 The 'cup type' air speed measurement

(Figure 5.5) is used for free air and has hemispherical cups on arms attached to a rotating shaft. The shape of the cups gives a greater drag on one side than the other and results in a speed of rotation approximately proportional to the air speed. Velocity is found by measuring revolutions over a fixed time.

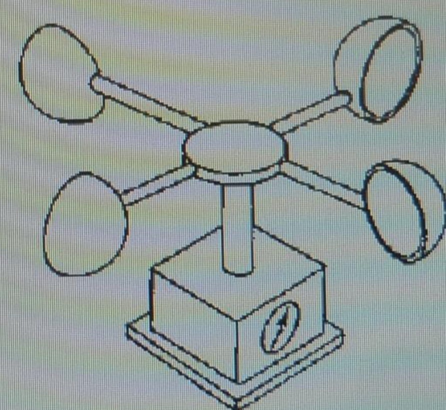


**Figure 5.5** Cup Type Anemometer

### 5.2.2 The 'vane anemometer'

(Figure 5.6) has an axial impeller attached to a handle with extensions and an electrical pick-up which measures the revolutions. A meter with several ranges indicates the velocity.