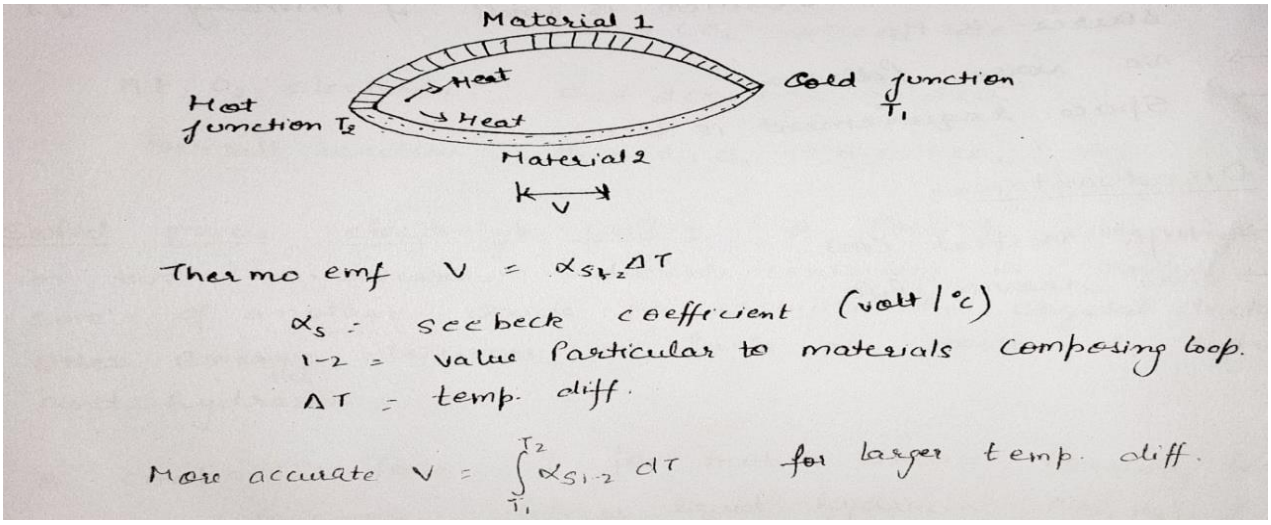
UNIT-4

THERMO-ELECTRICAL POWER

Principle :
Thermo electric generator is a device which converts heat energy into electrical energy through semiconductor or conductor. The direct conversion of heat energy into electric energy is based on seebeck thermoelectric effect.

Seeback effect : It is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between two substances.



The seeback coefficient depends upon the choice of the materials. Depending upon the choice of materials. Depending upon the choice of materials, the drop in the potential may be either +ve or –ve in the direction of the drop of temperature. Thus the sign as well as magnitude of the seeback coefficient of significant.

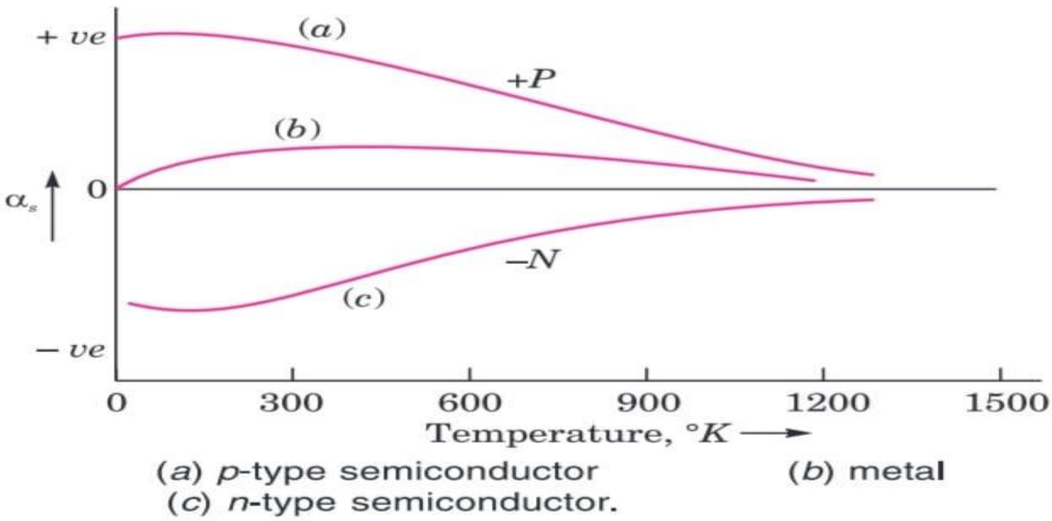


Fig. 1 Variation of Seebeck coefficient with temperature

The thermodynamic conversion of heat to work actually involves four distinct process, only two of which are reversible. The reversible processes are the Peltier and Thomson effects. The irreversible ones are fourier effect and joule effect.

Joule effect : This refers to irreversible conversion of electrical energy into heat when a current I and flows through a resistance R, an amount of heat equal to I2R is generated per unit time. This heat is called Joulean heat.

$$\mathbf{Q_f = I^2 R}$$

Peltier effect : When an electric current flows across an isothermal junction of two dissimilar materials, there is either an evolution or absorption of heat at the junction. This effect is called the peltier heat Fig. 2. The Peltier effect is a reversible effect because if heat is evolved when current flows in one direction, the same amount of heat is absorbed at the junction if the current flow is reversed.

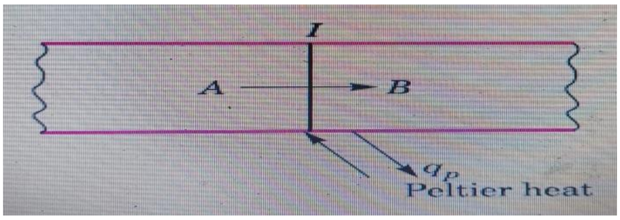


Fig. 2 Peltier effect

The Peltier Coefficient $\alpha_{P_{1-2}}$ is defined as the heat evolved or absorbed at the junction per unit current flow, per unit time.

$$\alpha_{P_{1-2}} = \alpha_{P_1} - \alpha_{P_2} = \frac{q_P}{I}$$

$$q_P = \alpha_{P_{1-2}} . I$$

I = Peltier heat per unit time.

Thomson effect – When an electric current flows through on material having a temperature gradient, there is an evolution of heat. This phenomenon is called Thomson effect. The Thomson heat is reversible because reversing the direction of current flow reverses the direction of heat transfer without change in magnitude.

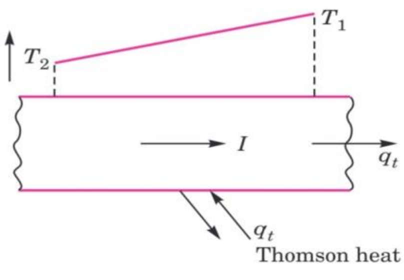


Fig.3 Thomson effect

Thomson coefficient $\sigma = \dfrac{dq_T/dx}{d_T/dx}$

where, $\dfrac{dq_T}{dx}$ = heat interchange per unit time per unit length of conductor.

$\dfrac{d_T}{dx}$ = temperature gradient.

Hence, the Thomson heat per unit time is given by

$$dq_T/dx = \sigma I \frac{d_T}{dx}$$

The Seebeck, Peltier and Thomson effects are more pronounced in *semiconductors* as compared to metals.

The relations between the Seebeck, Peltier and Thomson Coefficients as derived by Kelvin are as follows:

$$\left.\begin{aligned} \alpha_p &= \alpha_S \,.\, T \\ \text{or} \quad \alpha_{P_{1-2}} &= \alpha_{S_{1-2}} \,.\, T \end{aligned}\right\} \qquad ...(13.12)$$

$$\left.\begin{aligned} \sigma &= T\frac{d\alpha_S}{d_T} \\ \sigma_{1-2} &= \frac{T\, d\alpha_{S_{1-2}}}{d_T} \end{aligned}\right\} \qquad ...(13.13)$$

In order to apply elementary thermodynamics of the thermoelectric system, we must ignore the irreversible processes. If the wires are assumed to have zero thermal conductivity, irreversible conduction of heat between the hot and cold reservoirs can not occur. Furthermore, if the wires also have zero electrical resistivity, the irreversible process of Joule heating is absent. We are thus left with the reversible *Peltier* and *Thomson* effects, which will be described below.

Equation (13.2), can be integrated by parts as

$$V_{1-2} = \int_{T_1}^{T_2} (\alpha_{S_1} - \alpha_{S_2})\, d_T$$

$$= (\alpha_{S_1} - \alpha_{S_2})T \Big|_{T_1}^{T_2} - \int_{T_1}^{T_2} \left\{\frac{d}{d_T}(\alpha_{S_1} - \alpha_{S_2})\right\} d_T \qquad ...(13.14)$$

We will define the following functions of the Kelvin temperature:

$$\alpha_{P_{1-2}} = (\alpha_{S_1} - \alpha_{S_2})T$$

$$= \alpha_{S_{1-2}} \,.\, T = \text{Peltier Coefficient at junction } 1-2 \qquad ...(13.15)$$

$$\left.\begin{aligned} \sigma_1 &= \frac{-T\, d\alpha_{S_1}}{d_T} = \text{Thomson Coefficient along wire 1} \\ \sigma_2 &= \frac{-T\, d\alpha_{S_2}}{d_T} = \text{Thomson Coefficient along wire 2} \end{aligned}\right\} \qquad ...(13.16)$$

In terms of these Coefficients, Equation (13.16) can be expressed as

$$\therefore \quad V_{1-2} = \alpha_{P_{1-2}} T_2 - \alpha_{P_{1-2}} T_1 + \int_{T_1}^{T_2} \sigma_1\, d_T - \int_{T_1}^{T_2} \sigma_2\, d_T$$

$$P = I \,.\, V_{1-2}$$

$$= I\,\alpha_{P_{1-2}} T_2 - I\,\alpha_{P_{1-2}} T_1 + I\int_{T_1}^{T_2} \sigma_1\, d_T - I\int_{T_1}^{T_2} \sigma_2 d_T \qquad ...(13.18)$$

From Equation (13.18) it can be seen that the electrical power produced by the thermocouple is equal to the difference between two Peltier effects and two Thomson effects.

THERMIONIC GENERATION

Another form of direct conversion of heat energy to electrical energy has been achieved in the thermionic converter. It utilizes the thermionic emission effect, that is, the emission of electrons from heated metal (and some oxide) surfaces. The energy required to extract an electron from the metal is an important parameter, known as the work function of the metal. Typical values of the order of a few electron volts. The value of the work function varies with the nature of the metal and its surface condition.

Principle

A thermionic consists of two metals (or electrodes) with different work functions sealed into an evacuated vessel. The electrode with the large work function is maintained at a higher temperature than one with the smaller work function.

System consists of two electrodes held in a container filled with ionized cesium vapour. Heating one electrode, electrons are emitted, that travel to the opposite, colder electrode. The hotter electrode (or emitter) emits electrons (i.e. negative charges) and so acquires a positive charge whereas the colder electrode (or collector) collects electrons and becomes negatively charged. A voltage (or electromotive force) thus develops between the two electrodes and a direct electric current will flow in an external circuit (or load) connecting them. The voltage which may be 1 volt (or so), is determined primarily by the difference in the work function of the electrode materials

Because electrons cannot travel far in air, thermionic converters require that the electrodes be in a vacuum. This limits the size of the converter so that only small scale power production is feasible.

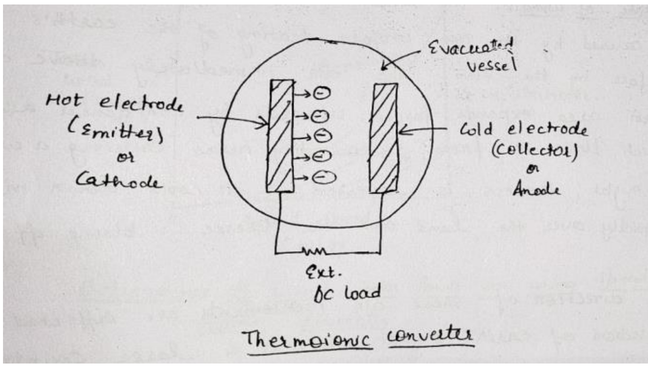


Fig. 4 Thermionic Converter

A common thermionic electrode combination is a tungsten emitter and a cesium-coated tungsten collector. To achieve a substantial electron emission rate (per unit are of emitter) and hence a significant current output as well as high efficiency, the emitter temperature, in a thermionic converter containing cesium should be atleast 1000 degree celcius. Higher efficiencies upto 40% can be obtained at still higher temperature.

Limitations of Thermionic Converter:

- The operating temperature of cathode is very high, so costly materials like tungsten, rhenium are required for cathode.
- Special shields of ceramic are required for protection of cathode from corrosive combustion gases.
- The collector may also have to be made of molybdenum coated with cesium.
- Ionized cesium vapour has to be filled in the inter space to reduce the space charge barrier to promote electron emission from the cathode.

Applications of Thermionic Converter:

- **Thermionic Converter in a Nuclear Reactor:**
  The fuel element containing the fissile material carries the cathode surrounded by the anode. The inter space is filled with ionized cesium gas. The anode is cooled by the coolant from outside. Some of the energy released by nuclear fission is directly converted into electrical energy by thermionic conversion. The remaining heat is used in conventional bottoming steam plant. The overall efficiency of the plant, therefore, increases.
- **Thermionic Converter in the Riser Tube of a Boiler:**
  The riser tubes of a boiler receive heat by radiation from combustion gases. The riser tube is provided by a cathode and anode of a thermionic converter. The interspace is filled with ionized cesium vapour. The use of the hot combustion gases to produce extra power before the steam cycle improves the overall plant efficiency.
- **MHD Thermionic-Steam Power Plant:**
  The waste heat from the MHD generator at about 1,900°C is used to heat the cathode of thermionic converter. The heat from the anode is used in the boiler of a steam power plant. The overall efficiency of the plant will, therefore increase.

WIND ENERGY

Nature of Wind

The circulation of air in the atmosphere is caused by the non-uniform heating over water. In coastal regions this manifests itself in a strong onshore wind. At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore.

The main planetary winds are caused in much the same way: Cool surface air sweeps down from the poles forcing the warm air over the tropics to rise. But the direction of these massive air movements is affected by the rotation of the earth and the net effect is a large countries-clockwise circulation of air around low pressure areas in the northern hemisphere, and clockwise Circulation in the southern hemisphere. 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 well inland. 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 increase with height. They have a traditionally been measured at a standard height of ten metres where they are found to be 20-25% greater than close to the surface. At height of 60 m they may be 30-60% higher because of the reduction in the drag effect of the earth's surface.

Power in the wind

The power in the wind can be computed by using the concept of kinetics. The wind mill works on the principle of converting K.E of the wind to the mechanical energy.
We know,

Power = energy per unit time

The energy available **K.E.** $= \frac{1}{2} mV^2$

where, **m= mass**
V= Velocity

Since, **m= pAV**
where, **p = density**
A = area
(Amount of air passing in unit time through an Area A with velocity V is A.V)

Therefore, **K.E** $= \frac{1}{2} PAV^3$

Power available is directly proportional to air density. Therefore, small increase in wind speed can marked effect on the power in the wind. It may vary 10-15% during the year because of pressure and temperature change.
Wind machines intended for generating substantial amount of power should have large rotors and be located in areas of high wind speeds.

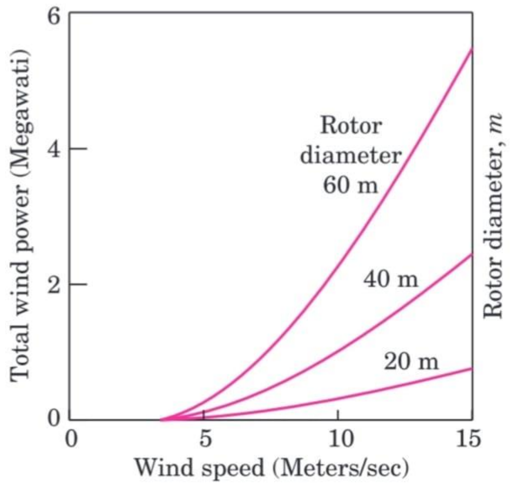


Fig. 5 Dependence of wind rotor power on wind speed & rotor diameter

The physical conditions in a wind turbine are such that only a fraction, of the available wind power can be converted into useful power As the free wind stream encounters and passes through a rotor, the wind transfer some of its energy to the rotor and its Speed decreases to a minimum in the rotor wake. Subsequently, the wind stream regains energy from the surrounding air and at a sufficient distance and energy is transferred to the rotor. Finally the pressure increases to the ambient atmospheric pressure.

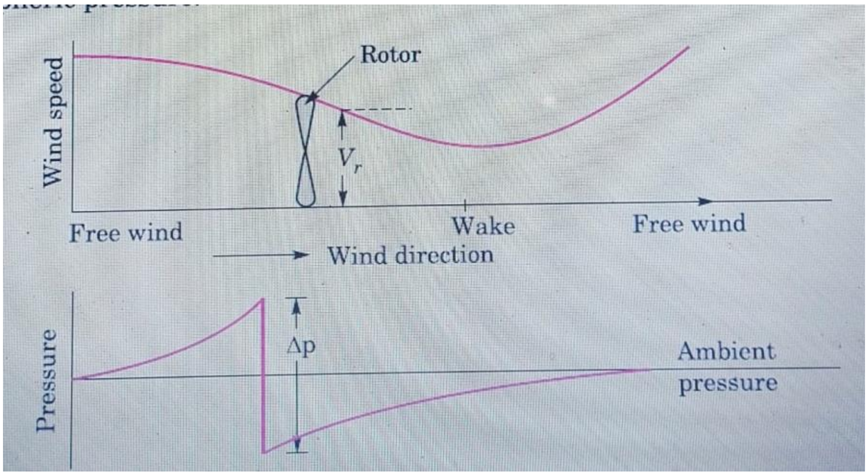


Fig. 6 Conditions in traversing a wind rotor

The power extracted by the rotor is equal to the product of the wind speed as it passes through the rotor and the pressure drop Δp. In order to maximize the rotor power it would therefore be desirable to have both wind speed and pressure drop as large as possible. However, as Vis increased for a given value of the free wind speed (and air density), Δp increases at first, passes through a maximum, and then decreases Hence for the specified free-wind speed, there is a maximum value of the rotor power.

The fraction of the free-flow wind power that can be extracted by a rotor is called the power-coefficient; thus

Power coefficient = (Power of wind rotor/ Power available in the wind)

where power available is calculated from the air density, rotor diameter, and free wind speed as shown above.

Site Selection Considerations:

1. **Availability of wind curve at the proposed site:** This curve determine the maximum energy in the wind & hence is the principal initially controlling factor in predicting the electrical output & hence revenue return of WECS.

2. **Availability of Anemometry data:** The principal object is to measure the wind speed which basically determines the WECS output power. The anemometer height above ground, accuracy, linearity, location on the support tower, shadowing etc. are a few of many difficulties encountered.

3. **Distance to roads or railways:** This is another factor the system engineer must consider for heavy machinery, structures, materials, blades etc. will have to be moved into any chosen WECS site.

4. **Nature of ground:** Ground condition should be such that the foundations for a WECS are secured.

5. **Favourable land cost:** Land cost should be favourable along with other siting costs.

6. Other problems such as icing, salt spray or blowing dust should not present at the site as they may affect aeroturbine blades, or environmental is generally adverse to machinery & electrical apparatus.

BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM (WECS)

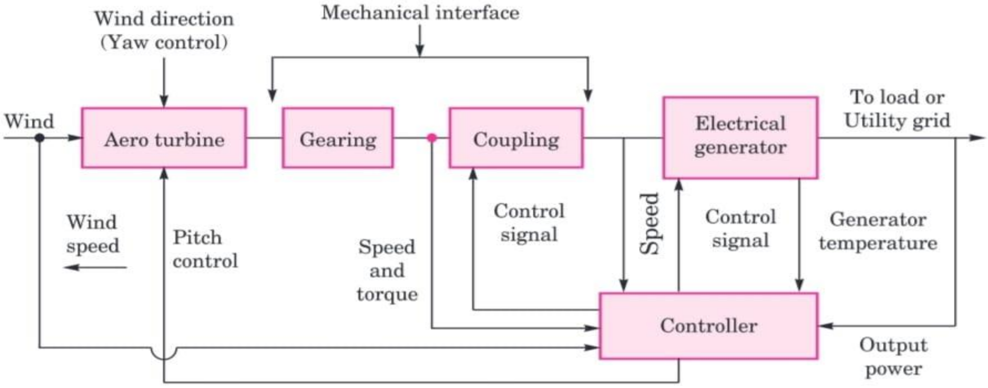


Fig. 7 Basic components of wind electric system

Aeroturbine convert energy in moving air to rotary mechanical energy. In general, they require pitch control & yaw control (only in the case of horizontal or wind axis machines) for proper operation. A mechanical interface consisting of a step up gear and a suitable coupling transmits the rotary mechanical energy to an electrical generator. The output of this generator is connected to the load or power grid.

Yaw control: When the rotor orientation is fixed with the swept area perpendicular to the predominant wind direction, such a machine is said to be yaw fixed. Most wind turbines are yaw active i.e. as the wind direction changes, motor rotates the turbine slowly about vertical (yaw) axis so as to face the blades into the wind. The area of wind stream swept by the wind rotor is then maximum.

In small turbines, yaw action is controlled by a tail vane, similar to that in a typical pumping windmill. In larger machines, a servomechanism operated by a wind direction sensor controls the yaw motor that keeps the turbine properly oriented.

The purpose of controller is to sense wind speed, wind direction, shafts speed and torque at one or more points, output power & generator temperature as necessary & appropriate control signal for matching the electrical output to the wind energy input & protect the system from extreme condition brought upon by strong winds electrical faults.

The sub-components of the windmill are

- Wind turbine or rotor
- Wind mill head
- transmission & control
- supporting structure

ROTORS

Rotor mainly of two types:

(1) Horizontal axis rotor
(2) Vertical axis rotor

- **Windmill head-** The windmill head supports the rotor, housing the rotor bearings. It also houses any control mechanism incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind. The latter is facilitated by mounting it on the top of the supporting structure on suitable bearings.

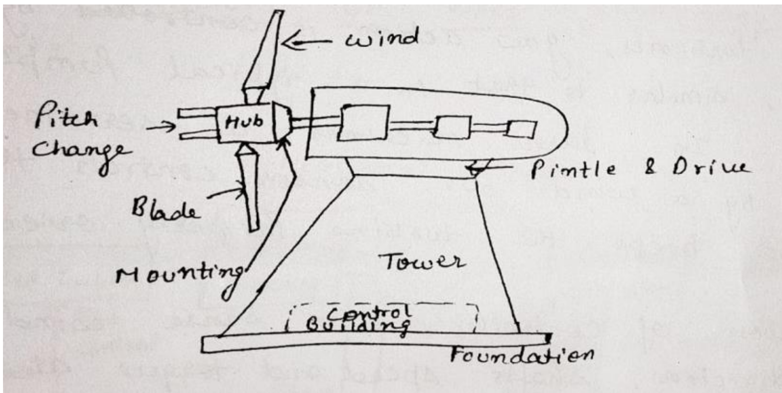


Fig. 8

- **Transmissions-** The rate of rotation of large wind turbine generators operating at rated capacity or below, is conveniently controlled by varying the pitch of the rotor blades, but it is low, about 40 to 50 revolutions per minute (rpm). Because optimum generator output requires much greater rates of rotation, such as 1800 r.p.m. it is necessary to increase greatly the low rotor rate of turning. Among the transmission options are mechanical systems involving fixed ratio gears, belts, and chains, singly or in combination or hydraulic systems involving fluid pumps and motors. Fixed ratio gears are recommended for top mounted equipment because of their high efficiency, known cost, and minimum system risk. For bottom mounted equipment which requires a right angle drive, transmission costs might be reduced substantially by using large diameter bearings with ring gears mounted on the hub to serve as a transmission to increase rotor speed to generator speed. Such a combination offers a high degree of design flexibility as well as large potential savings.

- **Generator -** Either constant or variable speed generators are a possibility, but variable speed units are expensive and/or unproved. Among the constant speed generator candidates for use are synchronous induction and permanent magnet types. The generator of choice is the synchronous unit for large aerogenerator systems because it is very versatile and has an extensive data base. Other electrical components and systems are, however, under development.

- **Controls-** The modern large wind turbine generator requires a versatile and reliable control system to perform the following functions:

  (1) the orientation of the rotor into the wind (azimuth of yaw);
  (2) start up and cut-in of the equipment;
  (3) power control of the rotor by varying the pitch of the blades
  (4) generator output monitoring-status, data computation, and storage;
  (5) shutdown and cut out owing to malfunction or very high winds;
  (6) protection for the generator, the utility accepting the power and the prime mover.

- Towers. Four types of supporting towers deserve consideration, these are:
  (1) the reinforced concrete tower,
  (2) the pole tower,
  (3) the built up shell-tube tower, and
  (4) the truss tower.

Among these, the truss tower is favoured because it is proved and widely adaptable, cost is low, parts are readily available, it is readily transported, and it is potentially stiff Shell-tube towers also have attractive features and may prove to be competitive with true towers.

Advantages of WECS

- Renewable source
- Non-polluting
- Avoid fuel provision and transport
- Upto few kw (on small scale) less costly.

Disadvantages of WECS

- Fluctuating in nature
- Noisy in operation
- Large areas are needed
- High overall weight

WIND ENERGY COLLECTORS:

Wind aerogenerator of WECS are generally classified:

- **Horizontal axis type:** These are further classified as single bladed, multi bladed and by cycle multi blades type.
- **Vertical axis type :** It is of two types (i) Savonius or 'S' type rotor mill (low velocity wind). (ii) Darrieus type rotor mill (high velocity wind)

Horizontal axis using two aerodynamics blades:

Horizontal axis using two aerodynamic blades. In this type of design, rotor drives a generator through a step up gearbox. The blade rotor is usually designed to be oriented downwind of the tower. The components are mounted on a bed plate which is attached on a pintle at the top of the tower. This arrangement is shown schematically in Fig. (6.14). The rotor blades are continuously flexed by unsteady aerodynamic, gravitational and inertia loads, when the machine is in operation, if the blades are made of metal, flexing reduces their fatigue life with rotor the tower is also Subjected to above loads, which may cause serious damage.

If the vibrational modes of the rotor happen to coincide with one of the natural mode of the vibration of the tower, the system may shake itself to pieces. Because of the high cost of the blade rotors with more than two blades are not recommended.
Rotors with more than two, say 3 or 4 blades would have slightly higher power coefficient.

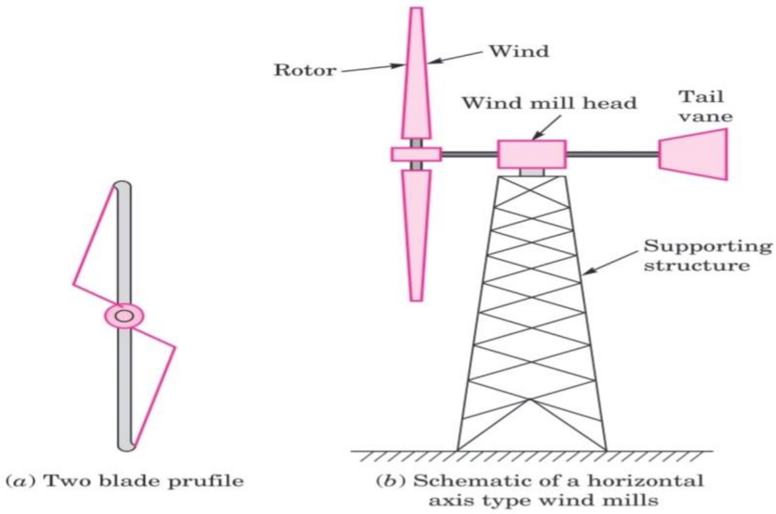


Fig. 9

Horizontal axis propeller type using single blades:

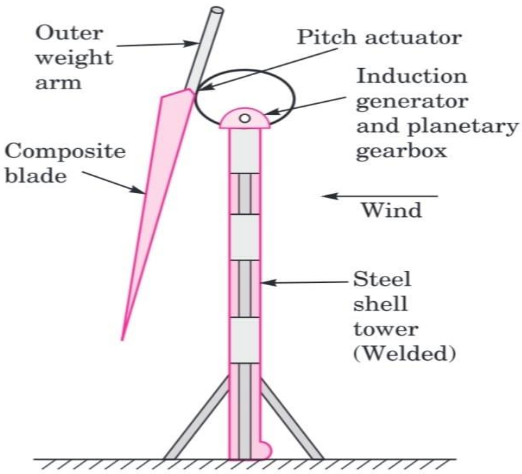


Fig. 10

A long blade is mounted on a rigid hub. If extremely long blade (60 m or above) is mounted, large blade root bending moments may occur due to tower shadow, gravity & sudden shifts in wind direction.

Advantages:

- Simple blade control
- Counter weight costs less than second blade
- Pitch bearing don’t carry centrifugal force.

Disadvantages:

- Large blade root bending moment

- Vibration produced due to aerodynamic torque

Horizontal axis multibladed type :

Horizontal axis multibladed type. This type ot design tor multiblades are made from sheet metal or aluminium. The rotors have high strength to weight ratios and have been known to service hours of freewheeling operation in 60 km/hr winds. They have good power coefficient, high starting torque and added advantage of simplicity and low cost.

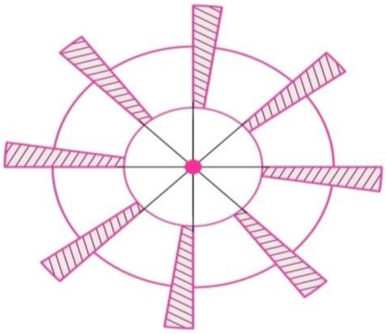


Fig. 11

Horizontal axis wind mill-Dutch type: It is one of the oldest designs. The blade surfaces are made from an array of wooden slots which feather at high wind speeds.

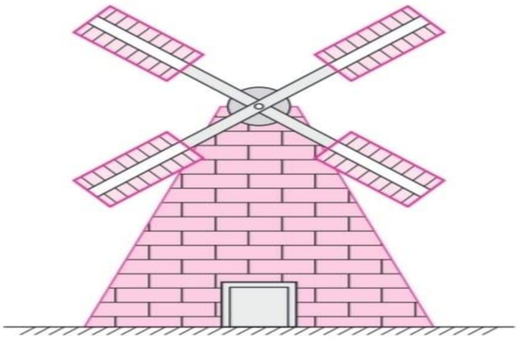


Fig. 12

Sail type: It is of recent origin. The black surface is made from cloth, nylon or plastics arranged as pole or sail wings.

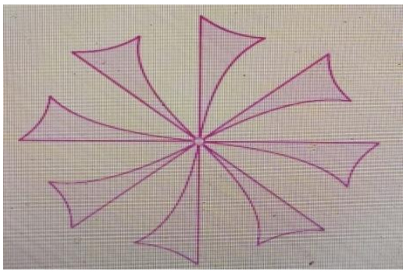


Fig. 13

Vertical axis type: Following are the advantages,

- They will react to wind from any direction and therefore do not need yawing equipment to turn the rotor into the wind.
- They can require less structural support because heavy components (like gearbox and generator) can be located at ground level. This configuration also eases installation and maintenance.
- Since the blades do not turn end over end, the rotor is not subjected to continuous cycle gravity loads. (Fatigue induced by such action is a major consideration in the design of large horizontal axis machines)

Probably the single biggest disadvantage with vertical axis machines is that far less is known about them than horizontal axis ones. This handicap is rapidly being removed.

Savonius Rotor –
This is invented by S.I Savonius in 1920. It consists of two half cylinders facing opposite direction in such a way as to have almost an S-shaped cross section. These two semi-conductor drums are mounted on a vertical axis perpendicular to the wind direction with a gap at the axis between the two drums. Irrespective of the wind direction the rotors rotates such as to make the convex sides of buckets head into the wind. From the rotor shaft we can tape power for use like water pumping, battery charging, etc.

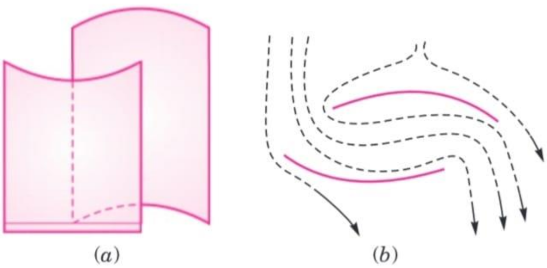


Fig. 14

Characteristics:

i. Self starting
ii. Low speed
iii. Low efficiency

Advantages:

i. Low cut in speed (wind speed required for switching electric power into line)
ii. Simple structure
iii. Ground level monitoring

Disadvantages:

i. Excessive weight
ii. Not useful for a very tall installation because of long drive shaft problems

Darrieus type (High velocity wind):

Invited by G.I.M Darrieus in 1925. This has same advantage. An additional advantage is that it supports its blades in a way that minimizes bending stresses in normal operation.

It has two or three thin, curved (egg beater) blades with airfoil cross section and constant chord length. Both ends of blades are attached to a vertical shaft. Thus the force in the blade due to rotation is pure tension. This provides a stiffness to help withstand the wind forces it experiences. The blades can thus be made lighter than in the propeller type. What happens in a serve storm is another question as yet unanswered. When rotating, these airfoil blades provide a torque about the central shaft in response to a wind stream. This shaft torque is being transmitted to a generator at the base of the central shaft for power generation.

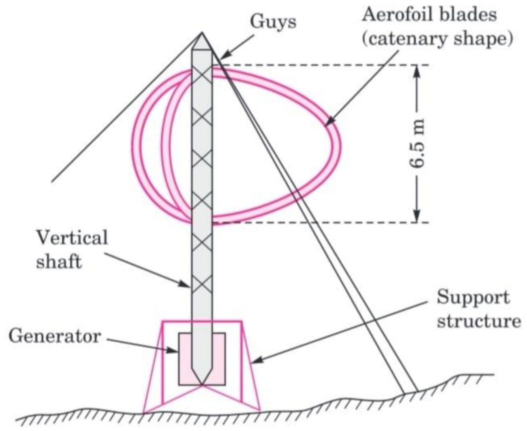


Fig. 15

Characteristics

i. Note self starting
ii. High speed
iii. High efficiency
iv. Potentially low capital

Advantages

i. Machine can be mounted on the ground
ii. Yaw control not needed

Disadvantages

i. Requires external mechanical aid for start up
ii. Output efficiency is lower