1.1 ENVIRONMENTAL CONSEQUENCES OF FOSSIL FUEL USE

The conversion of energy from one form to another generally affects the environment. Hence, without considering the impact of energy on the environment, the study of energy is not complete. Fossil fuels have been used since 1700s which has helped the industrial growth and the amenities of modern life. During the combustion of fossil fuels the emitted pollutants are strongly responsible for smog, acid rain, global warming and climate change.

1.2.1 Major air pollutants and their sources are listed below:

Carbon monoxide (CO):

This is a colorless, odorless gas that is produced by the incomplete burning of carbon-based fuels including petrol, diesel and wood. It is also produced from the combustion of natural and synthetic products such as cigarettes. It lowers the amount of oxygen that enters our blood. It can slow our reflexes and make us confused and sleepy

Carbon dioxide (CO_2):

This is the principle greenhouse gas emitted as a result of human activities such as the burning of coal, oil, and natural gases.

Chlorofluorocarbons (CFC):

These are gases that are released mainly from air conditioning systems and refrigeration. When released into the air, CFCs rise to the stratosphere, where they come in contact with other gases, which lead to a reduction of the ozone layer that protects the Earth from the harmful ultraviolet rays of the Sun.

Lead:

This is present in petrol, diesel, lead batteries, paints, hair dye products, etc. Lead affects children in particular. It can cause nervous system damage and digestive problems and, in some cases, cause cancer.

Ozone (O_3):

This occurs naturally in the upper layers of the atmosphere. This important gas shields the Earth from the harmful ultraviolet rays of the Sun. However, at the ground level, it is a pollutant with highly toxic effects. Vehicles and industries are the major source of ground level ozone emissions. Ozone makes our eyes itch, burn, and water. It lowers our resistance to colds and pneumonia.

Nitrogen oxide (NOx):

This causes smog and acid rain. It is produced from burning fuels including petrol, diesel, and coal. Nitrogen oxides can make children susceptible to respiratory diseases in winters.

Suspended particulate matter (SPM):

This consists of solids in the air in the form of smoke, dust, and vapour that can remain suspended for extended periods and is also the main source of haze, which reduces visibility. The finer of these particles, when breathed in can lodge in our lungs and cause lung damage and respiratory problems.

Sulfur dioxide (SO_2):

This is a gas produced from burning coal, mainly in thermal power plants. Some industrial processes, such as production of paper and smelting of metals, produce sulfur dioxide. It is a major contributor to smog and acid rain. Sulfur dioxide can lead to lung diseases

The major areas of environmental problems may be classified as follows water pollution, ambient air quality, hazardous air pollutants, maritime pollution, solid waste disposal, land use and sitting impact, acid rain, stratospheric ozone depletion, global climate change(Green House Effect)

1.2.2 Vital Problems Because of Environmental Issues:

Acid Rain:

Acid rain is a widespread term used to describe all forms of acid precipitation (rain, snow, hail, fog, etc.) Atmospheric pollutants, particularly oxides of sulfur and nitrogen, can cause precipitation to become more acidic when converted to sulfuric and nitric acids, hence the term acid rain. Motor vehicles also contribute to SO2 emissions since petrol and diesel fuel also contains small amounts of sulfur.

The sulfur oxides (SO_2) and nitric oxides (NO) react with water vapors (H_2O) and other chemicals in the atmosphere in the presence of sunlight to form sulfuric acid (H_2SO_4) and nitric acid (HNO_3).

These are below in above Figure 1.2. The acids formed usually dissolve in the suspended water droplets in clouds or fogs. These acid-laden droplets are washed from the air to the soil by rain or snow onto the Earth. This is known as acid rain

The soil is capable of neutralizing a certain amount of acid. However, the power plant, which uses high-sulfur coal, pollutes many lakes and rivers in industrial areas that have become too acidic for fish to grow. Forests in different regions of the Earth also experience a slow death due to absorption of acids from acid rain through the leaves, needles and roots of the trees.

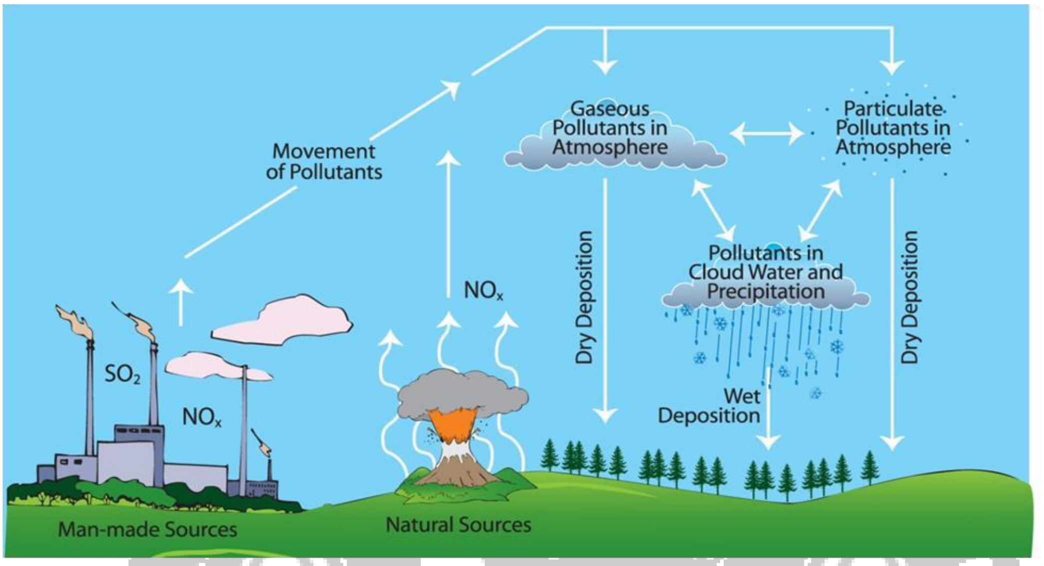


Figure 1.1.1

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 225]

Depletion of Ozone Layer:

It is well known that the natural build up of oxygen in the atmosphere gradually led to the formation of the ozone layer. This layer is found between 19 and 30 kilometers (km) above the ground. The ozone layer filters out incoming radiation from the Sun that is harmful to life on Earth. The development of the ozone layer allowed more advanced life forms to evolve. Most ozone is produced naturally in the stratosphere, a layer of atmosphere between 10 and 50 km above the Earth‟s surface, but it can be found throughout the whole of the atmosphere. The ozone layer plays a natural and equilibrium maintaining role for the Earth through the absorption of ultraviolet (UV) radiation (240–320 nm) and absorption of infrared radiation

A global environmental problem is the distortion and regional depletion of the stratospheric ozone layer. This effect due to the emissions of NOx and CFCs, etc. Ozone depletion in the stratosphere can lead to increased levels of damaging ultraviolet radiation reaching the ground. This increases rates of skin cancer, eye damage and other harm to many biological species. Chlorofluorocarbons (CFCs) and NOx emissions are produced by fossil fuel and biomass combustion processes and play the most significant role in ozone depletion. Hence, the major pollutant, NOx emissions, needs to be minimized to prevent stratospheric ozone depletion

Global Warming and Climate Change (Greenhouse Effect):

The greenhouse effect is a process by which radiative energy leaving a planetary surface is absorbed by some atmospheric gases, called greenhouse gases. They transfer this energy to other components of the atmosphere, and it is reradiated in all directions, including back down towards the surface. This transfers energy to the surface and lower atmosphere, so the temperature there is higher than it would be if direct heating by solar radiation were the only warming mechanism

The greenhouse effect is also experienced on a larger scale on Earth. This warms up as a result of the absorption of solar energy (shortwave length) during the day, cools down at night by radiating part of its energy into deep space as infrared radiation (long wavelength). Carbon dioxide (CO2), water vapour and trace amounts of some other gases such as methane (CH4) and nitrogen oxides act like a blanket and keep the Earth warm at night by blocking the heat radiation from the Earth, as shown in the Figure 1.2 Therefore, they are called "greenhouse effect"" gases. In this case, the CO_2 is the primary component.

The greenhouse effect makes human life on the planet Earth feasible by keeping the Earth warm at about 30°C. However, excessive amounts of greenhouse gases emitted by human being disturb the delicate balance by trapping too much energy. This causes the average temperature of the Earth to rise and the climate generally changes at some localities. These undesirable features of the greenhouse effect are generally referred to as global warming or climate change

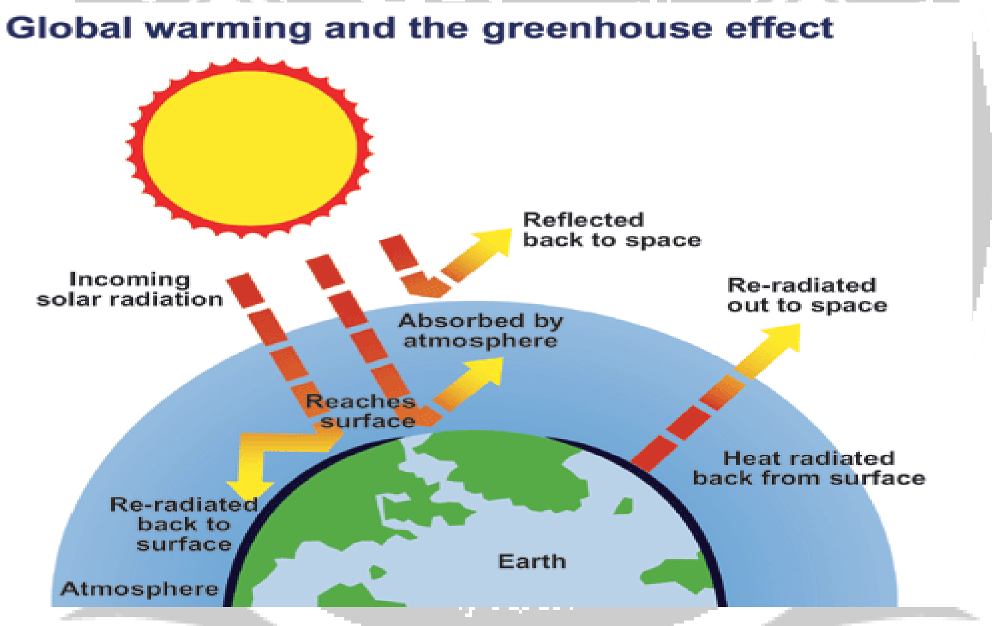


Figure 1.1.2

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 226]

The excessive use of fossil fuels such as coal, petroleum products and natural gas, petroleum products and natural gas in electric power generation, transportation and manufacturing processes is responsible for global climate change. The present concentration of CO2 in the atmosphere is about 416.39 ppm . This is 20 percent higher than the level a century ago.Under normal conditions, vegetables consume CO_2 and release CO_2 during the photosynthesis process, thus keeping the CO_2 concentration in the atmosphere in check. A mature growing tree consumes about 12 kg of CO_2 a year and exhales enough oxygen to support a family of four. However, deforestation and the huge increase in CO_2 production due to the fast growing industrialization in recent decades have disturbed this balance.

1.3 IMPORTANCE OF RENEWABLE ENERGY SYSTEM:

1.3.1 There is a growing concern worldwide on the use of fossil fuels for the following reasons:

(a) There is ever-increasing use of fossil fuels.

(b) Depletion of fossil fuels is taking place at a rapid pace.

(c) Oil crisis that happened in 1973 during that year Organization of Petrol Exporting Countries (OPEC) has put restriction on oil production and export, they also started controlling strategy on oil price resulting in energy crisis and steep rise in oil prices worldwide.

Owing to above reasons, more importance is being given to the development of alternative sources of energy such as non-conventional, renewable and environmental-friendly.

The importance of non-conventional energy resources is also increasingly felt due to the following reasons:

- The demand of energy is rapidly increasing due to fast industrialization and population growth. The conventional energy resources are insufficient to meet such growing demand.
- The conventional energy resources are non-renewable and these are depleting fast.
- The conventional energy resources cause pollution, thereby degrading the environment.
- The projects to harness large hydro resources affect wildlife, cause deforestation and affect nearby villagers due to submerging of a vast area.
- Fossil fuels are also used as raw materials in the chemical industry. There is need to conserve fossil fuels for future generation.

It is important to explore and develop renewable energy resources to reduce excessive dependence on Non-Renewable resources. The present trend is to develop Renewable resources to serve as supplement rather than alternative for Non-Renewable Resources

1.3 Sustainable Design and development:

- Sustainable technology in the energy sector is based on utilizing renewable sources of energy such as solar, wind, hydro, bioenergy, geothermal, and hydrogen. The plan must justify energy demand and supply and assess the actual costs and benefits to the local, regional, and global environments
- Sustainable design will reduce or remove negative environmental impacts through thoughtful design. The basic objectives of sustainability are to reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments.

Sustainable design principles include the ability to:

- o p t i m i z e site potential;
- minimize non-renewable energy consumption;
- use environmentally preferable products;
- protect and conserve water;
- enhance indoor environmental quality; and
- Optimize operational and maintenance practices.

- Utilizing a sustainable design philosophy encourages decisions at each phase of the design process that will reduce negative impacts on the environment and the health of the occupants, without compromising the bottom line. It is an integrated, holistic approach that encourages compromise and tradeoffs. Such an integrated approach positively impacts all phases of a building's life-cycle, including design, construction, and operation and decommissioning.

1.3.1 A UTILITY-LED EFFICIENT LIGHTING PROGRAM IN BANGALORE, INDIA

The Bangalore Electric Supply Company (BESCOM), a distribution company that serves the Bangalore metropolitan area in the state of Karnataka recently partnered with the International Institute for Energy Conservation to implement a program to replace inefficient incandescent light bulbs with compact fluorescent lights (CFLs).

POLICIES AND ACTIONS

The energy challenges that developing countries face are significant and increasing. Further, it is clear that developing countries will be unable to avoid the potentially large and adverse consequences without concerted policy interventions by developing and developed countries alike

I. ENERGY EFFICIENCY

Energy efficiency can be especially important in rapidly industrializing countries as a way to manage rapid demand growth, improve system reliability, ease supply constraints and allow energy the production and distribution infrastructure to ‘catch up.’

Efficiency standards or codes for buildings, especially commercial buildings, are extremely important because of the long useful life of most structures. However, to be effective, countries will need to educate architects and builders and develop the means to monitor performance and enforce compliance with the codes. By setting a floor or baseline for energy efficiency, minimum standards can ensure that there will be substantial energy savings in the future.

II. SUBSIDY REFORM

Fossil fuel subsidies are not restricted to developing countries. They are provided in many countries. They are also addictive and those who benefit from them are usually unwilling to give them up. Thus, analysts may conclude that subsidies should be eliminated or phased out.

Where there is concern that poor households will be unable to access basic energy services if they are required to pay the full market price, it might be feasible to provide subsidies of up to only a certain level of consumption. This is more likely to be practicable for electricity than for portable fuels like petrol or kerosene. For example, low-income households could be offered reduced electrical rates for the first increments of consumption.

III. INDIGENOUS SUSTAINABLE RESOURCES

Many developing countries have abundant renewable energy potential and could benefit from the positive economic spillovers generated by renewable energy development, especially in underserved rural areas where decentralized, small-scale renewable energy technologies are likely to be competitive with conventional alternatives.

However, government involvement is needed even more in the early stages of research and development (R&D). Not surprisingly, developed countries have historically taken the lead in energy R&D spending because they have had the resources to do so. This will likely continue. However, this does not mean that there is no role for developing countries. Some of the larger developing countries have sufficient resources to permit them to invest significantly in technology. Others can participate by targeting investments and/or working cooperatively with other countries or institutions to ensure that their R&D efforts address the specific opportunities and constraints that apply in developing countries. Investment in energy R&D can also be seen as a way to build indigenous human capital in science and engineering. Brazil, for example, has nurtured a viable domestic biofuels industry through all stages of technology development, deployment and commercialization.

IV. TECHNOLOGY TRANSFER AND DEVELOPMENT OF HUMAN AND INSTITUTIONAL CAPACITY

In summary, successful technology transfer and a worldwide expansion of the human and institutional capacities needed to implement sustainable technologies are essential elements of an effective global response to the energy challenges that we face. To meet these challenges, developed countries will need to follow through on current commitments and work closely with developing countries to make the most effective use of scarce resources. Developing countries must not be passive bystanders in that process. They have everything to gain by leveraging future investments to build their indigenous human and institutional capacities and by taking the lead in adapting and improving sustainable energy technologies to suit their particular needs.

V. CLEAN, EFFICIENT COOK STOVES

Improved cook stoves are worth mentioning, however, because they offer enormous public health and welfare benefits at a relatively low cost. It has been estimated that exposure to indoor pollution from the use of fuels like wood and dung for cooking and space heating causes as many as 1.6 million deaths annually throughout the world, primarily women and young children (WHO, 2002). In addition, the need to gather fuel can cause local environmental degradation and take up great amounts of time, particularly for women and girls that might otherwise be available for more productive activities. A shift away from traditional fuels for cooking could marginally increase demand for commercial fuels like propane, natural gas or electricity

The situation in developing countries is in many ways more difficult than that for developed countries. Not only are there obvious resource constraints, but also a significant part of the population may lack access to basic energyservices. et, developing countries also have some advantages. They can learn from past experience, avoid some of the policy missteps of the last half century and have an opportunity to “leapfrog” directly to cleaner and more efficient technologies. Fortunately many essential elements of a sustainable energy transition can be expected to mesh well with other critical development objectives, such as improving public health, broadening employment opportunities, nurturing domestic industries, expanding reliance on indigenous resources and improving a country’s balance of trade.

1.4 Types of RE sources:

True renewable energy sources are energy supplies that are refilled by natural processes at least as fast as we use them. All renewable energy comes, ultimately, from the sun. We can use the sun directly (as in solar heating systems) or indirectly (as in hydroelectric power, wind power, and power from biomass fuels). Renewable energy supplies can become exhausted if we use them faster than they become replenished: most of England’s forests were cut down for fuel before the English started using coal. If used wisely, however, renewable energy supplies can last forever.

Types of renewable energy:

1. Solar energy
2. Wind energy
3. Hydro energy
4. Tidal energy
5. Geothermal energy
6. Biomass energy

1. SOLAR ENERGY

Solar Cells (or) Photovoltaic Cell

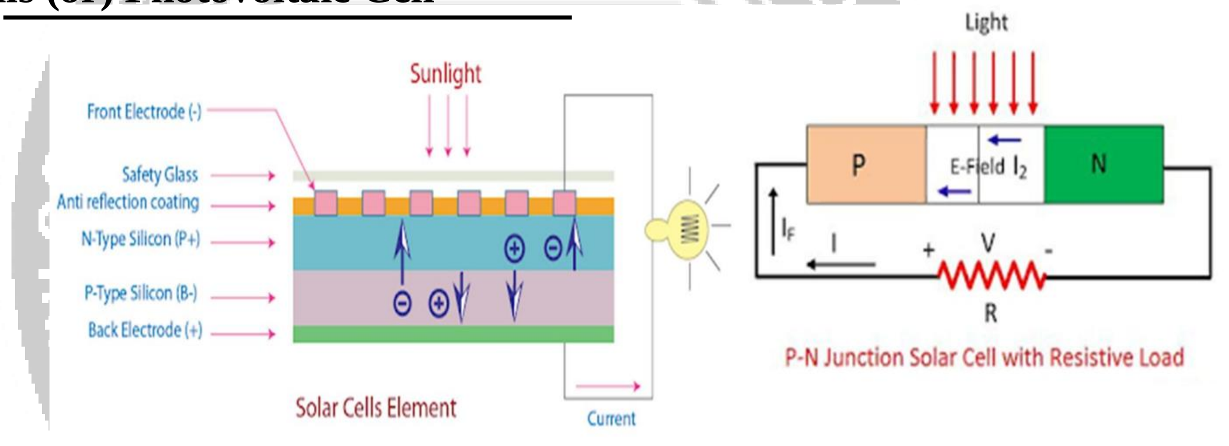


Figure: 1.4.1

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 125]

- ❖ The direct conversion of solar energy into electricity is done by the photovoltaic effect. The basic unit of photovoltaic system is the solar cell. Solar cell is made from single crystal silicon
- ❖ The solar cell is a semi-conductor device. It generates voltage when sun light falls on it. the power obtained in day time is stored in solar batteries. The configuration of a solar cell to forma p-n junction semi-conductor is shown in Diagram.
- ❖ Silicon with added materials such as arsenic or phosphorus is called n type silicon, i.e., negatively charged silicon. The silicon with added materials such as boron is called p-type silicon, i.e.,positively charged silicon.
- ❖ The charge distribution near the p-n junction gives rise to an electric field and hence a potential difference across the junction. If an external load is applied, this charge difference will drive a current through it. The current will flow so long as the sun light keeps generating the electron pairs.

Applications of Solar Cells

- ❖ Used in remote, unmanned devices, where utility power is unavailable and batteries are impractical.
- ❖ They are used to operate calculators, irrigation pumps, TV station, satellite, rail-crossing signals, navigational signals, space craft, etc

2. Wind energy:

Principle of Wind Mill

- ❖ Wind is air in motion. Wind flow is created as an effect of solar beat. Winds are caused due to the absorption of solar energy on the earth surface and the rotation of earth about its own axis and around the sun.
- ❖ Because of this, alternate heating and cooling occurs. Thus, difference in pressure is Obtained and the air movement is caused. It is estimated that roughly 10 million MWof energy is continuously available in the earth's winds.
- ❖ Windmills are used for pumping water, grinding grains, etc. Interests in large scale power generations had developed over the past 50 years.

Types of Wind Mill

Depending on the axis of rotation, wind mills are classified as follows.

i) Horizontal AxisType ii) Vertical AxisType

The horizontal axis type has better performance than the vertical type

Horizontal Axis Wind Mill

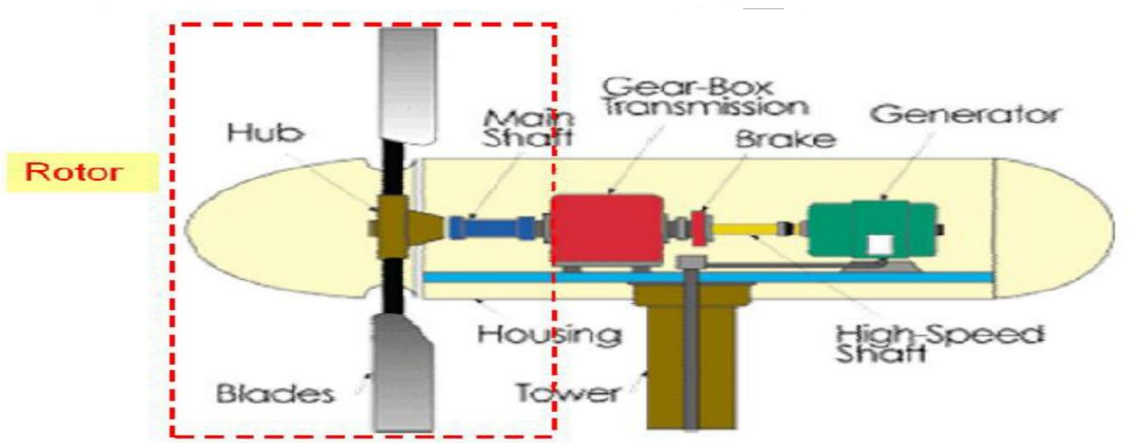


Figure:1.4.2

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 126]

Horizontal axis single blade wind mill as shown in Diagram is of propeller type with counter-weight arrangement. The double blade type gives a better performance than single blade type.

- In the double-blade wind mill, the wind mill head is mounted on a bed plate attached on the top of the tower. The wind mill head accommodates a step-up gear box, control device and the generator.
- The blade rotor drives the generator through the transmission gear box. The two blades have thick cross section of an aerofoil, made of aluminium or sheet metal. The blades are set at right angles to the direction of the wind.
- The energy inherent in the moving air is converted into mechanical energy due to the dynamic action of air on the blades. This mechanical energy is transmitted to the generator, through the gear box. The output of the generator is connected to the load.
- With rotor, the tower is also subjected to the wind loads which may cause serious damage. Hence, the structure of the tower should also withstand the wind load
- The best sites for wind energy are found off-shore and along seacoast with no tall obstruction in the neighboring area. The lowest level of wind energy is found in plains. The present production of capacity of wind mills in Tamil Nadu is around 300 MW.

Hydro energy

Hydropower plants convert the energy of flowing water into electricity. This is primarily done by damming rivers to create large reservoirs and then releasing water through turbines to produce electricity. Hydropower results in no emissions into the atmosphere but the process of damming a river can create significant ecological problems for water quality and for fish and wildlife habitat.

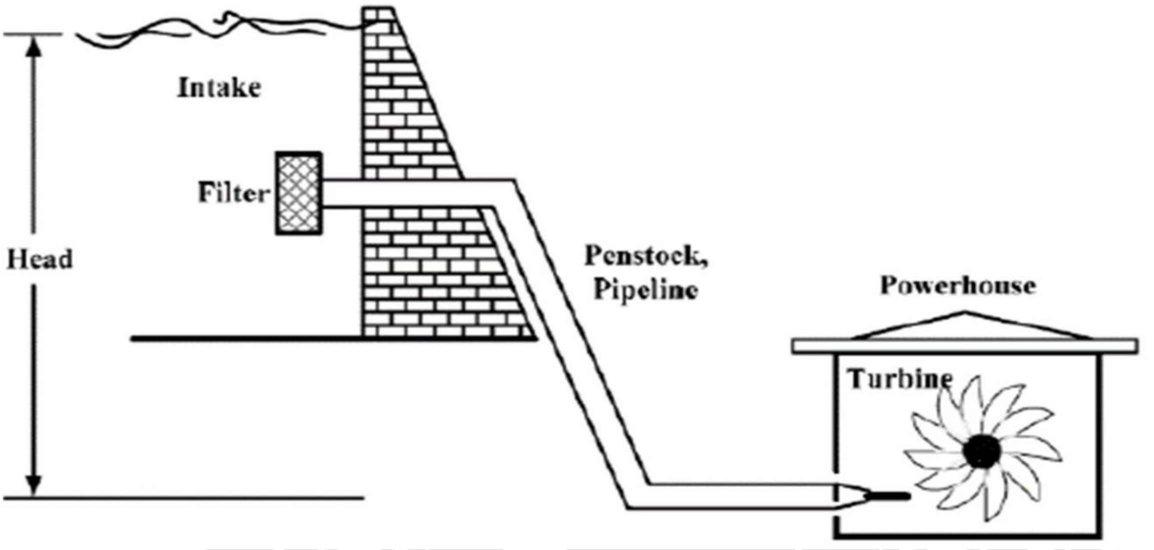


Figure: 1.4.3

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 128]

Tidal Energy:

Tidal power is extracted from the Earth's oceanic tides; tidal forces are periodic variations in gravitational attraction exerted by celestial bodies. These forces create corresponding motions or currents in the world's oceans. The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth, the effects of Earth's rotation, and local geography of the sea floor and coastlines

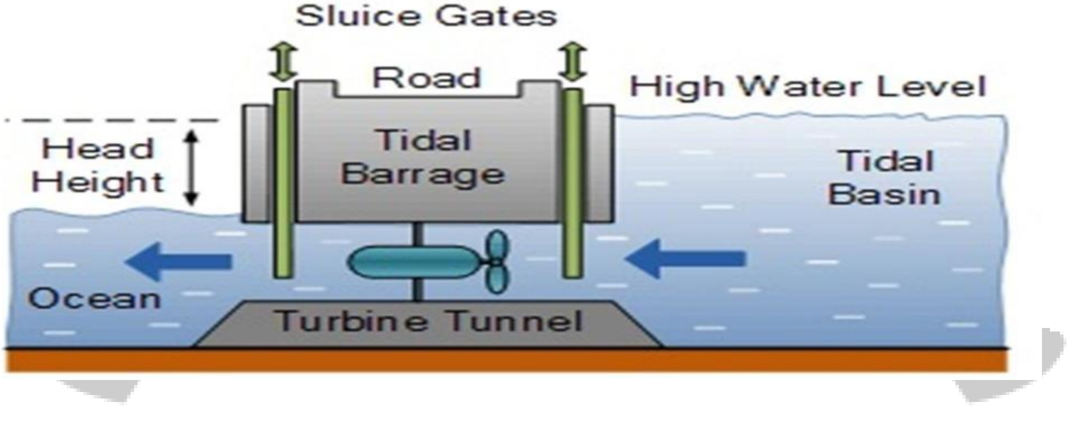


Figure: 1.4.4

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 130]

Geothermal energy:

Geothermal energy is heat derived within the sub-surface of the earth. Water and/or steam carry the geothermal energy to the Earth's surface. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes or be harnessed to generate clean electricity. However, for electricity, generation high or medium temperature resources are needed, which are usually located close to tectonically active regions.

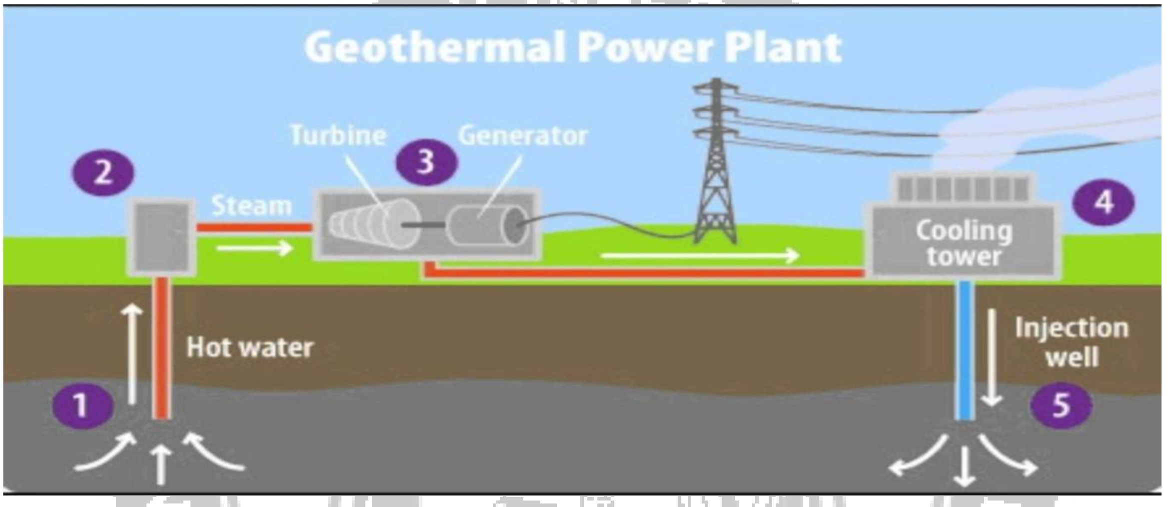


Figure: 1.4.5

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 225]

Biomass energy:

This is the conversion of solid fuel made from plant materials into electricity. Although fundamentally, biomass involves burning organic materials to produce electricity, this is not burning wood, and nowadays this is a much cleaner, more energy-efficient process. By converting agricultural, industrial and domestic waste into solid, liquid and gas fuel, biomass generates power at a much lower economic and environmental cost.

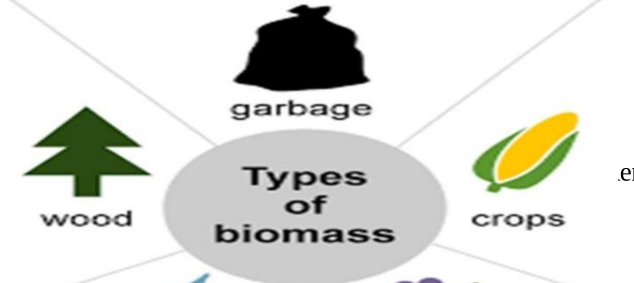


Figure: 1.4.6

[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari,K.C Singal, RakeshRanjan, Page: 225]

2.1 Power in the Wind:

Wind has kinetic energy due to its motion. This kinetic energy can be given by

$$KE = \frac{1}{2}\,\dot{m}u0^2$$

$$\dot{m} = \frac{dm}{dt}$$

Where,

$\dot{m}$ = mass of air passing through an area A per unit time

If $\mathbf{u_o}$ is the speed of free wind in unperturbed state,

the volume of air column passing through an area **A** per unit time is given by

$\mathbf{Au_o}$.

If **ρ** is the density of air,

the air mass flow rate, through area A, is given as, $\boldsymbol{\rho}\mathbf{Au_o}$

Power (Po) available in wind, is equal to kinetic energy rate associated with the mass of moving air, i.e.:

$$P0 = \frac{1}{2}(\rho Auo)uo^2$$

(Or)

$$P0 = \frac{1}{2}(\rho A)uo^3$$

Power available in wind per unit area:

$$\frac{P_0}{A} = \frac{1}{2}(\rho A)uo^3$$

This indicates that power available in wind is proportional to the cube of wind speed.

The air density **ρ** varies in direct proportion with air pressure and inverse proportion with temperature as:

$$\rho = \frac{P}{RT}$$

Where,

P is air pressure in Pa,

T is air temperature in kelvin and

R is the gas constant, (= 287 J/kg K).

At the standard value of air pressure, 1.0132 × 105 Pa (i.e. 1 atmosphere), and at 15 °C, the value of air density

$$\rho = \frac{1.0132 * 10^5}{287 * 288} = 1.226\frac{J}{Kg}\ K/m^3$$

Assuming the above value of wind density, **ρ** at 15 °C and at sea level, the power available in moderate wind of 10 m/s is 613 W/m2.

2.2 Types of Wind Power Plants (WPPs):

- The wind has its kinetic energy as it nothing but the flow of atmospheric air. A wind turbine is a machine which utilizes the kinetic energy of wind to produce rotational mechanical energy in its shaft.

- The rotational motion of the shaft turns an electrical generator to generate electricity. There are mainly two types of wind turbine available one is the horizontal axis type another is vertical axis type.
- The turbines are also available in different sizes depending upon their mode of applications. In many places of the modern world, people use small-sized wind turbines to charge batteries for auxiliary power supply to boats, caravans etc.
- Many electric utility companies use medium-sized wind turbines to supply a portion of the domestic load when sufficient wind is available so that they can sale back the surplus demanded power to the electrical grid.
- The stock of fossil fuels on that planet is becoming nil day by day, so there is a significant need for renewable sources of energy to produce electricity to meet up the on-growing demand for electricity.
- The wind power generating station is one of the solutions for that. The wind power generating stations, use many giant wind turbines to produce required electricity.
- The wind turbines can have either horizon shaft or vertical shaft depending on their design criteria. The horizontal design is more common as it produces more power compared to a vertical one.

Wind turbines are broadly classified into two categories.

- When the axis of rotation is parallel to the air stream (i.e. horizontal), the turbine is said to be a Horizontal Axis Wind Turbine (HAWT), and
- When it is perpendicular to the air stream (i.e. vertical), it is said to be a Vertical Axis Wind Turbine (VAWT).
- The size of the rotor and its speed depends on rating of the turbine.

2.3.1 Horizontal Axis Wind Turbine (HAWT):

- HAWTs have emerged as the most successful type of turbines. These are being used for commercial energy generation in many parts of the world. Their theoretical basis is well researched and sufficient field experience is available with them.

2.3.1.1. Main Components

❖ The constructional details of most common, three-blade rotor, horizontal axis wind turbine are shown in Fig. Main parts are as follows:

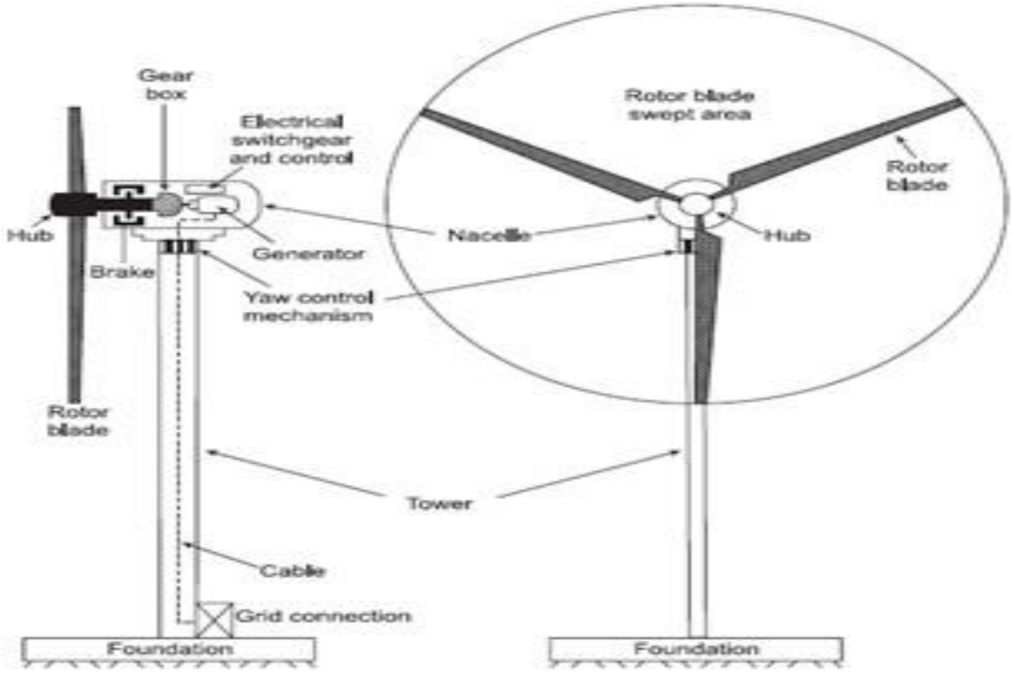


Figure: 2.2.1

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 175]

(a) Turbine Blades:

❖ Turbine blades are made of high-density wood or glass fiber and epoxy composites. They have airfoil type cross-section. The blades are slightly twisted from the outer tip to the root to reduce the tendency to stall.

❖ In addition to centrifugal force and fatigue due to continuous vibrations there are many extraneous forces arising from wind turbulence, gust, gravitational forces and directional changes in the wind, etc. All these factors are to be taken care off at the designing stage. Diameter of a typical, MW range, modern rotor may be of the order of 100 m.

❖ Modern wind turbines have two or three blades. Two/three blade rotor HAWT are also known as propeller type wind turbines owing to their similarity with propellers of old aero planes. However, the rotor rpm in case of wind turbine is very low as compared to that for propellers.

(b) Hub:

- The central solid portion of the rotor wheel is known as hub. All blades ate attached to the hub. Mechanism for pitch angle control is also provided inside the hub.

(c) Nacelle:

- The term nacelle is derived from the name for housing containing the engines of an aircraft. The rotor is attached to nacelle, mounted at the top of a tower.
- It contains rotor brakes, gearbox, generator and electrical switchgear and control.
- Brakes are used to stop the rotor when power generation is not desired. Gearbox steps up the shaft rpm to suit the generator. Protection and control functions are provided by switchgear and control block. The generated electrical power is conducted to ground terminals through a cable.

(d) Yaw Control Mechanism:

- The mechanism to adjust the nacelle around vertical axis to keep it facing the wind is provided at the base of nacelle.

(e) Tower:

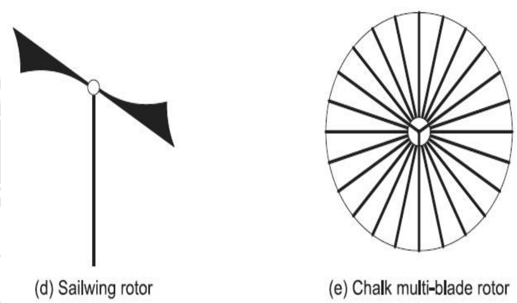
- Tower supports nacelle and rotor. For medium and large sized turbines, the tower is slightly taller than the rotor diameter. In case of small sized turbine, the tower is much larger than the rotor diameter as the air is erratic at lower heights.
- Both steel and concrete towers are being used. The construction can be either tubular or lattice type.

- The tower vibrations and resulting fatigue cycles under wind speed fluctuations are avoided by careful design. This requires avoidance of all resonance frequencies of tower, the rotor and the nacelle from the wind fluctuation frequencies.

2.3.1.2. Types of Rotors:

- Depending on the number of blades, wind speed and nature of applications, rotors have been developed in various types of shapes and sizes. These are shown in Fig.2.2.The types of rotors shown in (a) to (e) are relatively high-speed ones, suitable for applications such as electrical power generation. Large HAWTs have been manufactured with two and three blades. A single-blade rotor, with a balancing counterweight is economical, has simple controls but it is noisier and produces unbalanced forces. It is used for low-power applications.

❖ Those given in Fig. (f) and (g) are low-speed rotors and most suited for water lifting applications, which require high starting torque. They can capture power even from very slow winds.



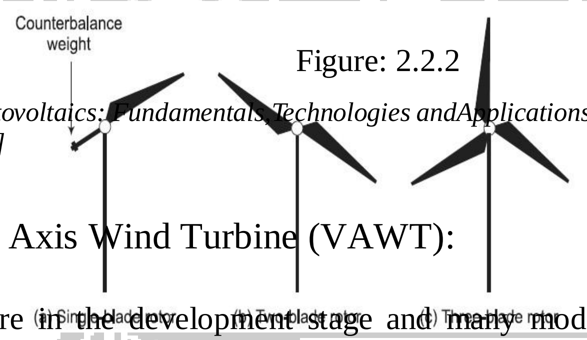


Figure: 2.2.2

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 177]

2.3.2. Vertical Axis Wind Turbine (VAWT):

▪ VAWTs are in the development stage and many models are undergoing field trial.

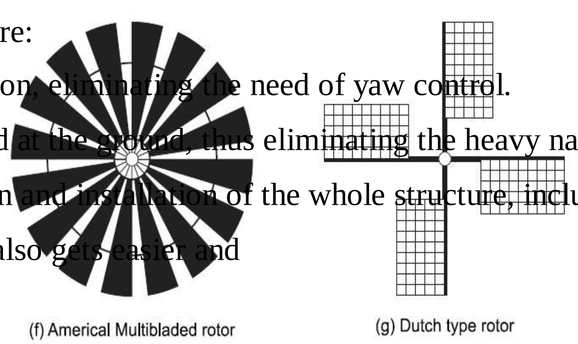
Main attractions of a VAWT are:

(i) It can accept wind from any direction, eliminating the need of yaw control.

(ii) Gearbox, generator etc. are located at the ground, thus eliminating the heavy nacelle at the top of the tower. This simplifies the design and installation of the whole structure, including tower

iii) The inspection and maintenance also gets easier and

(iv) It also reduces the overall cost.



2.3.2.1. Main Components:

- The constructional details of a vertical axis wind turbine (Darrieus type rotor) are shown in fig. The details of main components are as follows,

(a) Tower (or Rotor Shaft):

- The tower is a hollow vertical rotor shaft, which rotates freely about vertical axis between top and bottom bearings. It is installed above a support structure. In the absence of any load at the top, a very strong tower is not required, which greatly simplifies its design. The upper part of the tower is supported by guy ropes. The height of the tower of a large turbine is around 100 m.

(b) Blades:

- It has two or three thin, curved blades shaped like an eggbeater in profile, with blades curved in a form that minimizes the bending stress caused by centrifugal forces-the so-called _Troposkien‘profile.
- The blades have airfoil cross section with constant chord length. The pitch of the blades cannot be changed.

  The diameter of the rotor is slightly less than the tower height.
- The first large (3.8 MW), Darrieus type, Canadian machine has rotor height as 94 m and diameter as 65 m with a chord of 2.4 m.

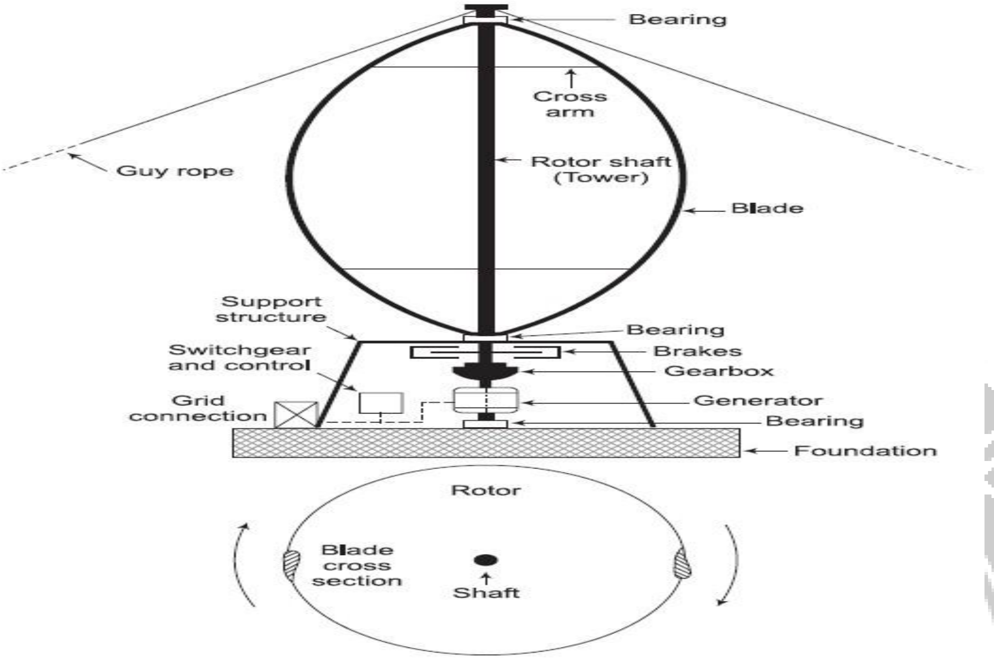


Figure: 2.2.3

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 178]

2.3.2.2. Types of Rotors:

Various types or rotors for VAWTs are shown in Fig.

- The simplest being three or four cups structure attached symmetrically to a vertical shaft.
- Drag force on concave surface of the cup facing the wind is more than that on convex surface.
- As a result, the structure starts rotating. Some lift force also helps rotation. However, it cannot carry a load and is, therefore, not used as power source.
- Main characteristic of this rotor is that its rotational frequency is linearly related to wind speed.
- Therefore, it is used as a transducer for measuring the wind speed and the apparatus is known as cup anemometer.

The Savonius or S-rotor:

- It consists of two half cylinders attached to a vertical axis and facing in opposite directions to form a two-vaned rotor. It has high starting torque, low speed and low efficiency.
- It can extract power even from very slow wind, making it working most of the time.

- These are used for low power applications. High starting torque particularly makes it suitable for pumping applications, using positive displacement pumps

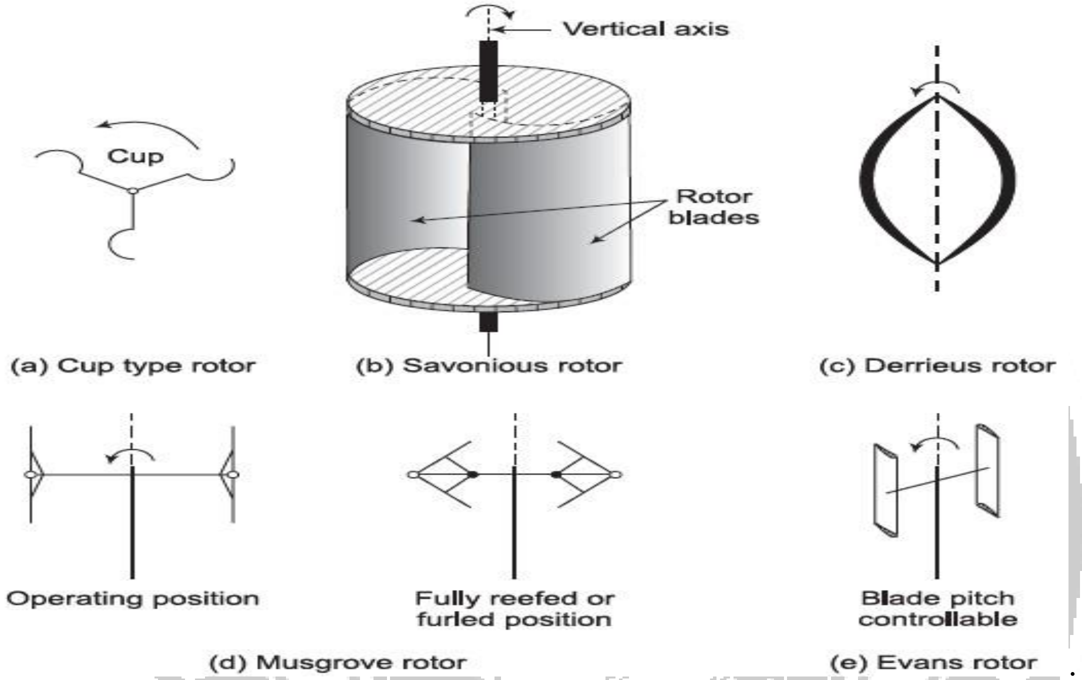


Figure: 2.2.4

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 179]

Darrieus rotor:

- ✓ It is used for large-scale power generation. Power coefficient is considerably better than S-rotor. It runs at a large tip-speed ratio.
- ✓ The aerodynamic force on the blade reverses in every revolution causing fatigue. This along with centrifugal force complicates the design of the blade.
- ✓ One of the drawbacks of this rotor is that it is usually not self-starting. Movement may be initiated by using electrical generator as motor.

- ✓ As the pitch of the blade cannot change, the rotor frequency and thus the output power cannot be controlled. Rotor frequency increases with wind speed and power output keeps on increasing till the blades stall.
- ✓ Hence at high wind speed it becomes difficult to control the output. For better performance and safety of the blades, gearbox and generator, etc., it is desirable to limit the output to a level much below its maximum possible value.

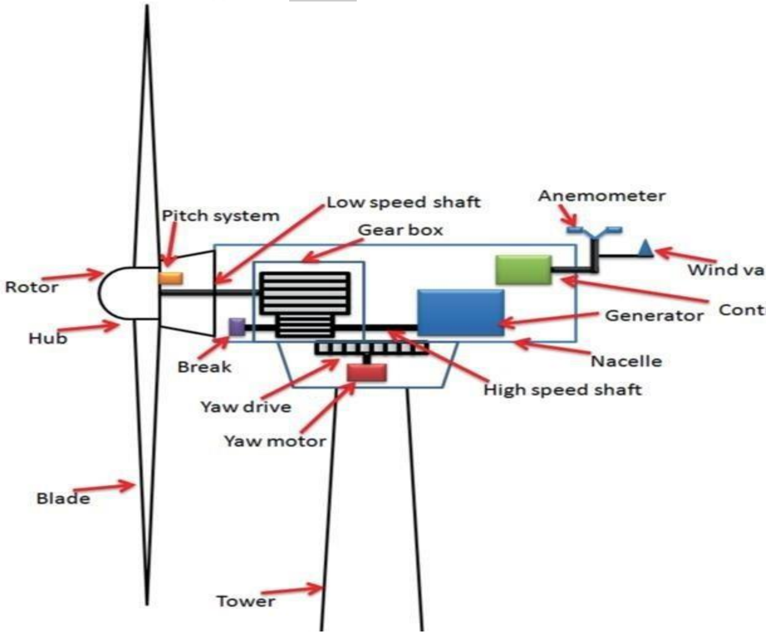
Musgrove suggested H shaped rotor :

- ✓ where blades with fixed pitch are attached vertically to a horizontal cross arm.
- ✓ Power control is achieved by controlled folding of blades. Inclining the blades to the vertical provides an effective means of altering the blades angle of attack and hence controlling the power output.
- ✓ Evans rotor, also known as Gyromill is an improvement over H shaped rotor.
- ✓ Here, the rotor geometry remains fixed (blades remain straight), but the blades are hinged on a vertical axis and the blade pitch is varied cyclically (as the blade rotates about vertical axis) to regulate the power output.
- ✓ But the need to vary the pitch cyclically through every rotor revolution introduces considerable mechanical complexity. However, this enables it to self-start.

2.3 Components of Wind Power Plants:

Wind energy systems include the following major components

- the rotor and its blades
- the hub assembly
- the main shaft
- the gear box system
- main frame
- transmission
- yaw mechanism
- over speed protection
- electric generator
- Nacelle



- yaw drive
- power conditioning equipment
- Tower

Figure: 2.3.1

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 152]

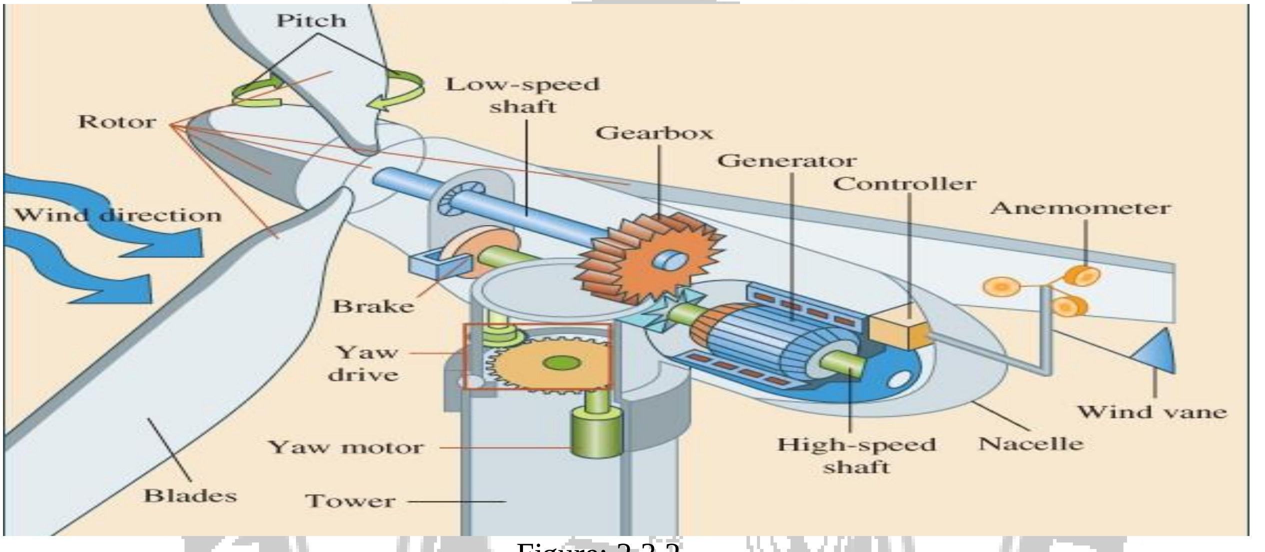


Figure: 2.3.2

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page:154]

- Early wind machines ranged in their rated powers from 50 to 100 kW, with rotor diameters from 15 to 20 meters. Commercial wind turbines now have ratings over 1 MW and machines for the land based and offshore applications have rated power outputs reaching 5 and even 7-10 MW of rated power for off-shore wind applications.
- Larger sizes are mandated by two reasons. They are cheaper and they deliver more energy. Their energy yield is improved partly because the rotor is located higher from the ground and so intercepts higher velocity winds, and partly because they are more efficient. The productivity of the 600 kW machines is around 50 percent higher than that of the 55 kW machines. Reliability has improved steadily with wind turbine manufacturers guaranteeing availabilities of 95 percent.
- Wind energy systems include the following major components: the rotor and its blades, the hub assembly, the main shaft, the gear box system, main frame, transmission, yaw mechanism, overspeed protection, electric generator, nacelle, yaw drive, power conditioning equipment, and tower

- The nacelle is the housing that protects the main frame and the components attached to it. This enclosure is particularly important for wind electric systems, but does not exist in water pumping machines.

HUB ASSEMBLY AND MAIN SHAFT

- The blades are attached by a hub assembly to a main shaft. The main shaft rotates in bearings supported in the main frame. If the blades are designed for pitch control, the hub can be fairly intricate. With fixed pitch, attachment is relatively simple.

- The main frame of the wind machine serves as the point of attachment for various components, such as the main shaft, transmission, generator, and nacelle. It usually contains a yaw bearing assembly.

TRANSMISSION MECHANISM:

A transmission assembly consisting of a gear box or chain drive is required to properly match the rotational speed to the desired speed of the electric generator, or air compressor because the rotational speed of the rotor does not match that of the pump or electric generator to which it is to be connected.

YAW MECHANISM:

- Horizontal axis machines must be oriented to face the wind by a process called yawing. Upwind machines with blades upwind of the tower incorporate instead a tail vane, small yaw rotors or fantails, or a servo mechanism to ensure that the machine always faces upwind.
- Downwind machines with blades downwind of the tower have the blades tilted slightly downwind or coned so that they simultaneously act as a tail; this angle ensures proper orientation.
- Vertical axis machines are affected by the wind from all directions and thus do not need yaw control.

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ELECTRIC GENERATOR:

- Variable speed machines are common and most generate power using an AC/DC/AC system. Variable speed brings several advantages. It means that the rotor turns more slowly in low wind, which keeps the noise level down. It reduces the loadings on the rotor and the power conversion system is usually able to deliver current at any specified power factor.
- Some manufacturers build direct drive machines, without a gearbox. These are usually of the variable speed type, with power conditioning equipment.

- The electric generator in a wind machine is attached to the main support frame and coupled to the high speed end of the transmission shaft. Alternating current generators often run at 1,800 rpm in the USA or 1,500 rpm in much of the world to maintain system frequencies of 60 Hz and 50 Hz, respectively. The most popular types are:
- For small independent wind systems, Direct Current (DC) generator alternators with built-in rectifier diodes are often used to change AC to DC.
- For larger independent systems, or those that are run in conjunction with a small diesel electric grid, synchronous generators are common. These machines produce Alternating Current (AC) and must be able to be regulated precisely, to ensure proper frequency control and matching.
- Wind machines connected to a utility grid may have induction generators. These induction machines produce AC current, but are electrically much simpler to connect to a grid than a synchronous generator. They normally require a utility connection to maintain the proper frequency and cannot operate independently without special equipment.

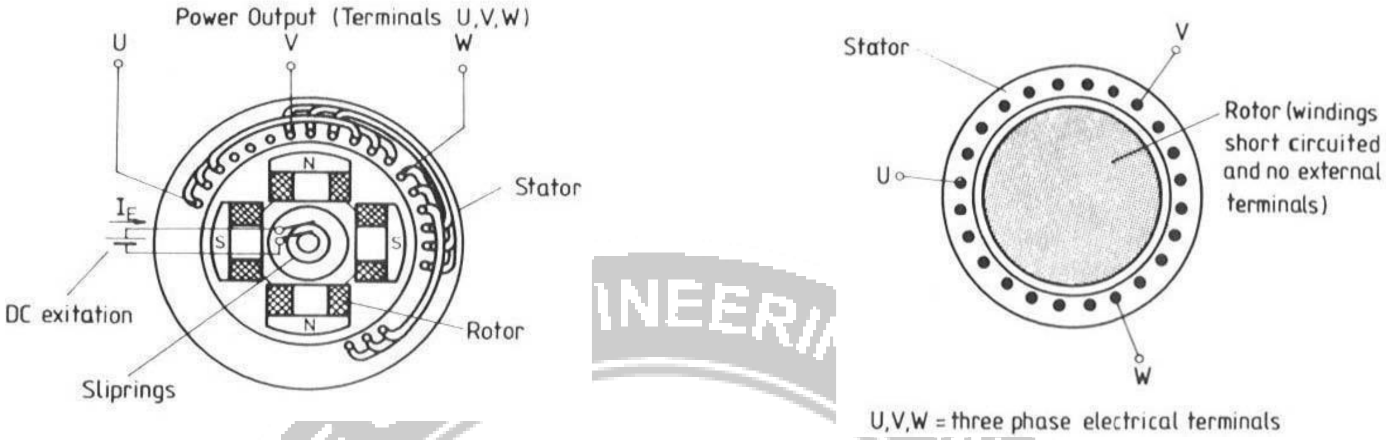

Figure 2.3.3 Wiring of three phase synchronous generator & Induction three-phase asynchronous generator

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 142]

ELECTRIC POWER CONDITIONING EQUIPMENT, INVERTER:

- The need for electrical equipment in addition to the generator will depend primarily on the type of generator. For small DC systems, at least a voltage regulator is needed. Battery storage is often used to provide energy in times of low winds.

- An inverter to convert DC to AC is used if some of the load requires alternating current.

- Because the mains grid operates on AC current, it is important that the current fed into the mains grid is properly synchronized. This is a key role of the inverter system.

- The inverter system is also designed to cut the power to the mains grid in the event that the mains grid connection is lost. This is a safety feature for the electrical utility workers.

- For grid connected systems, a control panel is needed that will typically include circuit breakers, voltage relays, and reverse power relays. Synchronous machines require special synchronizing equipment and frequency relays.

STRUCTURAL TOWER

- A structural tower is needed to get the wind machine up into the air, away from the slower and more turbulent winds near the ground. A wind machine should be at least 10 m higher than any obstructions in the surroundings such as trees.
- Small wind machines towers are typically of truss design or of poles supported by guy wires. Guy wires are cables attached to the tower and anchored in the ground so that the tower will not move or shake from the force of the wind.

- Large wind machines towers are usually made of steel and the great majority is of the tubular or conical type. Some towers have been built out of reinforced concrete sections. Lattice or truss towers, common in the early days are now rare, except for very small machines in the range 100 kW and below. Guyed pole towers are used for small wind machines.

- Towers must be designed to resist the full thrust produced by an operating windmill or a stationary wind machine in a storm. Special concern must be given to the possibility of destructive vibrations caused by a natural frequency mismatch between the wind machine and tower.

2.4 Working of Wind Power Plants:

- Wind is a form of kinetic energy created in part by the sun. About two percent of the sun's energy that reaches the earth is converted to wind energy.
- The atmosphere is heated during the day by the sun and at night it cools by losing its heat to space. Wind is the reaction of the atmosphere to the heating and cooling cycles, as well as the rotation of the earth.
- Heat causes low pressure areas, and the cool of the night results in high pressure areas. This process creates wind when air flows from high pressure areas into low pressure areas. Wind energy has been used for hundreds of years.
- The windmills of Europe and Asia converted the kinetic energy of the wind into mechanical energy, turning wheels to grind grain. Today wind-driven generators are used to convert the kinetic energy of wind into electrical energy.
- Wind-driven systems consist of a tower to support the wind generator, devices regulating generator voltage, propeller and hub system, tail vane, a storage system to store electricity for

use during windless days, and a converter which converts the stored direct current (DC) into alternating current (AC).

- Wind energy accounts for 6 percent of renewable electricity generation. The U.S. wind energy industry achieved unprecedented success in the first year of the new century, installing nearly 1700 megawatts or $1.7 billion worth of new generating capacity.
- Due to continuing research and better placement of turbines, wind power has become much more reliable. Virtually all regions of Canada have areas with good wind resources. Oceans and large lakes, open prairie, and certain hill or mountain areas often have good winds, and these areas are where Canada_s current wind generation facilities are located.
- There are commercial wind turbines in five provinces and the Yukon, with plans for further installations in almost all the rest of the provinces. Natural Resources Canada estimates that Canada has almost 30,000 megawatts of developable wind resource.
- This compares to the current installed base of 200 megawatts, and would be enough to supply 15 percent of Canada's electricity supply. The wind energy future looks bright and there is a growing interest in wind power within the North American electric industry.

- Wind power is a clean and renewable energy source, it produces no pollution and it doesn_t harm our earth. Also important is the fact that the price of wind power is not affected by fuel price increases or supply disruptions—it is a domestic, renewable energy source. The land used for wind turbines can still be used for other purposes such as grazing and farmland.

WORKING PRINCIPLE OF WIND TURBINE:

- There is an air turbine of large blades attached on the top of a supporting tower of sufficient height. When wind strikes on the turbine blades, the turbine rotates due to the design and alignment of rotor blades. The shaft of the turbine is coupled with an electrical generator. The output of the generator is collected through electric power cables.

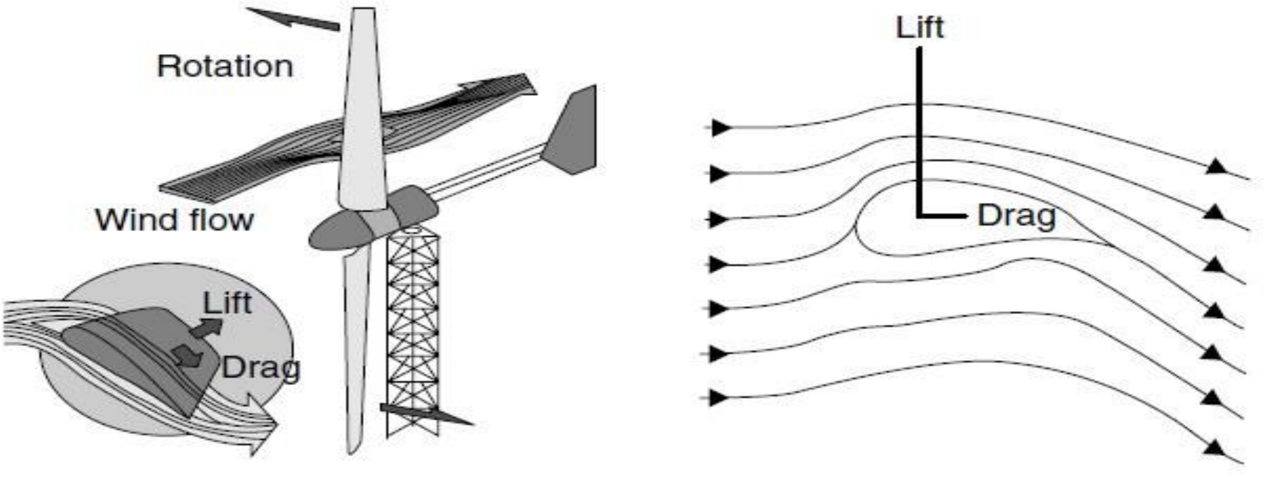

Figure 2.4.1. Principles of Wind turbine aerodynamics

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 072]

- When the wind strikes the rotor blades, blades start rotating. The turbine rotor is connected to a high-speed gearbox.
- Gearbox transforms the rotor rotation from low speed to high speed. The high- speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed.
- An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity. The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator.
- The speed is governed by wind power which is out of control. Hence to maintain uniformity of the output power from the alternator, excitation must be controlled according to the availability of natural wind power.
- The exciter current is controlled by a turbine controller which senses the wind speed. Then output voltage of electrical generator(alternator) is given to a rectifier where the alternator output gets rectified to DC.
- Then this rectified DC output is given to line converter unit to convert it into stabilized AC output which is ultimately fed to either electrical transmission network or transmission grid with the help of step up transformer

- An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc.), this is called Internal Supply Unit. There are other two control mechanisms attached to a modern big wind turbine.
  - (i) Controlling the orientation of the turbine blade.
  - (ii) Controlling the orientation of the turbine face.
- The orientation of turbine blades is governed from the base hub of the blades. The blades are attached to the central hub with the help of a rotating arrangement through gears and small electric motor or hydraulic rotary system.
- The system can be electrically or mechanically controlled depending on its design. The blades are swiveled depending upon the speed of the wind. The technique is called pitch control. It provides the best possible orientation of the turbine blades along the direction of the wind to obtain optimized wind power.
- The orientation of the nacelle or the entire body of the turbine can follow the direction of changing wind direction to maximize mechanical energy harvesting from the wind.
- The direction of the wind along with its speed is sensed by an anemometer (automatic speed measuring devices) with wind vanes attached to the back top of the nacelle.
- The signal is fed back to an electronic microprocessor-based controlling system which governs the yaw motor which rotates the entire nacelle with gearing arrangement to face the air turbine along the direction of the wind.

2.5 Siting of Wind Power Plants:

The power available in wind increases rapidly with wind speed. Therefore main consideration for locating a wind power generation plant is the availability of strong and persistent wind. A suitable site should preferably have some of the following features:

1. No tall obstructions for some distance (about 3 km) in the upwind direction (i.e. the direction of incoming wind) and also as low a roughness as possible in the same direction
2. A wide and open view, i.e. open plain, open shoreline or offshore locations
3. Top of smooth well-rounded hill with gentle slopes (about 1:3 or less) on a flat plain
4. An island in a lake or the sea

5. A narrow, mountain gap through which wind is channeled
6. The site should be reasonably close to power grid
7. The soil conditions must be such that building of foundations of the turbines and transport of road construction material loaded on heavy trucks must be feasible
8. If there are already wind turbines in the area, their production results are an excellent guide to local wind conditions.

2.5.1 WIND TURBINE SITE SELECTION:

- ➔ The selection of a wind farm site is complex and time consuming, and also it involves multiple disciplines working on parallel paths.
- ➔ It is imperative in all of the above-referenced steps that construction expertise be involved and consulted to achieve maximum use of the approved site.
- ➔ Wind is the energy resource that drives a wind turbine.
- ➔ A windmill needs to be placed on a high tower located in wind area. Not just any wind will do, a wind turbine needs air that moves uniformly in the same direction.
- ➔ The rotor cannot extract energy from turbulent wind, and the constantly changing wind direction due to turbulence causes excessive wear and premature failure of turbine.
- ➔ This means that turbine must be placed high enough to catch strong winds, and above turbulent air.
- ➔ Since the tower price goes up quickly with height, there is a limit to what is practical and affordable.

2.5.2 TURBINE HEIGHT:

In general, wind turbines should be sited well above trees, buildings, and other obstacles. When the wind flows over an obstacle like a building or a tree, the wind is slowed down and turbulent air is created, and if a wind turbine is located in this zone of turbulence, the result will be poor energy production and increased wear and tear on the turbine. One way to get above the zone of turbulence is to put the wind turbine on a tall tower.

Figure 2.18 (Installation of wind turbine) is an illustration of a simple rule of thumb that is often used to specify a minimum tower height for a residential-sized wind turbine. The rule of thumb is to make sure that the tower is tall enough so that the entire turbine rotor is at least 10 m above the tallest obstacle within 150 m of the tower. Because trees grow and towers do not, the growth of trees over the lifetime of the wind turbine (typically 20-30 years between major rebuilds) should be considered in installation.

This should really be regarded as an absolute minimum for a wind turbine; at 10 m above an obstacle, there will still be some amount of turbulence and additional clearance is highly desirable. Changes in height of obstacles should be kept in mind as well. For example, if the obstacle like trees that are expected to grow up to 20 m high, it is advisable to use a 33m tower.

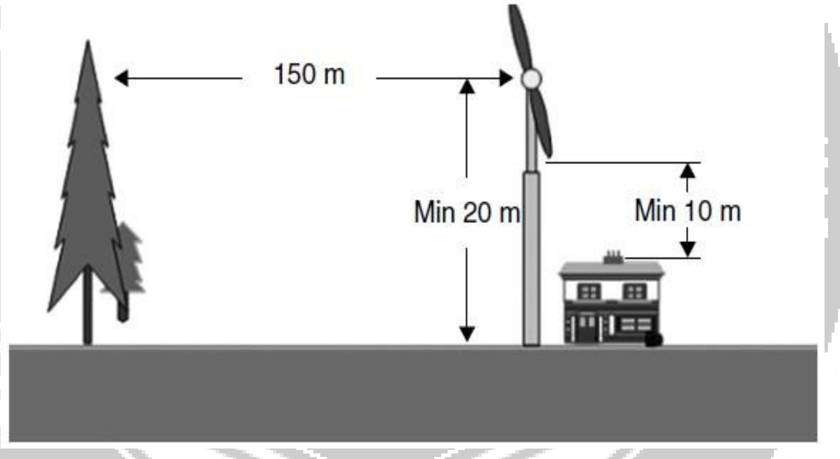

Figure: 2.5.1

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 122]

- ➔ Likewise, a 20-m tower should only be used when the terrain is very flat with no obstacles in a wide area around; for example, at the edge of the sea, or on top of a cliff with a clear area around it, or in the tundra
- ➔ For most situations, a 20-m tower will only save a little money up front, while short selling energy production in the long run
- ➔ To go beyond the rule of thumb, the airflow over any blunt obstruction, including a tree, tends to create a _bubble‘ of turbulent air of twice the height of the obstacle, extending 20 times the height of the obstacle behind it. Therefore, your 10-m high house disturbs the air up to 200 m away.

2.5.3 Considerations and Guidelines for Site Selection:

When looking for a place for a wind turbine, engineers consider factors such as wind hazards, characteristics of the land that affect wind speed, and the effects of one turbine on nearby turbines in wind farms.

The following important factors need careful considerations

Hill effect:

When it approaches a hill, wind encounters high pressure because of the wind that has already built up against the hill. This compressed air rises and gains speed as it approaches the crest, or top of the hill. The installation of wind turbines on hilltops takes advantage of this increase in speed

Roughness or the amount of friction that earth's surface exerts on wind:

Oceans have very little roughness. A city or a forest has a great deal of roughness, which slows the wind

Tunnel effect:

The increase in air pressure undergoes when it encounters a solid obstacle. The increased air pressure causes the wind to gain speed as it passes between, for example, rows of buildings in a city or between two mountains. Placing a wind turbine in a mountain pass can be a good way to take advantage of wind speeds that are higher than those of the surrounding air.

Turbulence:

Rapid changes in the speed and direction of the wind,often caused by the wind blowing over natural or artificial barriers are called turbulence. Turbulence causes not only fluctuations in the speed of the wind but also wear and tear on the turbine. Turbines are mounted on tall towers to avoid turbulence caused by ground obstacles.

Variations in wind speed:

During the day, winds usually blow faster than they do at the night because the sun heats the air, setting air currents in motion. In addition, wind speed can differ depending on the season of the year. This difference is a function of the sun, which heats different air masses around earth at different rates, depending on the tilt of the earth towards or away from the sun

Wake:

Energy can neither be created nor destroyed. As wind passes over the blades of a turbine, the turbine seizes much of the energy and converts it into mechanical energy. The air coming out of the blade sweep has less energy because it has been slowed. The abrupt change in the speed makes the wind turbulent, a phenomenon called wake. Because of wake, wind turbines in a wind farm are generally placed about three rotor diameters away from one another in the direction of the wind, so that the wake from one turbine does not interfere with the operation of the one behind it.

Wind obstacles:

Trees, buildings, and rock formations are the main obstacles in the installation of wind turbines. Any of these obstacles can reduce wind speed considerably and increase turbulence. Wind obstacles like tall buildings cause wind shade, which can considerably reduce the speed of the wind, and therefore, the power output of a turbine.

Wind shear:

It is the differences in wind speeds at different heights. When a turbine blade is pointed straight upward, the speed of the wind hitting its tip can be, for example, 9 miles (14 km) per hour, but when the blade is pointing straight downward, the speed of the wind hitting its tip can be 7 miles (11 km) per hour. This difference places stress on the blades. Further, too much wind shear can cause the turbine to fail. Choosing the right site for wind turbine is the most important decision. Further, the location plays a vital part in the performance and efficiency of a wind turbine.

2.6 Grid integration issues of Wind Power Plants:

To integrate large amounts of wind power into electricity grid, a number of issues need to be addressed, including design and operation of the power system, grid infrastructure issues, and grid connection of wind power,

A. Transient Stability and Power Quality Problems:

- Consider a grid-connected wind generator system. During a transient fault in the power network, the rotor speed of the wind generator goes very high, active power output goes very low, and terminal voltage goes very low or collapses.
- The wind speed might be considered constant during a transient fault. According to grid code requirements, the voltage level should not be less than 85% of the rated voltage. Usually the wind generator is shut down during these emergency situations.
- Recent tradition is not to shut down the wind generator during a network fault but to keep it connected to the grid through appropriate power electronics control. In other words, the wind

generators should have fault ride-through (FRT) capability. This clearly indicates that wind generator stabilization is necessary during network faults.

B. Variability of Wind Power:

- Wind energy does not suddenly trip the system off. Variations are smoother because there are hundreds or thousands of units rather than a few large power stations, making it easier for the system operator to predict and manage changes in supply.
- Especially in large, interconnected grids, there is little overall impact if the wind stops blowing in one particular place. Predictability is key in managing wind power‘s variability, and significant advances have been made to improve forecasting methods.
- Today, wind power prediction is quite accurate for aggregated wind farms. Using increasingly sophisticated weather forecasts, wind power generation models, and statistical analysis, it is possible to predict generation from 5-minute to hourly intervals over time scales up to 72 hours in advance and for seasonal and annual periods.

C. Power, Frequency, and Voltage Fluctuations Due to Random Wind Speed Variation:

- Due to random wind speed variation, wind generator output power, frequency, and terminal voltage fluctuate. In other words, power quality of the wind generator deteriorates. However, consumers need constant voltage and frequency. Thus, frequency, grid voltage, and transmission line power should be maintained constant.

D. Grid Connection Requirements:

The major requirements of typical grid codes for operation and grid connection of wind turbines are summarized as follows:

1. **Voltage operating range**: The wind turbines are required to operate within typical grid voltage variations.

2. **Frequency operating range**: The wind turbines are required to operate within typical grid frequency variations.

3. **Active power control**: Several grid codes require wind farms to provide active power control to ensure a stable frequency in the system and to prevent overloading of lines. Also, wind turbines are required to respond with a ramp rate in the desired range.

4. **Frequency control**: Several grid codes require wind farms to provide frequency regulation capability to help maintain the desired network frequency.

5. **Voltage control**: Grid codes require that individual wind turbines control their own terminal voltage to a constant value by means of an automatic voltage regulator.

6. **Reactive power control**: The wind farms are required to provide dynamic reactive power control capability to maintain the reactive power balance and the power factor in the desired range.

7. **Low-voltage ride-through (LVRT)**: In the event of voltage sag, the wind turbines are required to remain connected for a specific amount of time before being allowed to disconnect. In addition, some utilities require that the wind turbines help support grid voltage during faults.

8. **High-voltage ride-through (HVRT)**: In the event that the voltage goes above its upper limit value, the wind turbines should be capable of staying online for a given length of time.

9. **Power quality**: Wind farms are required to provide the electric power with a desired quality, such as maintaining constant voltage or voltage fluctuations in the desired range or maintaining voltage–current harmonics in the desired range.

10. **Wind farm modelling and verification**: Some grid codes require wind farm owners and developers to provide models and system data to enable the system operator to investigate by simulations the interaction between the wind farm and the power system. They also require installation of monitoring equipment to verify the actual behaviour of the wind farm during faults and to check the model.

11. **Communications and external control**: The wind farm operators are required to provide signals corresponding to a number of parameters important for the system operator to enable proper operation of the power system. Moreover, it must be possible to connect and disconnect the wind turbines remotely.

D.1 Islanding and Auto Reclosure:

- Critical situations can occur if a part of the utility network is islanded, and an integrated distributed generation (DG) unit is connected. This situation is commonly referred to as loss of mains (LOM) or loss of grid (LOG).
- When LOM occurs, neither the voltage nor the frequency is controlled by the utility supply. Normally, islanding is the consequence of a fault in the network. If an embedded generator continues its operation after the utility supply was disconnected, faults may not clear since the arc is still charged.
- Small embedded generators (or grid interfaces, respectively) are often not equipped with voltage control; therefore, the voltage magnitude of an islanded network is not kept between desired limits, and undefined voltage magnitudes may occur during island operation.
- Another result of missing control might be frequency instability. Since real systems are never balanced exactly, the frequency will change due to active power unbalance. Uncontrolled frequency represents a high risk for machines and drives.

- Since arc faults normally clear after a short interruption of the supply, automatic (instantaneous) reclosure is a common relay feature. With a continuously operating generator in the network, two problems may arise when the utility network is automatically reconnected after a short interruption:
- The fault may not have cleared since the arc was fed from the DG unit; therefore, instantaneous reclosure may not succeed.
- In the islanded part of the grid, the frequency may have changed due to active power unbalance. Reclosing the switch would couple two asynchronously operating systems.
- Extended dead time has to be regarded between the separation of the DG unit and the reconnection of the utility supply to make fault clearing possible. Common time settings of auto reclosure relays are between 100 and 1,000 ms.
- With DG in the network, the total time has to be prolonged. A recommendation is to maintain a reclosure interval of 1 sec or more for distribution feeders with embedded generators.
- The only solution to this problem seems to be to disconnect the DG unit as soon as LOM occurred. Thus, it is necessary to detect islands quickly and reliably.

D.2 Other Issues:

- There are some other problems concerning the integration of DG besides those already mentioned.

D.2.1 Ferroresonance

- Ferroresonance can occur and damage customer equipment or transformers. For cable lines, where faults are normally permanent, fast-blowing fuses are used as overcurrent protection.

- Since the fuses in the three phases do not trigger simultaneously, it may happen that a transformer is connected via only two phases for a short time.

- Then, the capacitance of the cable is in series with the transformer inductance that could cause distorted or high voltages and currents due to resonance conditions.

D.2.2 Grounding

- There are possible grounding problems due to multiple ground current paths. If a DG unit is connected via a grounded delta-wye transformer, earth faults on the utility line will cause ground currents in both directions—from the fault to the utility transformer as well as to the DG transformer.

- This is normally not considered in the distribution system ground fault coordination. The problem of loss of earth (LOE) for single-point grounded distribution systems is that whenever the utility earth connection is lost the whole system gets ungrounded.

3.2 Thermal Power Plant:

- Solar thermal power plant comprises power plants which first convert solar radiation into heat. The resulting thermal energy is subsequently transformed into mechanical energy by a thermal engine, and then converted into electricity.
- For thermodynamic reasons high temperatures are required to achieve the utmost efficiency. Such high temperatures are reached by increasing the energy flux density of the solar radiation incident on a collector.

According to the type of solar radiation concentration, solar thermal power plants are subdivided into:

- Concentrating (point and line focusing systems)
- Non-concentrating systems

The former Classification can be further made according to:

- type of receiver of the solar radiation
- the heat transfer media and the heat storage system
- additional firing based on fossil fuel energy

Concentrating systems concepts:

- ✓ Solar tower power plants (i.e. central receiver systems) as point focusing power plants
- ✓ Dish/Stirling systems as point focusing power plants
- ✓ Parabolic trough and Fresnel trough power plants as line focusing power plants
- ✓ Concentrating collectors can reach temperature levels similar to that of existing fossil-fuel fired thermal power stations (e.g. power plants fired with coal or natural gas)

Non-concentrating systems concepts:

- ✓ Solar updraft tower power plants
- ✓ solar pond power plants

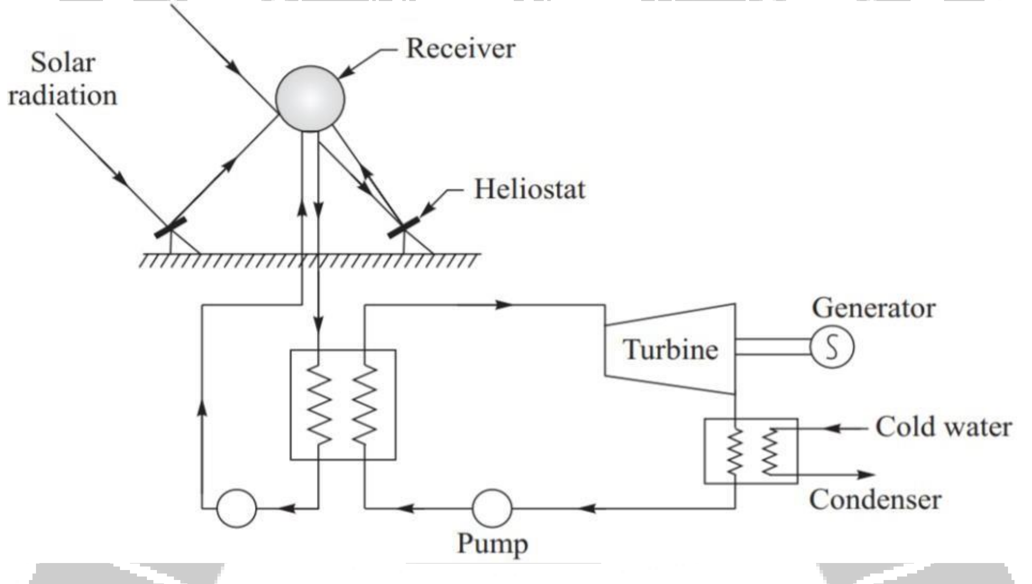

Figure: 3.2.1

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 202]

- Solar thermal power plants are electricity generation plants that utilize energy from the Sun to heat a fluid to a high temperature. This fluid then transfers its heat to water, which then becomes superheated steam. This steam isthen used to turn turbines in a power plant, and this mechanical energy is converted into electricity by a generator.

- This type of generation is essentially the same as electricity generation that uses fossil fuels, but instead heats steam using sunlight instead of combustion of fossil fuels. These systems use solar collectors to concentrate the Sun's rays on one point to achieve appropriately high temperatures.
- There are two types of systems to collect solar radiation and store it: passive systems and active systems. Solar thermal power plants are considered active systems. These plants are designed to operate using only solar energy, but most plants can use fossil fuel combustion to supplement output when needed.
- Some of the drawbacks include the large amount of land necessary for these Plants to operate efficiently
- As well, the water demand of these plants can also be seen as an issue, as the production of enough steam requires large volumes of water. A final potential impact of the use of large focusing mirrors is the harmful effect these plants have on birds.
- Birds that fly in the way of the focused rays of Sun can be incinerated. Some reports of bird deaths at power plants such as these amounts the deaths to about one bird every two minutes.

3.2.1 Facts about Solar Thermal Energy:

- Solar thermal energy has been used in various ways for millennia, ranging from simple fire starting with a pocket mirror to solar architecture to capture heat in buildings.
- 48% of the the sun's energy is in the infrared spectrum, invisible to the human eye, as heat.
- Solar thermal collectors can employ (absorb) nearly the entire solar spectrum
- The sun is the most abundant and reliable source of energy
- Financially, solar thermal energy conversion systems have reached grid- parity in many locations

➔ Currently, we (humans) use an abundance of fossil fuels for much of our heat needs.

- ➔ While in the long run our society will switch to the source of all of those fossil fuels (the sun), the reality is that most of you have probably not experienced the direct impact of a solar thermal energy conversion system on your life.
- ➔ The truth is that we can do everything that we currently do in our society with solar energy. Much of the burden can be carried by solar thermal solutions.
- ➔ One terrific modern day example of a solar thermal energy system is the Drake Landing Solar Community in Alberta, Canada, where 95% of the the community's heating needs are supplied by on-site solar thermal collection and a connected seasonal thermal energy storage system. Our society uses a lot of heat.
- ➔ We need to keep working to make solar thermal energy solutions make sense andwork well in more places whenever possible.

.2 Process of solar thermal power generation:

- Concentrating solar radiation by means of a collector system
- Increasing radiation flux density (i.e. concentrating of the solar radiationonto a receiver)
- Absorption of the solar radiation (i.e. conversion of the radiation energy intothermal energy (i.e. heat) inside the receiver)
- Transfer of thermal energy to an energy conversion unit
- Conversion of thermal energy into mechanical energy using a thermal engine(e.g. steam turbine)
- Conversion of mechanical energy into electrical energy using a generator

3.2 (a) SOLAR TOWER POWER STATION:

Main principles and components:

- Central receiver systems in the tower
- Mirrors tracking the course of the sun in two axes (Heliostats)
- Heliostats reflect the direct solar radiation onto a receiver, centrally positioned ona tower.

- In the receiver, radiation energy is converted into heat and transferred to a heat transfer medium (e.g. air, liquid salt, water/steam).
- This heat drives a conventional thermal engine.
- To ensure constant parameters and a constant flow of the working medium alsoat times of varying solar radiation, either a heat storage can be incorporated into the system or additional firing using e.g. fossil fuels (like natural gas) or renewable energy (like biofuels) can be used.

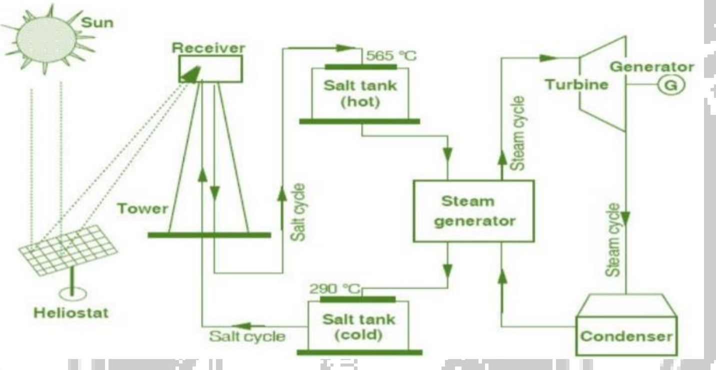

Figure 3.2.2

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 222]

Heliostats:

- Heliostats are reflecting surfaces provided with a two-axis tracking system which ensures that the incident sunlight is reflected towards a certain target point throughout the day.
- Heliostats commonly concentrate sunlight by means of a curved surface or an appropriate orientation of partial areas, so that radiation flux density is increased.

Heliostats consist of

- the reflector surface (e.g. mirrors, mirror facets, other sunlight-reflectingsurfaces)
- a sun-tracking system provided with drive motors
- foundations and control electronics. The individual heliostat"s orientation is commonly calculated on the basis of:

- the current position of the sun
- the spatial position of the heliostats
- the target point.

- The target value is communicated electronically to the respective drive motors viaa communication line.
- This information is updated every few seconds.
- The concentrator surface size of currently available heliostats varies between 20and 150 m^2 ; to date, the largest heliostat surface amounts to 200 m^2.

Faceted glass/metal heliostat
Figure: 3.2.3

metal membrane heliostat
Figure: 3.2.4

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 204]

- The heliostat field accounts for about half the cost of the solar components of such a power plant.
- This is why tremendous efforts have been made to develop heliostats of good optical quality, high reliability, long technical life and low specific costs.
- Due to economic considerations there is a tendency to manufacture heliostats withsurfaces ranging between 100 m^2 and 200 m^2 and possibly beyond.
- However, there are also approaches to manufacture smaller heliostats to reduce costs by efficient mass-production.

Controller:

- Heliostats are usually centrally controlled and centrally supplied withelectrical energy.

- As an alternative, autonomous heliostats have been developed which are controlled locally.
- There, the energy required for the control processor and the drives isprovided by photovoltaic cells mounted parallel to the reflector surface.

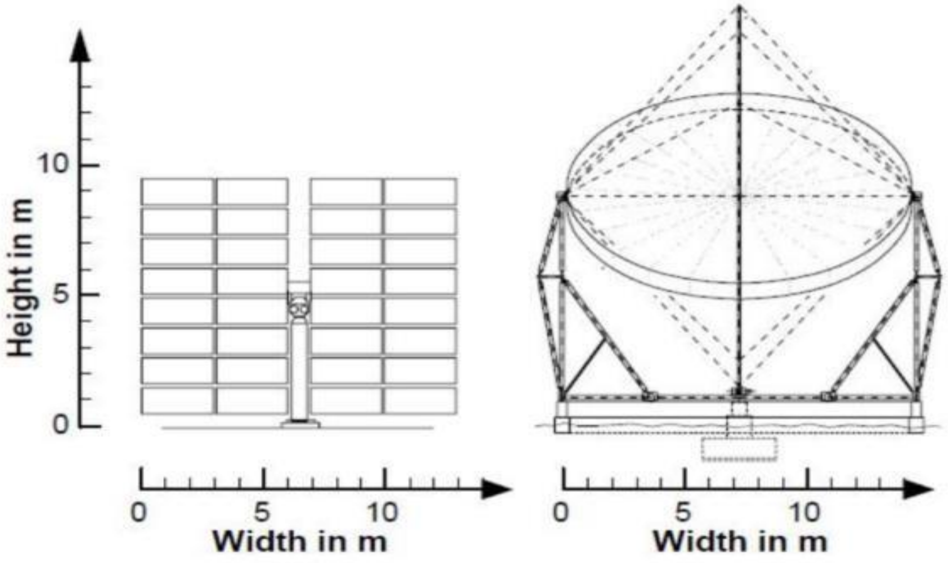

Figure 3.2.5

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 205]

Heliostat fields:

The layout of a heliostat field is determined by technical and economic optimization:

- Heliostats located closest to the tower present the lowest shading,
- Heliostats placed north on the northern hemisphere (or south on the southern hemisphere) show the lowest cosine losses.
- Heliostats placed far off the tower, by contrast, require highly precise tracking and, depending on the geographic location, have to be placed farer from the neighboring heliostats.
- The cost of the land, the tracking and the orientation precision thus determine the

economic size of the field.

- **Cosine losses**: representing the difference between the amount of energy falling on a surface pointing at the sun, and a surface parallel to the surface of the earth.

Tower:

- The height of the tower, on which the receiver is mounted, is also determined by technical and economic optimization.
- Higher towers are generally more favorable, since bigger and denser heliostat fields presenting lower shading losses may be applied.
- However, this advantage is counteracted by the high requirements in termsof tracking precision placed on the individual heliostats, tower and piping costs as well as pumping and heat losses.
- Common towers have a height of 80 to 100 m.Lattice as well as concrete towers are applied.

CEIVER:

Receivers of solar tower power stations serve to transform the radiation energy,diverted and concentrated by the heliostat field, into technical useful energy.

Nowadays, common radiation flux densities vary between 600 and 1,000kW/m^2.

Receivers classification according to:

- the applied heat transfer medium (e.g. air, molten salt, water/steam, liquidmetal)
- the receiver geometry (e.g. even, cavity, cylindrical or cone-shaped receivers)

According to heat transfer medium:

Water/steam receiver

- Salt receiver
- Open volumetric air receiver Closed
- (pressurized) air receivers

Water/steam receiver:

- first solar tower power stations
- Similar to conventional steam processes, water is vaporized and partly superheated in such a heat exchanger (i.e. tube receiver).
- Since superheating is prone to unfavorable heat transmission, and due to thefact that start-up operation or part-load operation require complicated controls, this approach is currently not developed further.

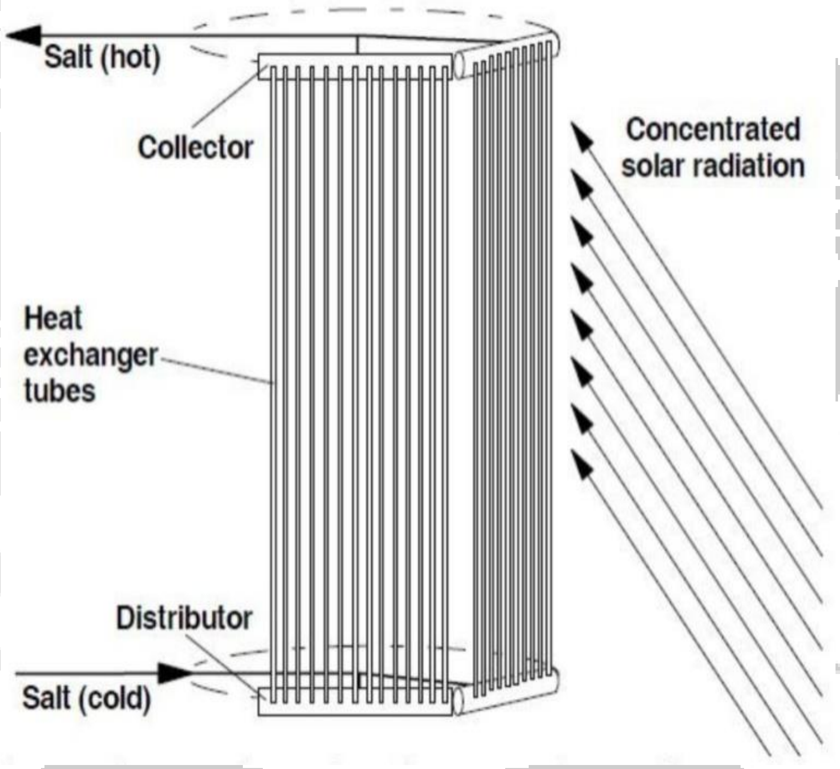

Figure 3.2.6

[Source: "Solar Photovoltaics: Fundamentals,Technologies andApplications" by ChetanSingh Solanki, Page: 209]

Salt receiver:

- The difficulties of heat transmission with a vertical tube receiver, exemplarily shown in the previous figure, can partly be avoided by an additional heat transfer medium circuit.
- The heat transfer medium applied for this secondary circuit should have a high heat capacity and good thermal conduction properties.
- Molten salt consisting of sodium or potassium nitrate ($NaNO_3$, KNO_3) complies with these requirements.
- One disadvantage of all such salt receiver:
  - the salt must be kept liquid also during idle times when there is no solarradiation. This requires to either heat the whole part of the installation that is filled with salt (including, among other components, tanks,tubes, valves) and thus increases the energy consumption of the plant itself, or to completely flush the salt circuit.
  - The highly corrosive gas phase of the used salts also has a detrimental effect, since, for certain operations, undesired evaporation of small amounts of salt due to local overheating cannot be entirely ruled out.

Open volumetric air receiver:

  - Such volumetric receivers are characterized by a high ratio of absorbing surface to flow path of the absorbing heat transfer medium air.
- **Principle**: Ambient air is sucked in by a blower and penetrates the radiated absorber material. The air flow absorbs the heat, so that those absorber areas facing the heliostat are cooled by the inflowing air.

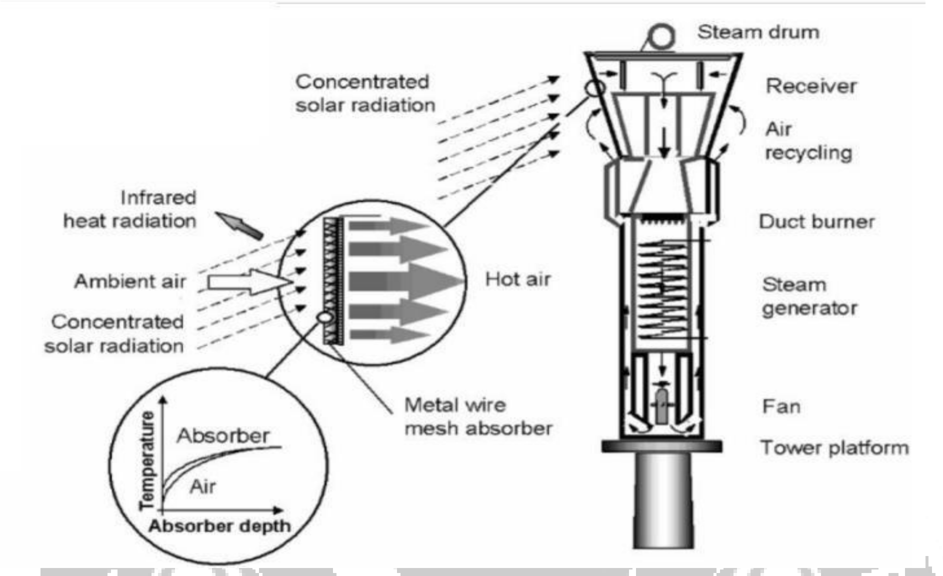

Figure 3.15

Closed (pressurized) air receivers:

- Receivers of solar tower power plants may also be designed as closedpressurized receivers.
- The aperture of such receivers is closed by a fused quartz window, so that the working medium air may be heated under overpressure and may, for instance, be directly transferred to the combustor of a gas turbine.
- E.g: a group of closed air receivers of a heat capacity of up to 1,000 kW has been tested at 15 bar.
- The obtained air outlet temperatures are slightly above 1,000 °C For
- commercial applications several module groups may be added.

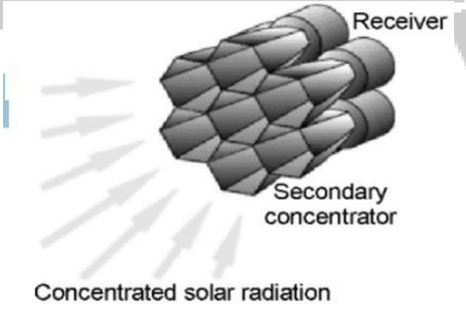

Figure 3.16

3.4 Thermal Energy storage system with PCM:

3.4.1 Latent Heat Storage (Storage in Phase Change MaterialsPCM)

In this class of storage, energy is stored by virtue of latent heat of change of phase of the storage medium. Phase change materials have considerably higher thermal energy storage densities as compared to sensible heat storage materials and are able to absorb or release large quantities of energy at a constant temperature. Therefore, these systems are more compact but more expensive than sensible heat storage systems.

Various phase changes that can occur are:

- solid-solid (lattice change)
- solid-gas
- solid-liquid
- liquid-gas

Solid-gas and liquid-gas transformations are not employed in spite of large latent heats as large changes in volume make the system complex and impracticable. In solid-solid transition, heat is stored as the material is transformed from one crystalline form to another. These transitions involve small volume changes;however, most of them have small latent heats.

For phase-change storage media, salt hydrates called Glauber‟s salt ($Na_2SO_4.10H_2O$) are preferred. The solid-liquid transformations include storage in salt hydrates. Certain inorganic salts, which are soluble in water and form crystalline salt hydrates, are employed. Let an inorganic salt, which is soluble in water represented by X(Y) n. The crystalline salt hydrate is symbolized by X(Y) n. mH2O. On heating up to transition temperature, the hydrate crystals releasewater of crystallization and the solid remainder (anhydrous salt) dissolves in the released water as following reaction takes place:

$$X(Y)_{n}.\, m\mathrm{H_2O} + \Delta \mathrm{H} \leftrightarrow X(Y)_{n} + m\mathrm{H_2O}$$

(Solid) (Liquid: aqueous solution of anhydrous salt)

One problem with most salt hydrates is that the released water of crystallization is not sufficient to dissolve all the solid phase present. Due to density difference, the anhydrous salt settles down at the bottom of the container. This incongruent melting makes the process irreversible since the anhydrous salt at the bottom is unable to find water for recrystallization to the original hydrate. The recrystallization of an incongruently melting salt can be achieved either by (i) the use of suspension media or thickening agent or by (ii) mechanical means (vibration, stirring, etc.)

Other potential phase change materials apart from salt hydrates are paraffin‟s (e.g. C18 H38, etc., alkanes containing 14 to 40 C-atoms) and non-paraffin organic materials (e.g. esters, fatty acids, alcohols and glycols), which are suitable at certain situations.

3.4.2 Heat transfer properties of phase change storage materials:

S.N.	Material	Chemical compound	Melting point (°C)	Heat of fusion (kJ/kg)	Density kg/m^3
1.	Sodium sulphate decahydrate (Glauber's salt)	Na_2SO_4. $10H_2O$	31–32	251	1534
2.	Sodium thiosulphate	$Na_2S_2O_3$. $5H_2O$	48–49	209	1666
3.	Calcium chloride hexahydrate	$CaCl_2$. $6H_2O$	29–39	177	1634
4.	Sodium carbonate dehydrate	Na_2CO_3. $10H_2O$	32–36	247	1442
5.	Disodium phosphate decahydrate	Na_2HPO_4. $12H_2O$	36	265	1522