1.5 CONVENTIONAL SOURCES OF ELECTRIC ENERGY

Thermal (coal, oil, nuclear) and hydro generations are the main conventional sources of electric energy. The necessity to conserve fossil fuels has forced scientists and technologists across the world to search for nonconventional sources of electric energy. Some of the sources being explored are solar, wind and tidal sources. The conventional and some of the nonconventional sources and techniques of energy generation are briefly surveyed here with a stress on future trends, particularly with reference to the Indian electric energy scenario. A panoramic view of energy conversion to electrical form is presented in Fig. 1.5.

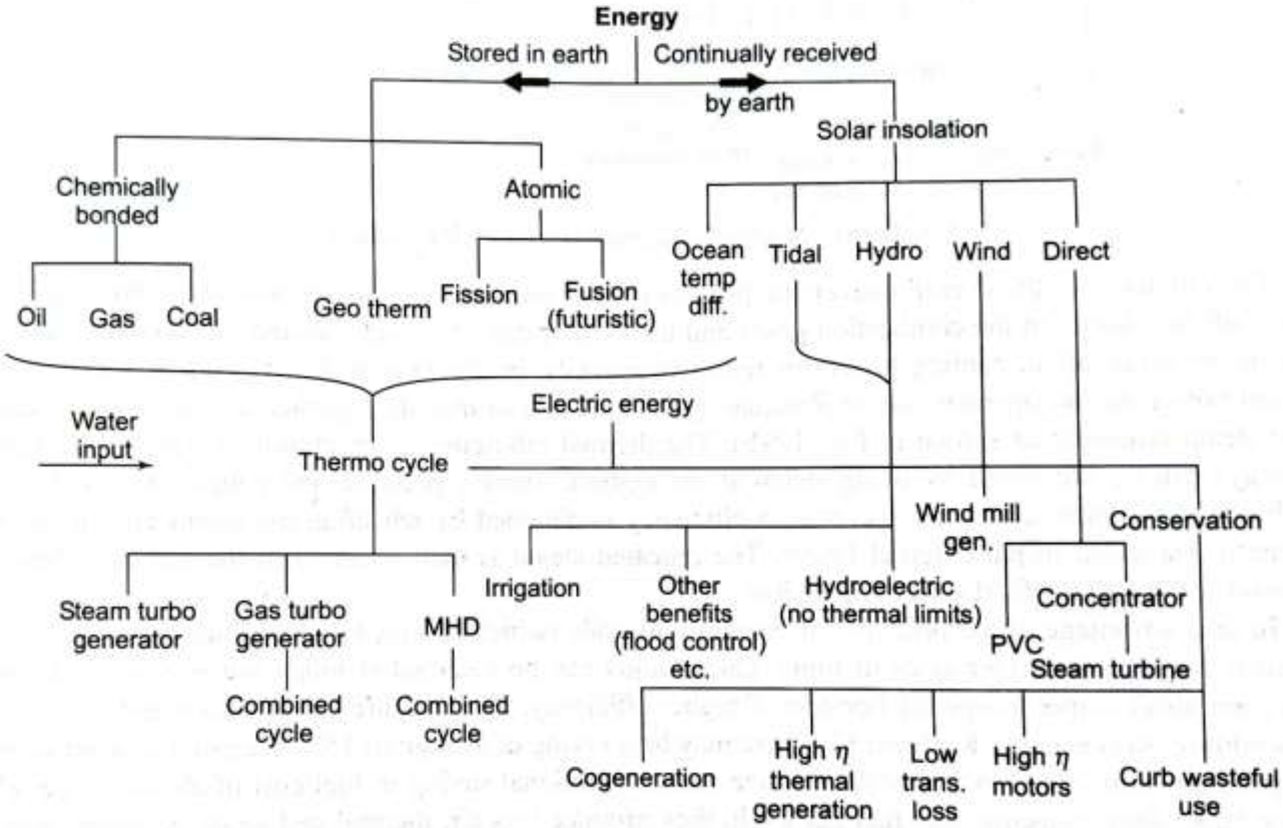


Fig. 1.5

1.5.3 Hydro Power

The oldest and cheapest method of power generation is that of utilising the potential energy of water. The energy is obtained almost free of running cost and is completely pollution free. Of course, it involves high capital cost because of the heavy civil engineering construction works involved. Also, it requires a long gestation period of about five to eight years as compared to four to six years for steam plants. Hydroelectric stations are designed, mostly, as multipurpose projects such as river flood control, storage of drinking water, irrigation and navigation. A simple block diagram of high head hydro plant is given in Fig. 1.12. The vertical difference between the upper reservoir and the tail race pond is called the *head*.

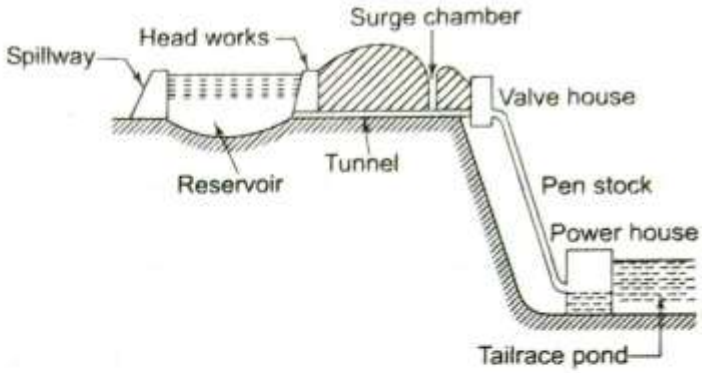


Fig. 1.12 *A typical layout for a storage type hydro plant*

Water falling through the head gains kinetic energy which then imparts energy to the blades of the hydraulic turbine. There are three main types of hydroelectric installations:

1. *High head or stored*—the storage area of reservoir fills in more than 400 hectares.
2. *Medium head or pondage*—the storage fills in 200–400 hectares.
3. *Run of river*—storage (in any) fills in less than 2 h and has a 3–15 m head.

A schematic diagram for hydroelectric schemes of Type 3 is shown in Fig. 1.13.

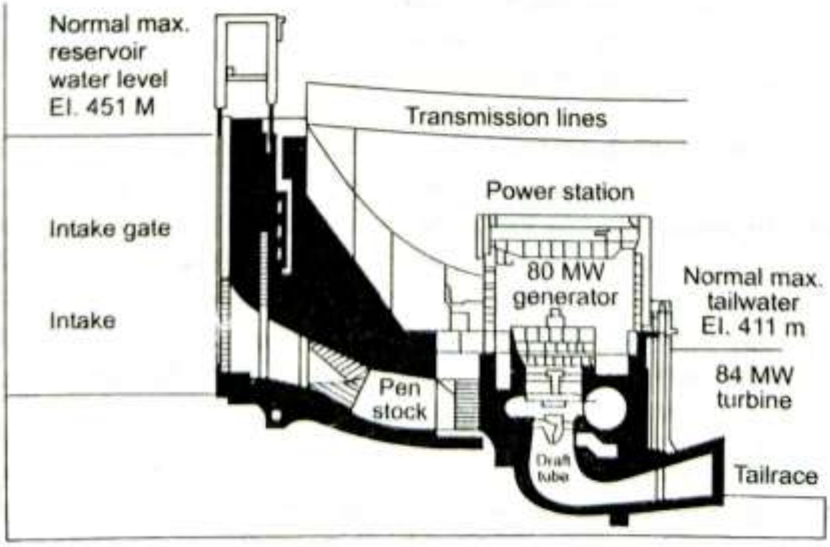


Fig. 1.13 *Run of river hydroelectric scheme—80 MW Kaplan turbine, 115.41 rpm*

There can be several of these turbines on a deep and wide river.

In India, mini and micro hydroelectric schemes have been installed on canals wherever 1 m or so head is available. Often cascaded plants are also constructed on the same water stream where the discharge of one plant becomes the inflow of a downstream plant.

For the three above identified heads of water level, the kind of turbines that are employed are as follows:

1. *Pelton*: This is used for heads of 184–1840 m and consists of a bucket wheel rotor with adjustable flow nozzles.
2. *Francis*: This is used for heads of 37–490 m and is of mixed flow type.
3. *Kaplan*: This is used for run-of-river and pondage stations with heads of up to 61 m. This type has an axial-flow rotor with variable-pitch blades.

Hydroelectric plants are capable of starting quickly—almost in 5 min. The rate of taking up load on the machines is of the order of 20 MW/min. Further, no losses are incurred at standstill. Thus, hydroelectric plants are ideal for meeting peak loads. The time from start up to the actual connection to the grid can be as short as 2 min.

The power available from a hydro plant is

$$P = g\,\rho\, WH \text{ W} \tag{1.4}$$

where W = discharge (m^3/s) through the turbine, ρ = density (1000 kg/m^3) and H = head (m), $g = 9.81\ m/s^2$

$$\therefore \quad P = 9.81\, WH \text{ kW} \tag{1.5}$$

Problems peculiar to hydroelectric plants which inhibit expansion are:

1. Silting—Bhakra dead storage has reportedly silted fully in 30 years.
2. Seepage.
3. Ecological damage to region.
4. Displacement of human habitation from areas behind the dam which will fill up and become a lake.
5. These cannot provide base load and must be used for peak shaving and energy saving in coordination with thermal plants.

Typical efficiency curves of the three types of turbines are depicted in Fig. 1.14. As the efficiency depends upon the head, which is continuously fluctuating, water consumption in m^3/kWh is used instead of efficiency, which is related to water head.

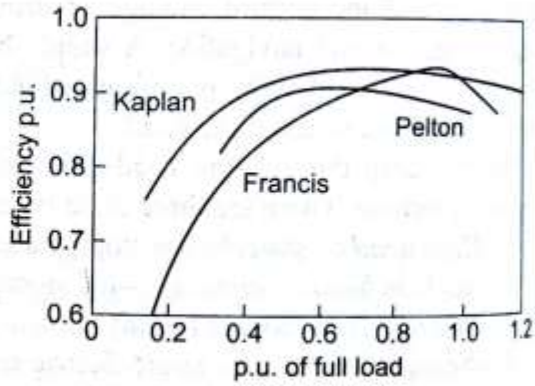


Fig. 1.14 *Typical efficiency curves of hydraulic turbines*

In certain periods when the water availability is low or when hydro-generation is not needed, it may be advantageous to run electric generators as motors from the grid, so as to act as synchronous condensers (these are overexcited). To reduce running losses, the water is pushed below the turbine runner by compressed air after closing the input valve. The runner now rotates in air and free running losses are low.

India also has a tremendous potential (5000 MW) of having large number of nano, pico, micro (< 1 MW), mini (< 1–5 MW) and small (< 15 MW) *hydel plants* in Himalayan region, North-East, HP, UP, UK and JK which must be fully exploited to generate cheap and clean power for villages situated far away from the grid power*. At present, 394 MW capacity is under implementation.

Pumped Storage Scheme In areas where sufficient hydrogeneration is not available, peak load may be handled by means of pumped storage. This consists of upper and lower reservoirs and reversible turbine-

* Existing capacity (small hydro) is 36877 MW as on 2010. Total ...

generator sets, which can also be used as motor-pump sets. The upper reservoir has enough storage for about 6 h of full load generation. Such a plant acts as a conventional hydroelectric plant during the peak load periods, when production costs are the highest. The turbines are driven by water from the upper reservoir in the usual manner. During the light load period, water in the lower reservoir is pumped back into the upper one so as to be ready for use in the next cycle of the peak load period. The generators in this period, change to synchronous motor action and drive the turbines which now work as pumps. The electric power is supplied to the generator sets from the general power network or an adjoining thermal plant. The overall efficiency of the generator sets is normally as high as 60–70%. The pumped storage scheme, in fact, is analogous to the charging and discharging of a battery. It has the added advantage that the synchronous machines can be used as synchronous condensers for VAR compensation of the power network, if required. In a way from the point of view of the thermal sector of the power system, the pumped storage scheme *shaves the peaks* and fills the *troughs* of the daily load-demand curve.

Some of the existing pumped storage plants are 900 MW Srisailem in AP, 80 MW of Bhiva in MS, 400 MW Kadamparai in TN.

Tidal Power Along the shores with high tides and when a basin exists, the power in the tide can be hydroelectrically utilised. This requires a long and low dam across the basin. Two sets of turbines are located underneath the dam. As the tide comes in, water flows into the basin operating one set of turbines. At low tide, the water flows out of the basin operating another set of turbine.

Let tidal range from high to low be h (m) and area of water stored in the basin be A (m^2), then the energy stored in the full basin is expressed as

$$E = \rho g A \int_0^h x\,dx \tag{1.6}$$

$$= \frac{1}{2}\rho g h^2 A$$

Average power, $P = \frac{1}{2}\rho g h^2 A/(T/2)$; T = period of tidal cycle

= 14 h 44 min, normally

$$= \rho g h^2 A/T$$

A few places which have been surveyed in the world as sites for tidal power are as follows:

Passanaquoddy Bay (N. America)	5.5 m, 262 km^2, 1,800 MW
San Jose (S. America)	10.7 m, 777 km^2, 19,900 MW
Sever (UK)	9.8 m, 70 km^2, 8,000 MW

A tidal power station has been constructed on the La Rance estuary in northern France where the tidal height range is 9.2 m and the tidal flow is estimated to be 18,000 m^3/sec.

Major sites in India where preliminary investigations have been carried out are Bhavnagar, Navalakhi (Kutch), Diamond Harbour and Ganga Sagar.

India's first Tidal Power Project is being developed by WBREDA at Durgaduani Creek in the Sunderbans delta. High tide water is stored in a reservoir and released at low tide, thus creating water flows which drive turbines that generate electricity. The total cost for 50 MW project in Gujarat is Rs 750 crores and will be ready by 2013.

The basin in Kandla in Gujarat has been estimated to have a capacity of 600 MW. The total potential of Indian coast is around 9000 MW. India has a vast coastline of 7517 kms, which does not compare favourably with the sites in the American continent stated above. The technical and economic difficulties still prevail.

metallurgy. The capital cost of these plants is 40 to 60% less than that of fossil fuel and nuclear plants, because no boiler or nuclear reactor is needed to generate steam.

Geothermal plants have proved useful for base-load power plants. These kind of plants are primarily entering the market where modest sized plants are needed with low capital cost, short construction period and life-long fuel (i.e., geothermal heat).

High air-quality standards are easily attained by geothermal plants at a minimal cost such that they have an edge over clean coal-fuelled plants. Considerable research and development effort is being devoted towards geothermal plants siting, designing, fabricating, installation and operation. Efforts are also on to tap the heat potential of volcanic regions and from hot volcanic rock.

No worth mentioning effort is being made in India at present. In India, feasibility studies of a 1 MW station at Peggy valley in Ladakh are being carried out. Another geothermal field has been located at Chumantang. There are a number of hot springs in India, but the total exploitable energy potential seems to be very little.

The present installed geothermal plant capacity in the world is about 10715 MW and the total estimated capacity is immense, provided volcanic 'regions' heat can be utilised. Since the pressure and temperatures are low, the efficiency is even less than that of the conventional fossil-fuelled plants, but the capital costs are less and the fuel is available free of cost.

1.8 ENVIRONMENTAL ASPECTS OF ELECTRIC ENERGY GENERATION

As far as environmental and health risks involved in nuclear plants of various kinds are concerned, these have already been discussed at length in Sec. 1.7. Equally, the problems related to large hydroelectric plants have been dwelled upon in Sec. 1.5. Therefore, we shall now focus our attention on fossil-fuel plants including gas-based plants.

Conversion of one form of energy or another to electrical form has unwanted side effects and the pollutants generated in the process have to be disposed off. The reader may refer to Fig. 1.16, which brings out all the associated problems at a glance. Pollutants know no geographical boundary; as a result of which the pollution issue has become a nightmarish problem and strong national and international pressure groups have sprung up and are having a definite impact on the development of energy resources. Governmental awareness has created increasing legislation at national and international levels. The power engineers have to be fully conversant with these in their professional practice and in the survey and planning of large power projects. Lengthy, time consuming procedures at government level, PIL (public interest litigation) and demonstrative protests have delayed several projects in several countries. This has led to favouring of small size projects and redevelopment of existing sites. But with the yawning gap in electric demand and production, our country has to move forward for several large thermal, hydro and nuclear power projects.

Emphasis is being laid on conservation issues, curtailment of transmission losses, theft, subsidised power supplies and above all on *sustainable development* with *appropriate technology* wherever feasible. It has to be particularly assured that no irreversible damage is caused to the environment which would affect the living conditions of the future generations. Irreversible damages like ozone layer holes and global warming caused by increase in CO_2 in the atmosphere are already showing up.

1.8.1 Atmospheric Pollution

We shall treat here only pollution as caused by thermal plants using coal as feed-stock. The fossil fuel-based generating plants form the backbone of power generation in our country and also round the globe as other

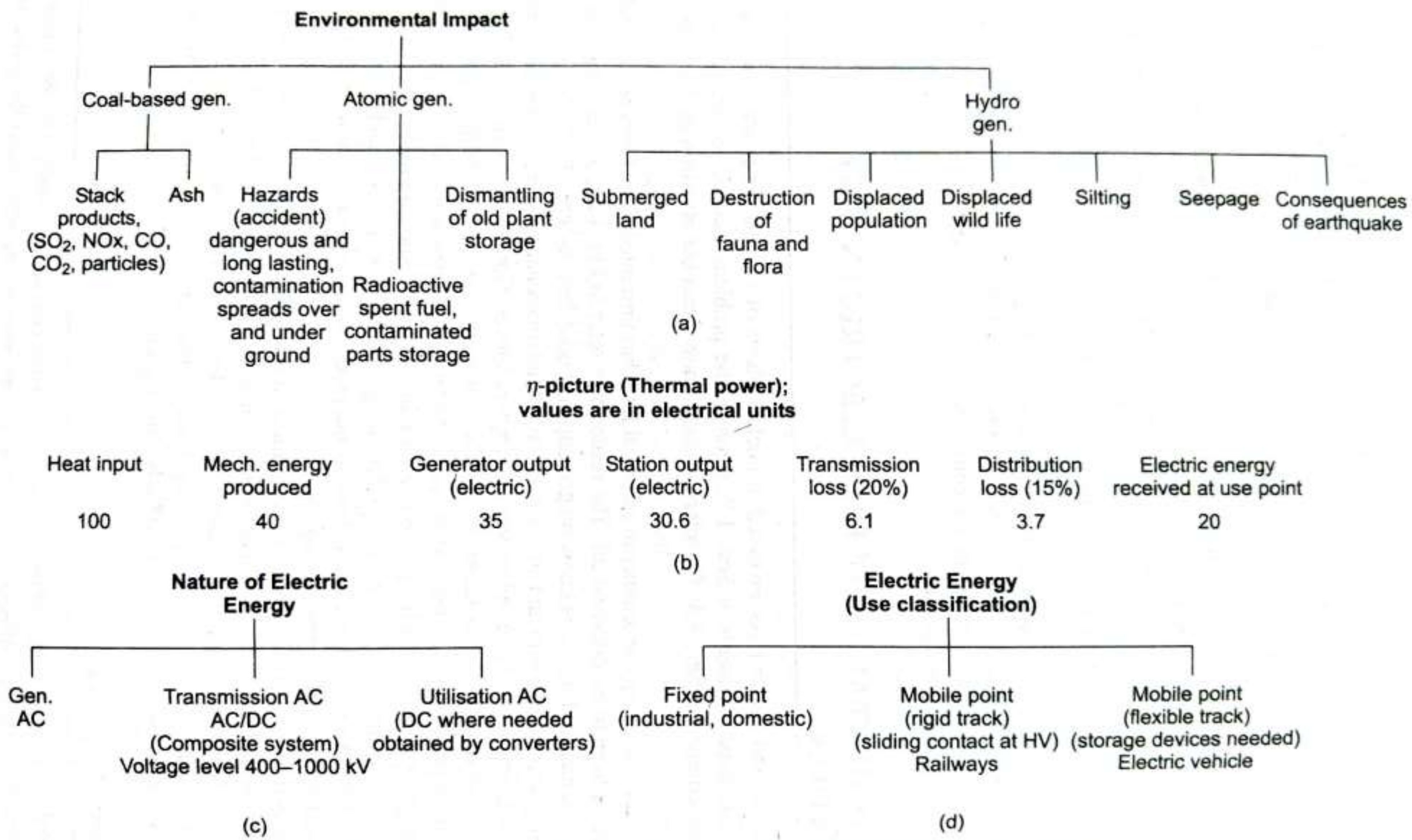


Fig. 1.16 *Environmental and other aspects of electric energy production and use*

options (like nuclear and even hydro) have even stronger hazards associated with them. Also, it should be understood that pollution in large cities like Delhi is caused more by vehicular traffic and their emission. In Delhi of course, Inderprastha and Badarpur power stations contribute their share in certain areas.

Problematic pollutants in emission of coal-based generating plants are:

1. SO_2
2. NO_x, nitrogen oxides
3. CO
4. CO_2
5. Certain hydrocarbons
6. Particulates

Although the account that follows will be general, it needs to be mentioned here that Indian coal has a comparatively low sulphur content but a very high ash content, which in some coals may be as high as 53%.

A brief account of various pollutants, their likely impact and methods of abatements are presented below.

Oxides of Sulphur (SO_2) Most of the sulphur present in the fossil fuel is oxidised to SO_2 in the combustion chamber before being emitted by the chimney. In atmosphere it gets further oxidised to H_2SO_4 and metallic sulphates, which are the major source of concern as these can cause acid rain, impaired visibility and damage to buildings and vegetation. Sulphate concentrations of 9–10 $\mu g/m^3$ of air, aggravate asthma, lung and heart disease. It may also be noted that although sulphur does not accumulate in air, it does so in soil.

Sulphur emission can be controlled by:

1. Use of fuel with less than 1% sulphur; generally not a feasible solution,
2. Use of chemical reaction to remove sulphur in the form of sulphuric acid from combustion products by limestone scrubbers or fluidised bed combustion, and
3. Removing sulphur from the coal by gasification or floatation processes.

It has been noticed that the byproduct sulphur could off-set the cost of sulphur recovery plant.

Oxides of Nitrogen (NO_x) Of these Nitrogen oxide, NO_2 is a major concern as a pollutant. It is soluble in water and can have adverse affects on human health as it enters the lungs on inhaling and after combining with moisture converts to nitrous and nitric acids, which damage the lungs. At levels of 25–100 parts per million, NO_x can cause acute bronchitis and pneumonia.

Emission of NO_x can be controlled by fitting advanced technology burners which can assure more complete combustion, thereby reducing these oxides from being emitted by the stack. These can also be removed from the combustion products by absorption process by certain solvents going on to the stack.

Oxides of Carbon (CO, CO_2) CO is a very toxic pollutant, but it gets converted to CO_2 in the open atmosphere (if available) surrounding the plant. On the other hand, CO_2 has been identified as a major cause of global warming. It is not yet a serious problem in developing countries.

Hydrocarbons During the oxidation process in combustion chamber, certain light weight hydrocarbons may be formed. The compounds are a major source of photo-chemical reaction that add to the depletion of ozone layer.

Particulates (Fly ash) Dust content is particularly high in the Indian coal. Particulates come out of the stack in the form of fly ash. It comprises of fine particles of carbon, ash and other inert materials. In high concentrations, these can cause poor visibility and respiratory diseases.

On account of the environmental impact of harnessing hydro energy and the limitation of harnessing tidal energy, these have been treated in Sec. 1.5. Geothermal energy has also been considered along with thermal generation in Sec. 1.7.

We shall now study solar energy and wind energy, the methods of harnessing these and the difficulties encountered. We shall also touch up biofuel.

Wave Energy The energy content of sea waves is very high. In India, with several hundreds of kilometers of coastline, a vast source of energy is available. The power in the wave is proportional to the square of the amplitude and to the period of the motion. Therefore, the long period (~10 s), large amplitude (~2 m) waves are of considerable interest for power generation, with energy fluxes commonly averaging between 50 and 70 kW/m width of oncoming wave. Though the engineering problems associated with wave-power are formidable, the amount of energy that can be harnessed is large and the development work is in progress. Sea wave power estimated potential is 20,000 MW.

Ocean Thermal Energy Conversion (OTEC) The ocean is the world's largest solar collector. Temperature difference of 20°C between warm, solar absorbing surface water and cooler 'bottom' water can occur. This can provide a continually replenished store of thermal energy which is in principle available for conversion to other energy forms. OTEC refers to the conversion of some of this thermal energy into work and thence into electricity. Estimated potential of ocean thermal power in India is 50,000 MW.

A proposed plant using sea temperature difference would be situated 25 km east of Miami (USA), where the temperature difference is 17.5°C.

1.10 SOLAR ENERGY AND ITS UTILISATION

Solar energy is a free source which is not only naturally renewable but is also environment friendly and thus, helps in lessening the greenhouse effects. As shall be seen in the account that follows, it can only supplement to a (very) limited extent the burgeoning need for energy across the globe. In India, with a deficient grid power and large number of sunny days across the country, solar energy as a supplement is particularly attractive.

1.10.1 The Sun and Solar Energy

The sun is a spherical mass of hot gases, with a diameter of about 1.39×10^9 m and at an average distance of 1.5×10^{11} m from the earth. Energy is being continuously produced in the sun through various nuclear fusion reactions, the most important one being where four protons combine to form a helium nucleus.

$$H_2 + H_2 \rightarrow He + 15 \text{ MeV}$$

The mass lost in the process is converted into energy. These reactions occur in the innermost core of the sun, where the temperature is estimated to be $(8\text{-}40) \times 10^6$ K. The various layers of differing temperatures and densities emit and absorb different wavelengths making the solar spectrum quite composite. However, the sun essentially acts as a black body having a 5800 K temperature. The spectral distribution of solar radiation at the earth's mean distance is shown in Fig. 1.17.

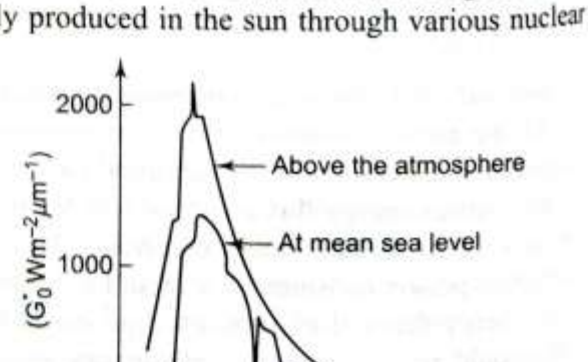


Fig. 1.17 *Spectral distribution of the sun's radiation*

The solar constant is the radiant flux density incident on a plane normal to the sun's rays at a distance of 1.49×10^8 km from the sun and is given by the area under the curve in Fig. 1.17. It has a value of

$$G_o^* = 1367 \text{ W/m}^2$$

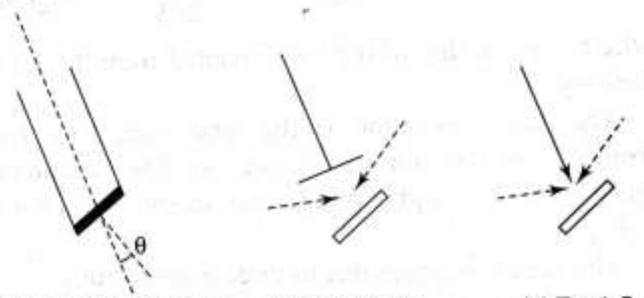
The received flux density varies by ±1.5% during the day's course due to variations in the sun's output, and by about ±4% over the year due to the earth's elliptic orbit. The solar spectrum can be divided into three main regions:

1. Ultraviolet region ($\lambda < 400\ \mu$m) 9%;
2. Visible region (400 nm $< \lambda <$ 700 nm) 45%; and
3. Infrared region ($\lambda >$ 700 nm) 46%.

The radiation in the wavelengths above 2500 nm are negligible.

The earth's atmosphere absorbs various components of the radiation to different levels. The short wave UV and X-ray regions are almost completely absorbed by oxygen and nitrogen gases and ions; the ozone absorbs UV rays. The atmosphere unaffected by dust or clouds acts as an open window for the visible region. Up to 20% of the IR (Infrared) radiation is absorbed by the water vapour and CO_2. The carbon dioxide concentration in the atmosphere is about 0.03% by volume and is beginning to rise with pollutants being let off into the atmosphere. The water vapour concentration can vary greatly (up to 4% by volume). Dust, water droplets and other molecules scatter the sun's radiation.

The sun's radiation at the earth's surface is composed of two components: *beam radiation* and *diffuse radiation*. Beam or direct radiation consists of radiation along the line connecting the sun and the receiver as shown in Fig. 1.18(a). Diffuse radiation is the radiation scattered by the atmosphere without any unique direction as in Fig. 1.18(b). There is also a reflected component due to terrestrial surface. Total radiation is shown in Fig. 1.18(c).



(a) Beam component G_{bc} (b) Diffuse G_{dc} (c) Total G_{tc}

Fig. 1.18 *Components of solar radiation reaching earth*

It easily follows from these figures that [21]

$$G_{bc} = G_b^* \cos\theta \tag{1.7}$$

For a horizontal surface, the relation becomes

$$G_{bh} = G_b^* \cos\theta_z \tag{1.8}$$

Here, θ_z (called the Zenith angle) is the angle of incidence of beam component of solar radiation for a horizontal surface. θ is shown in Fig. 1.18(a). G_b^* is intensity of beam component of normally incident solar radiation on a surface. Adding the beam of the diffuse components, we get

$$G = G_{tc} = G_{bc} + G_{dc} \tag{1.9}$$

1.10.2 Variation of Insolation

Practically the earth is a sphere of radius 6400 km which rotates once in 24 h about its own axis. The axis defined by the North and South poles is shown in Fig. 1.19.

Any point P on the earth's surface is determined by its latitude ϕ and longitude ψ. The latitude is positive in the northern hemisphere, and negative in the southern hemisphere. The longitude is measured positive eastward from Greenwich, England. The vertical North-South plane through P is called *Local Meridional Plane*. Solar noon at P and all places of the same longitude is defined, when the sun is included in the meridional plane. However, clocks do not necessarily show solar time as they are set to civil time common to time zones spanning 15° of longitude. Also, the true interval between two successive solar noons is not exactly 24 h due to the elliptic orbit of the earth. The hour angle ω is the angle by which the earth has rotated since the solar noon.

$$\omega = 15°/\text{h} \times (T_{\text{solar}} - 12\ \text{h}) \tag{1.10}$$

or,

$$\omega = 15°\ \text{h} \times (T_{\text{zone}} - 12\ \text{h}) + (\psi - \psi_{\text{zone}}) \tag{1.11}$$

where T_{solar} is the solar time and T_{zone} is the zone time.

The earth revolves around the sun in an elliptic orbit in 365 days with its axis inclined at angle $\delta_0 = 23.5°$ to the normal to the plane of revolution around the sun.

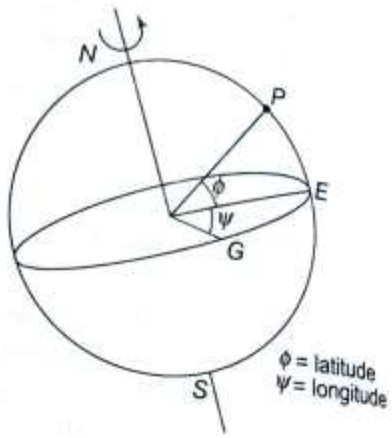


Fig. 1.19

The *declination* δ is defined as the angle between the equatorial plane and the sun's direction. It varies from +23.5° to −23.5° from 21st June to 21st December—the *summer and winter solstices in the Northern Hemisphere*. It is zero on the *equinoxes*. The declination can be expressed as

$$\delta = \delta_0 \sin\left(\frac{360°(284 + n)}{365}\right) \tag{1.12}$$

where n is the day of the year counted from the 1st of January.

The daily insolation is the total energy received from the sun per unit area in one day. The variation of daily insolation with latitude and season is shown in Fig. 1.20.

The variation arises due to three main factors:

1. Variation in the length of the day;
2. Orientation of the receiving surface due to the earth's declination; and
3. Variation in atmospheric absorption.

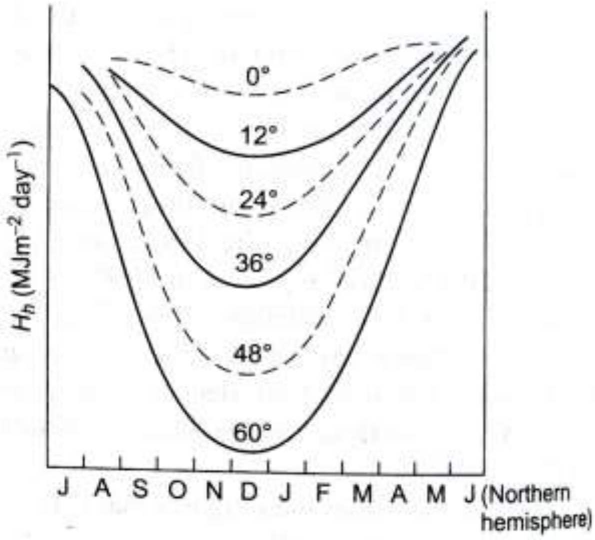


Fig. 1.20 *Variation in daily insolation*

1.10.3 Geometry of the Collector and Solar Beam

For a tilted collector surface as in Fig. 1.21, the following angles are defined. Slope β is the angle between the collector surface and the horizontal surface. *Azimuth angle* γ is the deviation of the projection of the normal to the collector surface on a horizontal plane. In the northern hemisphere for a south facing surface or horizontal surface, $\lambda = 0$. λ is positive for surface facing West of South, and negative for surfaces facing East of South. The general relation between various angles can be shown to be

$$\cos\theta = (A - B)\sin\delta + [C\sin\omega + (D + E)\cos\omega]\cos\delta \tag{1.13}$$

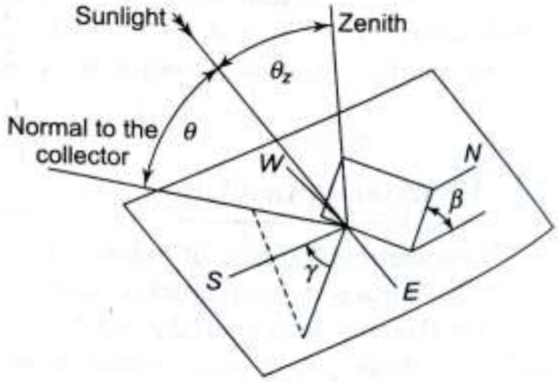


Fig. 1.21 *Geometry of the collector and solar beam*

For a solar energy system collecting heat at 121°C, the maximum thermal efficiency of any heat engine using this heat and rejecting heat to atmosphere at a low temperature of 10°C is

$$\eta = 1 - \frac{273 + 10}{273 + 121} = 0.282 \text{ or } 28.2\%$$

The efficiency of a real engine will be considerably less.

For obtaining efficiencies close to those of fossil fuel based stations, T_H must be raised to the same order of value. This is achieved by installing an array of mirrors, called heliostats, tracking the sun. One proposed scheme is shown in Fig. 1.23 for major generation of electricity with reflectors (with concentration factor of 30 or more) concentrating the sun's rays on to a single boiler for raising steam. A collector area of 1 km^2 would raise 100 MW of electrical power. The cost of such a scheme at present is prohibitive.

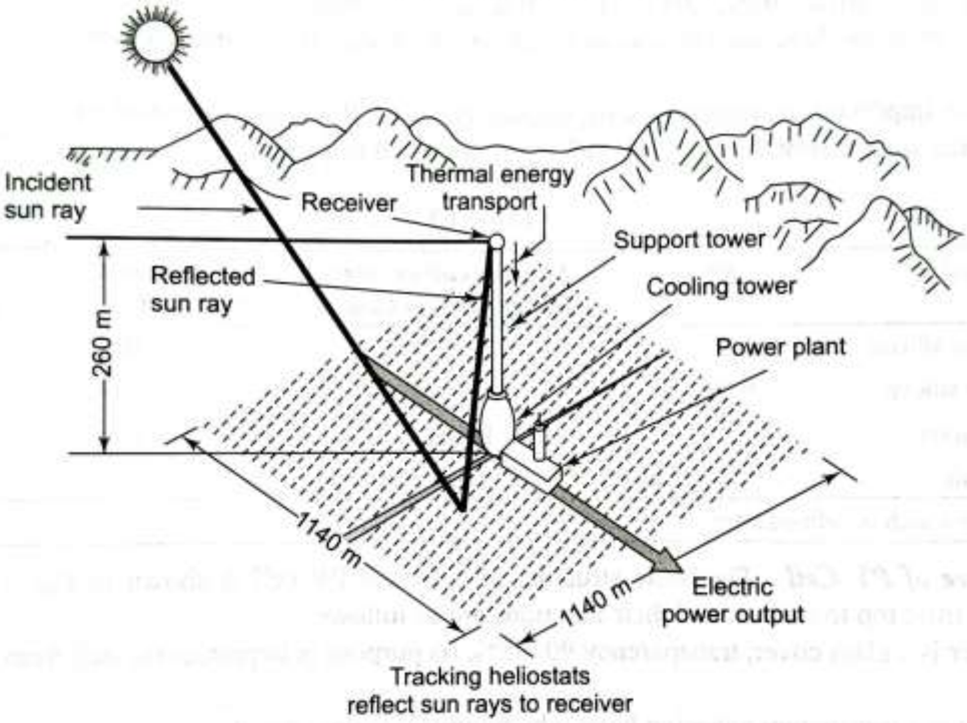


Fig. 1.23 *Proposed scheme for a large central solar-thermal electric generation*

A less attractive alternative to this scheme (because of the lower temperatures) is the use of many individual absorbers tracking the sun unidirectionally, the thermal energy being transferred by a fluid (water or liquid sodium) to a central boiler.

Solar-thermal electric systems have certain inherent disadvantages of a serious nature. These are as follows:

1. Low efficiency. Raising efficiency to acceptable value brings in prohibitive costs.
2. The efficiency of the collecting system decreases as its temperature increases, but the efficiency of the heat engine increases with temperature.
3. All solar-thermal schemes essentially require storage because of the fluctuating nature of the sun's energy, although it has been proposed that the schemes be used as pure fuel savers.
4. In general, mechanical systems need great maintenance.
5. For a reliable system, fossil fuel backup may be needed.

Because of these factors considerable research effort is being devoted to solar photovoltaics as a viable alternative.

where,

$$A = \sin\phi \cos\beta$$
$$B = \cos\phi \sin\beta \cos\gamma$$
$$C = \sin\beta \sin\gamma$$
$$D = \cos\phi \cos\beta$$
$$E = \sin\phi \sin\beta \cos\gamma$$

ω = hour angle given by the equation

For a horizontal plane, $\gamma = \beta = 0$; giving

$$\cos\theta = \sin\phi \sin\delta + \cos\phi \cos\omega \cos\delta \qquad (1.14)$$

If the collector's slope equals the latitude, i.e., $\beta = \phi$, it will face the solar beam directly at noon. In this case,

$$\cos\theta = \cos\omega \cos\delta \qquad (1.15)$$

1.10.4 Optimum Orientation of the Collectors

The insolation received at the collector's plane is the sum of beam and diffuse components, i.e.,

$$H_c = \int (G_b^* \cos\theta + G_d)\, dt \qquad (1.16)$$

To maximise the energy collected, cos θ should be as close to 1 as possible. This is achieved by continuous *tracking*, always maintaining cos θ as 1 by letting the collector directly face the solar beam. By mounting the array on a two-axis tracker, upto 40% more energy, as compared to a fixed slope collector, can be collected. But this increases complexity and results in higher capital operation and maintenance costs. Single-axis tracking is less complex, but yields a smaller gain. However, as cos $\theta \approx 1$ for $\theta < 30°$, for most applications the collector can be kept with $\beta = \phi$ and $\gamma = 0°$. The specific tracking method to be adopted will depend on the energy demand variation. Tracking is particularly important in systems that operate under concentrated sunlight.

1.10.5 Applications of Solar Energy

Solar energy finds many applications, some of these being water heating, solar drying, desalination, industrial process heating and passive/active heating of buildings. However, because of the well known advantages of electrical power, the methods of converting solar radiation into electricity have attracted the greatest attention. There are two essential ways of converting solar energy into electricity.

1. *Solar thermomechanical systems:* Here, the solar radiation is used to heat a working fluid which runs turbines.
2. *Solar photovoltaics*: Solar photovoltaics (SPV) convert radiant energy directly into an electric current.

In both of these systems, collecting systems are used to receive the radiant energy. These are described below.

Flat-plate Collectors These are used in low efficiency photovoltaics and low medium temperature thermal systems. In thermomechanical system, the flat-plate collector acts as a heat exchanger; transferring the radiant energy to a working fluid. The advantages of flat-plate collectors over concentrators are as follows:

1. Absorb the diffuse, direct and reflected components of the radiation;
2. Comparatively easy to fabricate and is cheaper; and
3. Since these are usually fixed in tilt and orientation, tracking is not required—this makes them maintenance free, except for surface cleaning.

For a solar-thermal flat-plate collector the components are as follows:

1. A flat metallic plate painted black to absorb radiation;
2. Channels attached to the plate where a working fluid removes the thermal energy; and
3. Thermal insolation at the back and sides of the collector, and a glass cover to minimise thermal losses.

Flat-plate collectors are popular in water heating systems.

Concentrating Collectors They are used in high temperature solar thermal systems and some high efficiency photovoltaics. There are various methods of classifying solar concentrators. They may be classified as refracting or reflecting, imaging or non-imaging, and on the basis of the type of reflecting surface as parabolic, spherical or flat. High temperatures are obtained by using central tower receivers and *heliostats*.

1.10.6 Solar Thermomechanical Systems

In solar thermomechanical systems, solar energy is converted to thermal energy of a working fluid. This thermal energy gets converted into shaft work by a turbine which runs generators. Heat engines (turbine) are based on the Rankine cycle, Sterling cycle or the Brayton cycle. Usually a fossil fuel heat source is also present as standby.

A schematic flow diagram for a solar power plant operating on Rankine cycle is shown in Fig. 1.22. The maximum theoretical *thermal efficiency*, the ratio of useful work done to the heat supplied, is expressed for the Carnot cycle in terms of the temperature of the reservoirs with which it is exchanging heat.

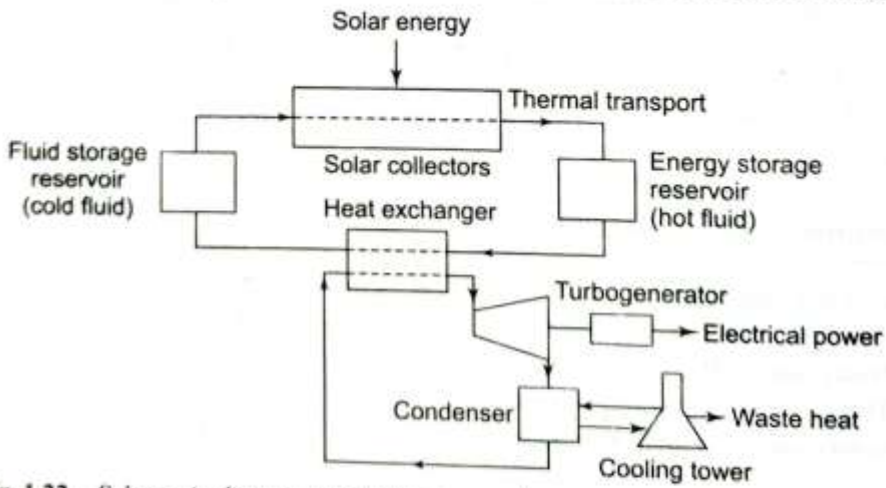


Fig. 1.22 *Schematic diagram of a solar power plant operating on the Rankine cycle*

$$\eta = 1 - \frac{T_L}{T_H} \tag{1.17}$$

where,

η = thermal efficiency of the Carnot cycle

T_L = absolute temperature (°C + 273) of the sink

T_H = absolute temperature of the source

For a solar energy system collecting heat at 121°C, the maximum thermal efficiency of any heat engine using this heat and rejecting heat to atmosphere at a low temperature of 10°C is

$$\eta = 1 - \frac{273 + 10}{273 + 121} = 0.282 \text{ or } 28.2\%$$

The efficiency of a real engine will be considerably less.

For obtaining efficiencies close to those of fossil fuel based stations, T_H must be raised to the same order of value. This is achieved by installing an array of mirrors, called heliostats, tracking the sun. One proposed scheme is shown in Fig. 1.23 for major generation of electricity with reflectors (with concentration factor of 30 or more) concentrating the sun's rays on to a single boiler for raising steam. A collector area of 1 km^2 would raise 100 MW of electrical power. The cost of such a scheme at present is prohibitive.

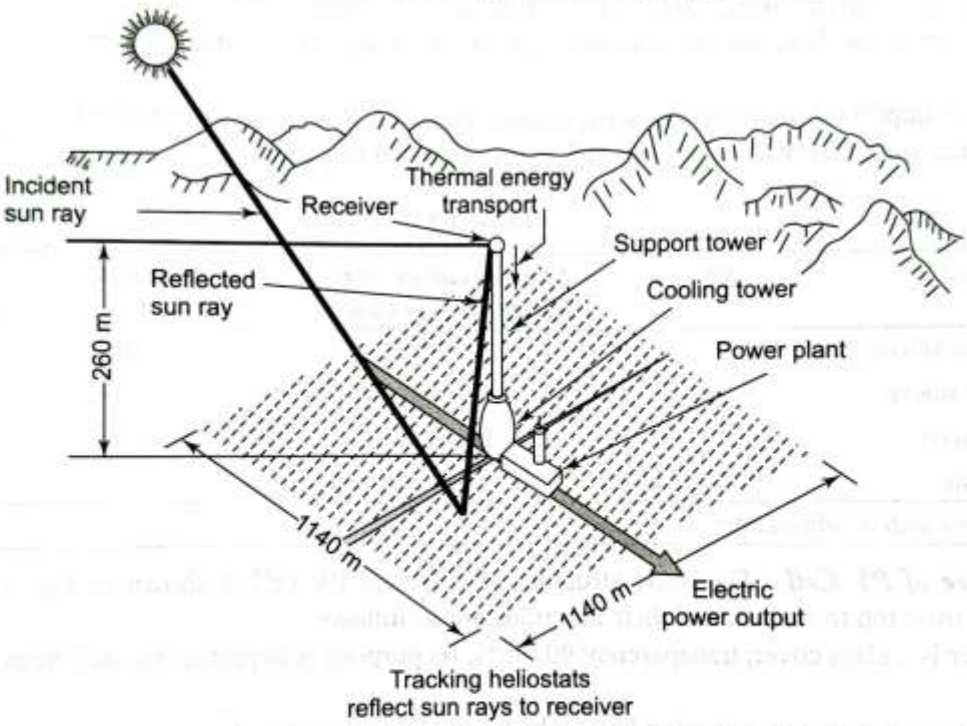


Fig. 1.23 *Proposed scheme for a large central solar-thermal electric generation*

A less attractive alternative to this scheme (because of the lower temperatures) is the use of many individual absorbers tracking the sun unidirectionally, the thermal energy being transferred by a fluid (water or liquid sodium) to a central boiler.

Solar-thermal electric systems have certain inherent disadvantages of a serious nature. These are as follows:

1. Low efficiency. Raising efficiency to acceptable value brings in prohibitive costs.
2. The efficiency of the collecting system decreases as its temperature increases, but the efficiency of the heat engine increases with temperature.
3. All solar-thermal schemes essentially require storage because of the fluctuating nature of the sun's energy, although it has been proposed that the schemes be used as pure fuel savers.
4. In general, mechanical systems need great maintenance.
5. For a reliable system, fossil fuel backup may be needed.

Because of these factors considerable research effort is being devoted to solar photovoltaics as a viable alternative.

1.10.7 Direct Conversion of Sunlight into Electricity

Introduction Photovoltaic (PV) or solar cell is a semiconductor device that converts sunlight directly into electricity. Initially PV cells had very limited use, e.g., in supplying electricity to satellites in space or for meeting energy requirements of defence personnel stationed at remote areas. However, with a gradual reduction in the cost of PV cells, current international price is now between 5–10$ per peak-watt and its use has been increasing steadily. It is projected that by the year 2015 or so, its share in power generation may be around 10–15%.

A PV cell can be classified–

1. in terms of materials: noncrystalline silicon, polycrystalline silicon, amorphous silicon, gallium arsenide, cadmium telluride, cadmium sulphide, idium arsenide, etc.
2. in terms of technology for fabrication single crystal bonds (or cylinders), ribbon growth, thin-film, etc.

Some of the important characteristics of various types of PV cells, measured at normal temperature (25°C) and under illumination level of 100 mW/cm^2, are listed in Table 1.1.

Table 1.1

PV cell	*ff**	*Short-circuit current density (Isc) (mA/cm^2)*	*Open-circuit voltage (V_{oc}) (V)*	*Conversion efficiency (%)*
Monocrystalline silicon	0.85	20–22	0.5–0.6	13–14
Polycrystalline silicon	0.85	18–20	0.5–0.6	9–12
Amorphous silicon		13–14	2.2–2.4	5–6
Gallium arsenide	0.87	–	–	20–25

* *ff* is fill-factor which is defined later.

Basic Structure of PV Cell The basic structure of a typical PV cell is shown in Fig. 1.24(a) and (b). Various layers from top to bottom and their functions are as follows:

1. Top layer is a glass cover, transparency 90–95%. Its purpose is to protect the cell from dust, moisture, etc.
2. The next is a transparent adhesive layer which holds the glass cover.
3. Underneath the adhesive is an antireflection coating (ARC) to reduce the reflected sunlight to below 5%.

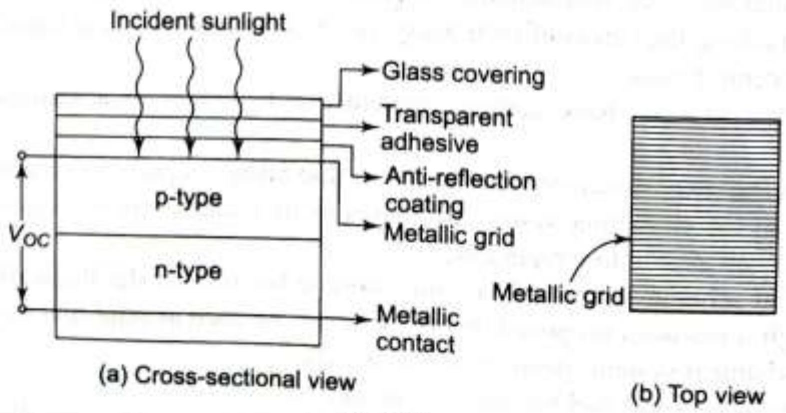


Fig. 1.24

4. Then follows a metallic grid (aluminium or silver) (Fig. 1.24(b)) which collects the charge carriers, generated by the cell under incidence of sunlight, for circulating to outside load.
5. Under the lower side of the metallic grid lies a p-layer followed by n-layer forming a pn-junction at their interface. The thickness of the top p-layer is so chosen that enough photons cross the junction to reach the lower n-layer.
6. Then follows another metallic grid in contact with the lower n-layer. This forms the second terminal of the cell.

Operation and Circuit Model The incidence of photons (sunlight) causes the generation of electron-hole pairs in both p and n-layers. Photons generated minority carriers (electrons in p-layer and holes in n-layer) freely cross the junction. This increases the minority carrier flow manyfolds. Its major component is the light generated current I_G (when load is connected across the cell terminals). There is also the thermally generated small reverse saturation current I_s (minority carrier flow in same direction as I_G), also called *dark current* as it flows even in absence of light. I_G flows in opposite direction to I_D, the forward diode current of the junction. The cell feeds current I_L to load with a terminal voltage V.

The above operation suggests the circuit model of a PV cell as drawn in Fig. 1.25. The following Eq. (1.19) can be written from the circuit model and the well-known expression for

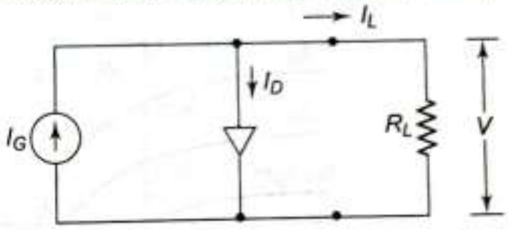


Fig. 1.25 *Circuit model of PV cell*

$$I_D = I_s(e^{\lambda V} - 1); \; \lambda = \frac{e}{kT} \tag{1.18}$$

where,

k = Boltzmann constant,

e = electronic charge and

T = cell temperature in degree K.

Load current

$$I_L = I_G - I_D$$
$$= I_G - I_s(e^{\lambda V} - 1) \tag{1.19}$$

From this equation, it easily follows that

$$V_{OC}(I_L = 0) = \frac{1}{\lambda} \ln\left(\frac{I_G}{I_s} + 1\right) \tag{1.20}$$

and

$$I_{SC}(V = 0) = I_G \tag{1.21}$$

Solar radiation generated current I_G is dependent on the intensity of light. The I–V characteristics of the cell are drawn in Fig. 1.26(a) for various values of intensity of solar radiation. One typical I–V characteristic of the cell is drawn in Fig. 1.26(b). Each point on this curve belongs to a particular power output. The point Q indicated on the curve pertains to the maximum power output at which the cell should be operated. At this point,

$$P_{max} = V_{Pmax} I_{Pmax} \tag{1.22}$$

The *fill-factor* (ff) of a cell is defined as

$$ff = \frac{P_{max}}{I_{SC} V_{SC}} \tag{1.23}$$

The cell efficiency is given as

$$\eta = \frac{P_{out}}{P_{in}} \tag{1.24}$$

where P_{out} is the power delivered to load and P_{in} is the solar power incident on the cell.

Effect of Temperature on Solar Cell Efficiency As the temperature increases, the diffusion of electrons and holes in the length of Si (or GaAs) increases causing an increase in the dark current and a decrease in V_{OC}. The overall effect causes a reduction in the efficiency of solar cell as the temperature increases. The practical efficiency of Si solar cell is about 12% and that of GaAs solar cell is 25% at the normal temperature of 300 K. With each degree rise in temperature, the efficiency decreases by a factor of 0.0042%.

26.8 C

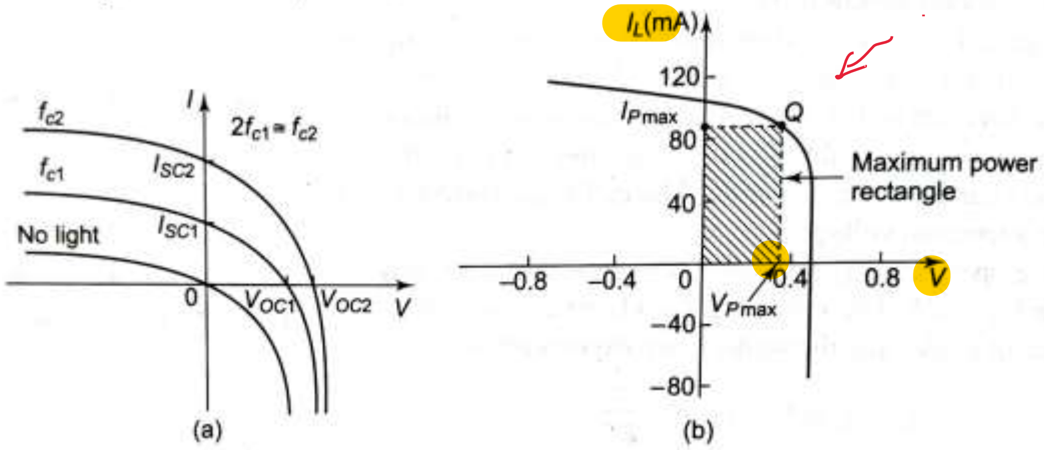


Fig. 1.26 *I–V (current–voltage) characteristics of a PV cell*

Spectral Response It is seen from the spectral response curves of Fig. 1.27 that the Selenium cell response curve nearly matches that of the eye. Because of this fact Se cell has a widespread application in photographic equipments such as exposure meters and automatic exposure diaphragm. Silicon response also overlaps the visible spectrum but has its peak at the 0.8 μm (8000 Å) wavelength, which is in the infrared region. In general, silicon has a higher conversion efficiency and greater stability and is less subject to fatigue. It is therefore widely used for present day commercial solar cells.

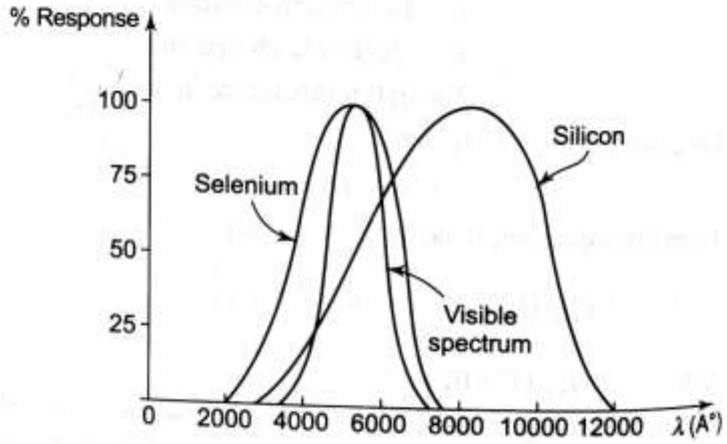


Fig. 1.27 *Spectral response of Si, Se and the naked eye*

1.10.8 Prevalent Technologies for Fabricating Silicon PV Cell

The most commonly used methods of manufacturing silicon PV cell from purified silicon feedstock are as follows:

1. Single crystal silicon with a uniform chemical structure.
2. Polycrystalline silicon-series of crystalline structures within a PV cell.
3. Amorphous silicon with a random atomic chemical structure.

A grid interactive SPV system for domestic use is shown in the form of conceptual blocks in Fig. 1.29. Solar cells are connected in series-parallel and the voltage after conversion to AC form by solid state devices is not compatible with grid voltage (400 V at distribution load). This scheme, therefore, differs from that of Fig. 1.22 as the DC voltage has to be raised by the method of DC/DC high frequency chopping with an intervening inductor for raising the voltage. For grid interaction, a converter–inverter is required so that power can flow either way depending upon the amount of solar power availability during the day. A battery via converter–inverter feeds the domestic load at night (or on a cloudy day) if the grid outage occurs.

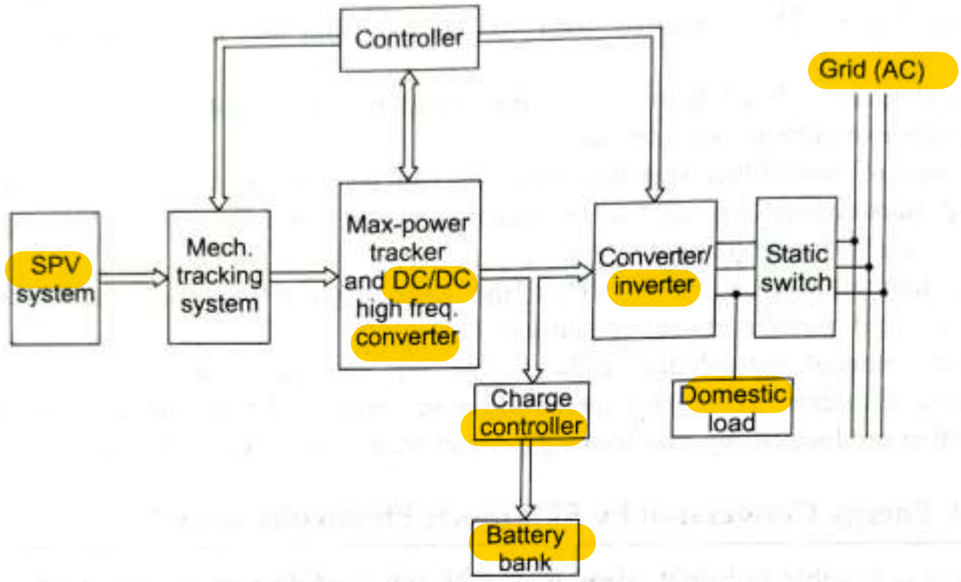


Fig. 1.29 *Grid interactive SPV system*

The process of conversion and reconversion with solid state devices like SCR (Silicon Controlled Rectifier) is called *power conditioning*. Such systems are already being used in cities in Japan, and are now available in India.

For bulk solar power systems, the basic scheme will be similar except that it would directly feed power into the grid and no power need flow the other way.

As and when a breakthrough in SPV technology and sharp reduction in cost is achieved, domestic and bulk power systems will become a common place. However, the intensity of solar insolation being low (1367 W/m^2), use of solar power requires considerable land area coverage (with shade underneath, all times, a different kind of pollution). The best estimate is that solar power will meet only 5–10% of the total electric energy need.

Total energy potential in India is 8×10^{15} kWh/yr. Upto 31.12.2010, 6,40,000 solar cookers, 55×10^4 m^2 solar thermal collector area, 47 MW of SPV power, 270 community lights, 5,38,718 solar lanterns (PV domestic lighting units), 640 TV (solar), 54,795 PV street lights and 7002 solar PV water pumps were installed. Village power plants (stand-alone) of 1.5 MW capacity and 1.1 MW of grid connected power plants were in operation. As per one estimate [2], solar power will overtake wind in 2040 and would become the world's overall largest source of electricity by 2050. 5000 MW grid-interactive solar power could be feasible by 2032 (MNES Annual Report 2005–06). Solar water heating systems are increasingly becoming more popular for homes, hostels, hotels and industrial and domestic purposes. Research has shown that the Gallium Arsenide (GaAs) based PV cell with multijunction device could give maximum efficiency of nearly 30% and Carbon Nano Tube (CNT) based PV cell may give upto 50% efficiency.

1.11 WIND POWER

A growing concern for the environmental degradation has led to the world's interest in renewable energy resources. Wind is commercially and operationally the most viable renewable energy resource.

Worldwide, five nations—Germany, USA, China, Spain and India—account for 73% of the world's installed wind energy capacity. The total worldwide wind power installed capacity is 1,57,899 MW. Kinetic energy available in the wind is converted to electrical energy by using rotor, gearbox and generator. The wind turns the blades of a windmill-like machine. The rotating blades turn the shaft to which they are attached. The turning shaft typically can either power a pump or turn a generator, producing electricity. Larger blades capture more wind. As the diameter of the circle formed by the blades doubles, the power increases four times.

Wind is air set in motion by the small amount of insolation reaching the upper atmosphere of earth. Nature generates about 1.67×10^5 kWh of wind energy annually over land area of earth and 10 times this figure over the entire globe. Wind contains kinetic energy which can easily be converted to electrical energy. Wind energy has been used in wind mills for centuries. In 1980s, wind energy use received a fillip with availability of excellent wind sites and rising cost of conventionally generated electrical power. Later in 1990s, interest in wind generated electrical power to displace conventional power, received further enhancement in order to reduce air pollution levels in the atmosphere. Wind is a clean power generating agent as it causes no pollution.

Power density in moving air is given by

$$P_W = KV^3 \text{ W/m}^2; \text{ [Here } K = 1.3687 \times 10^{-2}] \quad (1.25)$$

or

$$P_W = 0.5\, \rho A V^3 \text{ W}$$

where, ρ = air density (1201 g/m^3 at *NTP*)

V = wind speed in km/h, mean air velocity (m/s)

A = Swept area (m^2)

Theoretically a fraction 16/27 = 0.5926 of the power in the wind is recoverable. This is called *Gilbert's limit* or *Betz coefficient*. Aerodynamical efficiency for converting wind energy to mechanical energy can be reasonably assumed to be 70%. So the mechanical energy available at the rotating shaft is limited to 40% or at the most 45% of wind energy.

Wind Characteristics

1. Wind speed increases roughly as the 1/7th power of height. Typical tower heights are about 20–30 m.
2. *Energy-pattern factor*: It is the ratio of actual energy in varying wind to energy calculated from the cube of mean wind speed. This factor is always greater than unity which means that energy estimates based on mean (hourly) speed are pessimistic.

Utilisation Aspects There are three broad categories of utilisation of wind energy:

1. Isolated continuous duty systems which need suitable energy storage and reconversion systems.
2. Fuel-supplement systems in conjunction with power grid or isolated conventional generating units.
3. Small rural systems which can use energy when wind is available.

Category 2 is the most predominant in use as it saves fuel and is fast growing particularly in energy deficient grids. Category 3 has application in developing countries with large isolated rural areas.

Aeroturbine Types and Characteristics Modern horizontal-axis aeroturbines (wind turbines) have a sophisticated blade design. They are installed on towers 20–30 m high to utilise somewhat high wind speed and also permit land use underneath. Cross-section view of a typical horizontal-axis wind turbine is shown in Fig. 1.30.

Tip Speed, also called *specific speed*, is by far the single most important parameter to be considered. It is defined as

$$\text{Tip speed} = \frac{\text{Peripheral speed}}{\text{wind speed}}$$

This ratio ranges from 2 to 10. Ratio's less than 4 require rotor with several blades and have lower rotational speed whereas higher ratio's (4 to 10) require fewer blades and have higher rotational speeds. Higher tip speed rotors have lower efficiency because of higher frictional loss. Typical blade diameters are about 20 m and rotor speeds 100–150 rpm.

Power Coefficient C_p is defined as the fraction of wind power at the rotor shaft. It is dependent on (i) tip speed ratio and (ii) pitch angle of blades. Rather than designing for C_p (max), these factors are determined by economics.

Blade Arrangements For harnessing large power, two to three blade configurations are used. Two blade arrangement is cost effective but prone to vibrations, which disappear with three blades. No unique answer on this issue has been arrived as yet. Modern machines have metal blades based on aircraft technology. Glass reinforced plastic has also been used successfully.

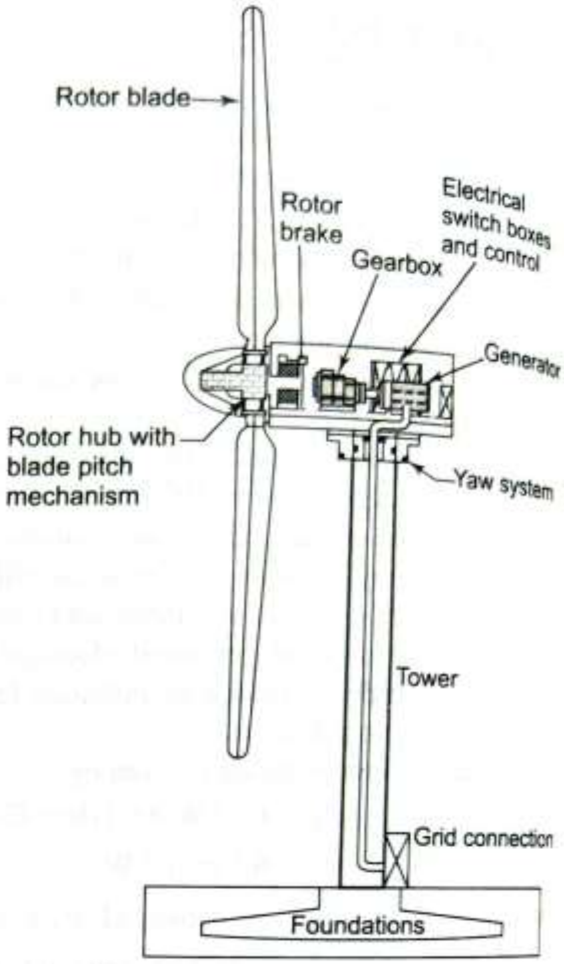


Fig. 1.30 *Cross-sectional view of a typical horizontal-axis aeroturbine*

Vertical-axis Wind Turbines (VAWTs) Vertical-axis aeroturbines accept the wind from any direction and have the added advantage that the generator is located on ground. As a result the weight on tower is considerably reduced. The technology of these turbines has reached the stage where their efficiencies are comparable with those of horizontal-axis machines.

A number of vertical-axis designs have been developed and tested. We shall discuss here the one that is now commercially available—the Darrieus. The Darrieus rotor has two or more curved airfoil blades, held together at the top and the bottom. These are so positioned that they respond to wind from any direction. Physically, it resembles the lower portion of an egg beater. The rotors are nonself-starting and operate at blade tip ratios of 6 to 8. These have efficiencies around 35–40%.

Wind to Electric Energy Conversion The choice of electrical system for an aeroturbine is guided by three factors:

1. *Type of electrical output*–DC, variable-frequency AC, constant-frequency AC.
2. *Aeroturbine rotational speed*–constant speed with variable blade pitch, nearly constant speed with simpler pitch-changing mechanism or variable speed with fixed pitch blades.
3. *Utilisation of electrical energy output*–in conjunction with battery or other form of storage, or interconnection with power grid.

Large scale electrical energy generated from wind is expected to be fed to the power grid to displace fuel generated kWh. For this application, present economics and technological developments are heavily weighted in favour of constant-speed constant-frequency (CSCF) system with alternator as the generating unit. It must be reminded here that to obtain high efficiencies, the blade pitch varying mechanism and controls have to be installed.

Wind turbines of electrical rating of 100 kW and above normally are of constant-speed type and are coupled to synchronous generators (conventional type). The turbine rated at less than 100 kW is coupled to fairly constant speed induction generators connected to grid and so operating at constant frequency drawing their excitation VARs from the grid or capacitor compensators.

With the advent of power switching technology (high power diodes and thyristors) and chip-based associated control circuitry, it has now become possible to use variable-speed constant-frequency (VSCF) systems. VSCF wind electrical systems (WES) and its associated *power conditioning* system operates is shown in Fig. 1.31.

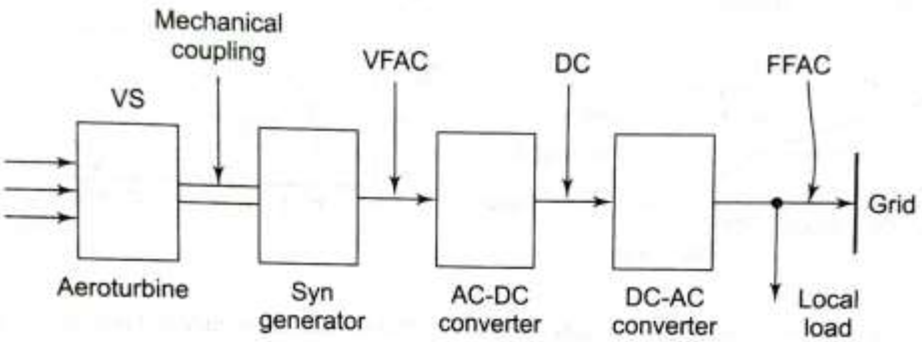


Fig. 1.31 *Block schematic of VSCF wind electrical system; VF (variable frequency), FF (fixed frequency)*

Various advantages of this kind of VSCF WES are:

1. No complex pitch changing mechanism is needed;
2. Aeroturbine always operates at maximum efficiency point (constant tip-speed ratio);
3. Extra energy in the high wind speed region of the speed-duration curve can be extracted; and
4. Significant reduction in aerodynamic stresses, which are associated with constant-speed operation.

1.11.1 Operation and Control of Wind Electrical Systems (WES)

To understand the operation and control of WES, let us first consider a typical wind duration curve of Fig. 1.32(a). Any point on this curve gives the number of hours in a year for which the wind speed is higher than the value corresponding to this point.

Sensors sense the wind direction and the *yaw control* (Fig. 1.30) orients the rotor to face the wind in case of horizontal-axis machines. With reference to the wind duration curve of Fig. 1.32(a) it is seen that the wind turbine begins to deliver power at the *cut-in-speed* V_C and the plant must be shut down for wind speed at the maximum safe limit called the *furling speed* V_F. Between these two limits, mechanical power output of the turbine is determined by the power coefficient C_p. The electrical power output is determined therefrom, by the coefficients η_m and η_g of the mechanical drive and the electrical generator, respectively.

In CSCF WES, the conventional synchronous generator locks into the grid and maintains a constant speed irrespective of wind speed. A suitable controller senses the generating/motoring mode of operation and makes the needed pitch adjustments and other changes for a smooth operation.

As the generator output reaches the rated value, the electrical load is held constant even though the wind speed may increase beyond this value. This extra energy in the wind is allowed to be lost as indicated in Fig. 1.32(b). This is also the case for an induction generator whose speed remains substantially constant.

With VSCF system, suitable output controls can be installed to maintain a constant tip speed ratio so as to keep C_p at its near maximum value. This results in somewhat more power output throughout the operating range compared to the CSCF system as shown in Fig. 1.32(b). Also, there is no need to install sophisticated pitch control systems. The extra cost entailed in the power conditioning system gets more or less balanced against the cost of extra energy output. Considerable development effort is therefore being applied to CSCF system for large rating WES. These systems are yet to be proved in the field.

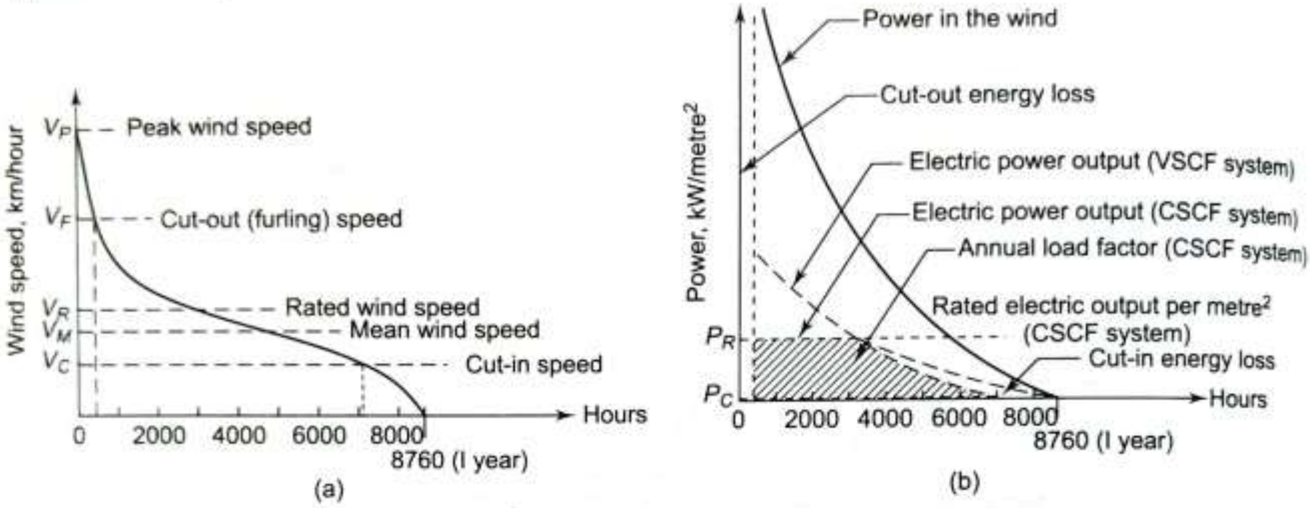


Fig. 1.32 *(a) Typical wind-speed-duration curve (b) Power-duration curve of wind-driven generator*

For CSCF WES, the operating curve shown shaded in Fig. 1.32(b) is redrawn in Fig. 1.33 with speed axis reversed for clarity. The aerogenerator starts to generate power at wind speed V_C, the cut-in speed. The aerogenerator produces rated power at speed V_R. At higher wind speeds, the aerogenerator speed is held constant by changing the pitch of blades (part of wind energy is being lost during this part of operation). The aerogenerator must be cut-out at V_F, the furling speed.

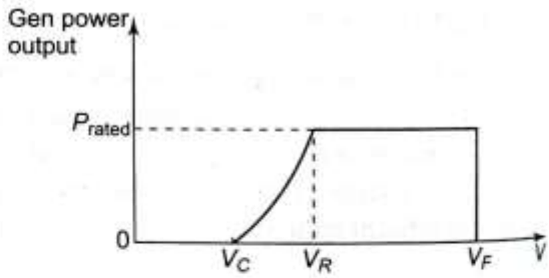


Fig. 1.33 *CSCF WES characteristics*

Typical wind turbine rotors of 20 m diameter rotate at 100–500 rpm and are geared upto about 750 rpm to drive an eight pole induction generator excited from 400 V, 3-phase, 50 Hz rural distribution system.

Consider as an example, an area with mean wind speed of 10 km/h. Power output of 300 MW is to be produced using aeroturbines of 20 m blade diameter. Let us calculate the number of aeroturbines required.

Power in the wind is given by the relationship,

$$P_W = KV^2/\text{m}^2 \text{ kW}$$

$$V = \text{wind speed in km/h}$$

$$K = 1.368 \times 10^{-2}$$

For the aeroturbine,

$$P_{\text{aero}}\,(\text{mech}) = 1.368 \times 10^{-2} \times (10)^2\, \pi \left(\frac{20}{2}\right)^2$$

$$= 4290 \text{ kW}$$

$$P_{gen}\,(\text{elect}) = 4290 \times 0.4 = 1716 \text{ kW}$$
$$= 1.7 \text{ MW}$$

Number of aeroturbines needed

$$= \frac{300}{1.7} = 177$$

These aerogenerators will be installed in a *wind farm* with suitable *X*, *Y* spacing so that the air turbulence of one aeroturbine on the exit side and also sideways does not affect the successive turbine.

1.11.2 Wind Farm

It is seen from the example given above that to contribute significant power to the grid, several standard size wind turbines have to be employed at a site where there is a vast enough wind field, flat or in a valley. Such an arrangement is called a wind farm.

How closely can the individual wind turbines be located to each other in a wind farm? The operation of a wind turbine causes an air turbulence on its back as well as sides; the region of turbulence is called the *wake* of the turbine. Optimal location of wind turbines is such that no turbines are located in the wake of the forward and side turbines. Any turbine that lies in the wake of another has its power output reduced and over a period of time, fatigue damage caused by stresses generated can occur specially for the yaw drive.

Spacing Rule A wind turbine has to be aligned perpendicular to the direction of wind. Where wind is unidirectional all day (which is rare), the spacing between turbines of a row (side ways) is 2 *D*–3 *D*, *D* being the diameter of the rotor. Inter row spacing is about 10 *D*. Normally, wind is not unidirectional; in which case a uniform spacing of 5–7*D* is recommended. A computer software 'Micropositioning' is available for this purpose.

Internal transformers and cabling will connect the aerogenerator to the grid. Each turbine will have its own control circuitry. Grid connection requires a certain sophisticated protection scheme whose purpose is:

1. To isolate the wind farm in case of any internal fault in the electrical system, and
2. To disconnect the wind farm if there is a fault on any section of utility network (grid).

1.12 BIOFUELS

We shall explain the biofuels and their utilisation with the help of Fig. 1.34 and explanation of certain terms.

Biomass It is the material of all the plants and animals. The organic carbon part of this material reacts with oxygen in combustion and in the natural metabolic processes. The end product of these processes is mainly CO_2 and heat as shown in Fig. 1.34.

Biofuels The biomass can be transformed by chemical and biological processes into intermediate products like methane gas, ethanol liquid or charcoal solid.

Agro Industries The use of biofuels when linked carefully to natural ecological cycles (Fig. 1.34) may be nonpolluting. Such systems are called agro industries. The well established of these industries are the sugarcane and forest product industries.

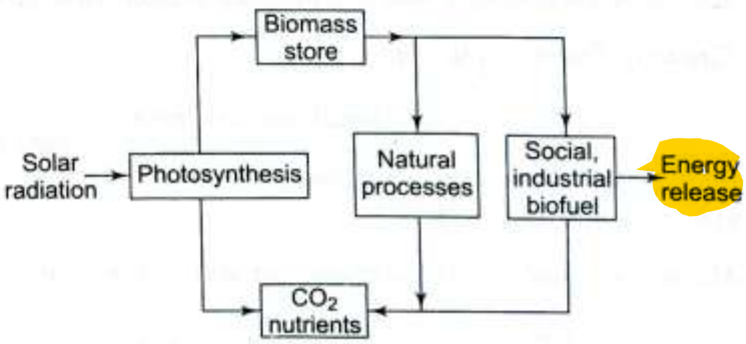


Fig. 1.34 *Biomass cycle*

Biofuels can be used to produce electricity in two ways:

1. By burning in a furnace to raise steam to drive turbines; or
2. By allowing fermentation in landfill sites or in special anaerobic tanks, both of which produce methane gas which can be used as fuel for household stoves and in spark ignition engines or gas turbines. The CO_2 produced in this process must be recycled by cultivating next crop or planting trees as CO_2 is absorbed by photosynthesis by plants.

Biofuels have a potential to meet about 5% of the electricity requirements of an industrialised country by exploiting all forms of these household and industrial wastes, sewerage, sledge (for digestion) and agricultural waste (cow dung, chicken litter, straw, sugarcane, etc.).

1.7 GEOTHERMAL ENERGY

The outer crust of earth contains a very large reserve of energy as sensible heat. It is estimated to be one to two orders of magnitude larger than all the energy recoverable from uranium (by fission) and thorium (by breeder reactor assuming 60–70% efficiency). Fusion as and when it becomes technologically practical would represent a large energy resource than geothermal energy.

Geothermal energy is present over the entire extent of earth's surface except that it is nearer to the surface in volcanic areas. Heat transfer from the earth's interior is by three primary means:

1. Direct heat conduction,
2. Rapid injection of ballistic magma along natural rifts penetrating deep into earth's mantle, and
3. Bubble like magma that buoys upwards towards the surface.

Rift geothermal areas in sedimentary rock basins undergo repeated injection of magma, though in small amount. Over a long period of time, these processes cause massive amounts of hot water to accumulate. Examples are the Imperiod Valley of Africa. The weight of the overburden in these sedimentary basins compresses the trapped water giving rise to a geopressurised geothermal resource. These high pressures serve to increase the productivity of hot-water wells, which may be natural or drilled.

Pressure released in the hot wells causes boiling and the steam and water mixture rise upwards. This mixture is passed through steam separators, which then is used to drive low-pressure steam turbines. Corrosive effects of this wet steam, because of mineral particles in it, have been tackled by advanced

Energy Storage

Because of the difficulties in storage of electricity, it has to be constantly generated, transmitted, and utilised. Large scale storage of energy, which can be quickly converted to electrical form can help fast changing the loads. This would help to ease operation and make the overall system economical as large capacity need not to be kept on line to take up short duration load surge. The options available are as follows:

1- Pumped storage
2- Heat storage
3- Hydrogen storage
4- Batteries
5- Fly wheels, superconducting coils

S.No.	Item	Steam Power Station	Hydro-electric Power Plant	Diesel Power Plant	Nuclear power Plant
1.	*Site*	Such plants are located at a place where ample supply of water and coal is available, transportation facilities are adequate	Such plants are located where large reservoirs can be obtained by constructing a dam *e.g.* in hilly areas.	Such plants can be located at any place because they require less space and small quantity of water.	These plants are located away from thickly populated areas to avoid radioactive pollution.
2.	*Initial cost*	Initial cost is lower than those of hydroelectric and nuclear power plants.	Initial cost is very high because of dam construction and excavation work.	Initial cost is less as compared to other plants.	Initial cost is highest because of huge investement on building a nuclear reactor.
3.	*Running cost*	Higher than hydroelectric and nuclear plant because of the requirement of huge amount of coal.	Practically nil because no fuel is required.	Highest among all plants because of high price of diesel.	Except the hydroelectric plant, it has the minimum running cost because small amount of fuel can produce relatively large amount of power.
4.	*Limit of source of power*	Coal is the source of power which has limited reserves all over the world.	Water is the source of power which is not dependable becuase of wide variations in the rainfall every year.	Diesel is the source of power which is not available in huge quantities due to limited reserves.	The source of power is the nuclear fuel which is available in sufficient quantity. It is because small amount of fuel can produce huge power.
5.	*Cost of fuel transportation*	Maximum because huge amount of coal is transported to the plant site.	Practically nil.	Higher than hydro and nuclear power plants	Minimum because small quantity of fuel is required.
6.	*Cleanliness and simplicity*	Least clean as atmosphere is polluted due to smoke.	Most simple and clean.	More clean than steam power and nuclear power plants.	Less cleaner than hydroelectric and diesel power plants.