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Non-Conventional and Conventional Sources of Energy

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1.0 NON-CONVENTIONAL

The contemporary non-conventional sources of energy like wind, tidal, solar etc. were the conventional sources until James Watt invented the steam engine in the eighteenth century. In fact, the New World was explored by man using wind-powered ships only. The non-conventional sources are available free of cost, are pollution-free and inexhaustible. Man has used these sources for many centuries in propelling ships, driving windmills for grinding corn and pumping water, etc. Because of the poor technologies then existing, the cost of harnessing energy from these sources was quite high. Also because of uncertainty of period of availability and the difficulty of transporting this form of energy, to the place of its use are some of the factors which came in the way of its adoption or development. The use of fossil fuels and nuclear energy replaced totally the non-conventional methods because of inherent advantages of transportation and certainty of availability; however these have polluted the atmosphere to a great extent. In fact, it is feared that nuclear energy may prove to be quite hazardous in case it is not properly controlled.

In 1973 the Arab nations placed an embargo on petroleum. People began to realise that the fossil fuels are not going to last longer and that remaining reserves should be conserved for the petro-chemical industry. But unfortunately, both nuclear and coal energy pose serious environmental problems. The combustion of coal may upset the planet's heat balance. The production of carbondioxide and sulphurdioxide may adversely affect the ability of the planet to produce food for its people. Coal is also a valuable petro-chemical and from long term point of view it is undesirable to burn coal for generation of electricity. The major difficulty with nuclear energy is waste disposal and accidental leakage (*e.g*. leakage at Chernobyl nuclear power plant).

As a result of these problems, it was decided by almost all the countries to develop and harness the non-conventional sources of energy, even though they are relatively costlier as compared to fossil-fuel sources. It is hoped that with advancement in technology and more research in the field of development of non-conventional sources of energy, these sources may prove to be cost-effective as well. The future of wind, solar, tidal and other energy sources is bright and these will play an important role in the world energy scenerio.

The following sections have been devoted to the study of some of the important non-conventional sources of energy.

1.1 TIDAL POWER

1.1.1 Introduction

Tidal or lunar energy as it is sometimes called, has been known to mankind since time immemorial. Various devices, particularly the mills were operated using tidal power. In the past water supply of London was pumped to a water tower by a mill operated by the tidal power (which consisted of a large paddle wheel, mounted on a raft and fastened between two of the piers of old London Bridge). The tidal power has been used to irrigate fields in Germany and to saw firewood in Canada.

Tides are caused by the combined gravitational forces of Sun and Moon on the waters of the revolving Earth. When the gravitational forces due to the Sun and the Moon add together, tides of maximum range, called spring tides, are obtained. On the other hand, when the two forces oppose each other, tides of minimum range, called neap tides, are obtained. In one year there are approximately 705 full tidal cycles.

1.1.2 Basic Schemes

It has been suggested, that for harnessing tidal power effectively the most practicable method is the basin system. Here a portion of the sea is enclosed behind a dam or dams and water is allowed to run through turbines, as the tide subsides.

The power available from a given head of water varies as the square of the head and since the head varies with the tidal range, the power available at different sites from tidal energy shows very wide variation. Various tidal basin systems have, therefore, been evolved, in order to overcome this wide variation in availability of tidal power.

Single Basin System

The simplest scheme for developing tidal power is the single basin arrangement, in which a single basin of constant area is provided with sluices (gates), large enough to admit the tide, so that the loss of head is small. The level of water in the basin is the same as that of the tide outside. When the tides are high, water is stored in the basin and sluice gates are closed. When the tides are falling, sluices are opened to allow water to go through the turbine to generate power. A head of water is obviously required for the turbine to generate water. This continues to generate power till the level of the falling tides coincides with the level of the next rising tide.

The major disadvantage of this single basin scheme is that it gives intermittent supply of power, varying considerably over the period of operation. It is for this reason that the tidal power has not been developed on a large scale. Also with this scheme, only about 50 per cent of tidal energy is available.

Two Basin System

An improvement over the single basin system is the two-basin system. In this system, a constant and continuous output is maintained by suitable adjustment of the turbine valves to suit the head under which these turbines are operating.

A two-basin system regulates power output of an individual tide but it cannot take care of the great difference in outputs between spring and neap tides. This system, therefore, provides a partial solution to the problem, of getting a steady output of power from a tidal scheme.

This disadvantage can be overcome by the joint operation of tidal power and pumped storage plant. During the period when the tidal power plant is producing more energy than required, the pumped storage plant utilizes the surplus power for pumping water to the upper reservoir. When the output of the tidal power plant is low, the pumped storage plant generates electric power and feeds it to the system. This arrangement, even though technically feasible, is much more expensive, as it calls for higher installed capacity for meeting a particular load.

This basic principle of joint operation of tidal power with steam plant, is also possible when it is connected to a grid. In this case, whenever tidal power is available, the output of the steam plant will be reduced by that extent which leads to saving in fuel and reduced wear and tear of steam plant. This operation requires the capacity of steam power plant to be equal to that of tidal power plant and makes the overall cost of power obtained from such a combined scheme very high. In the system shown in Fig. 1.1, the two basins close to each other, operate alternatively. One basin generates power when the tide is rising (basin getting filled up) and the other basin generates power while the tide is falling (basin getting emptied). The two basins may have a common power house or may have separate power house for each basin. In both the cases, the power can be generated continuously. The system could be thought of as a combination of two single basin systems, in which one is generating power during tiding cycle, and the other is generating power during emptying.

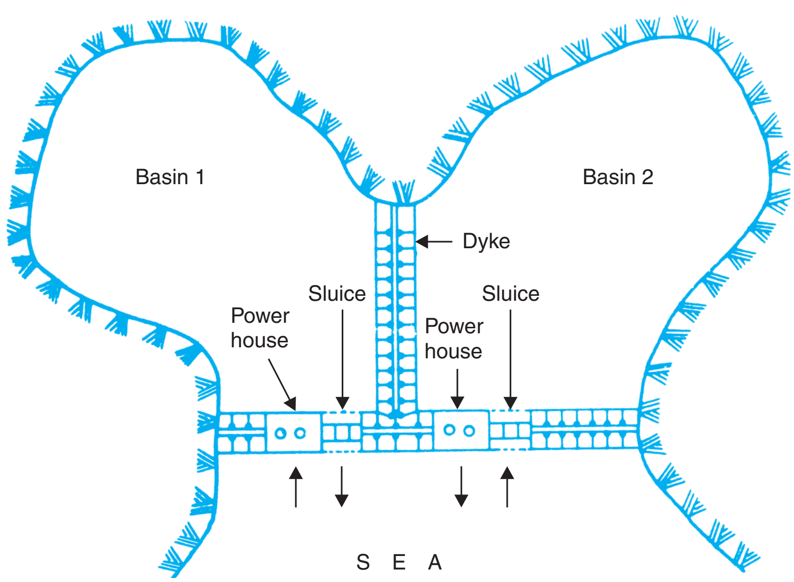


Fig. 1.1 Double Basin System

Cooperating double basin system. This scheme consists of two basins, at different elevation connected through turbine. The sluices in the high and low level basin communicate with sea water directly as shown in Fig. 1.2. The high level basin sluices are called the inlet sluices and the low level as outlet sluices. Ths basio operation of the scheme is as follows.

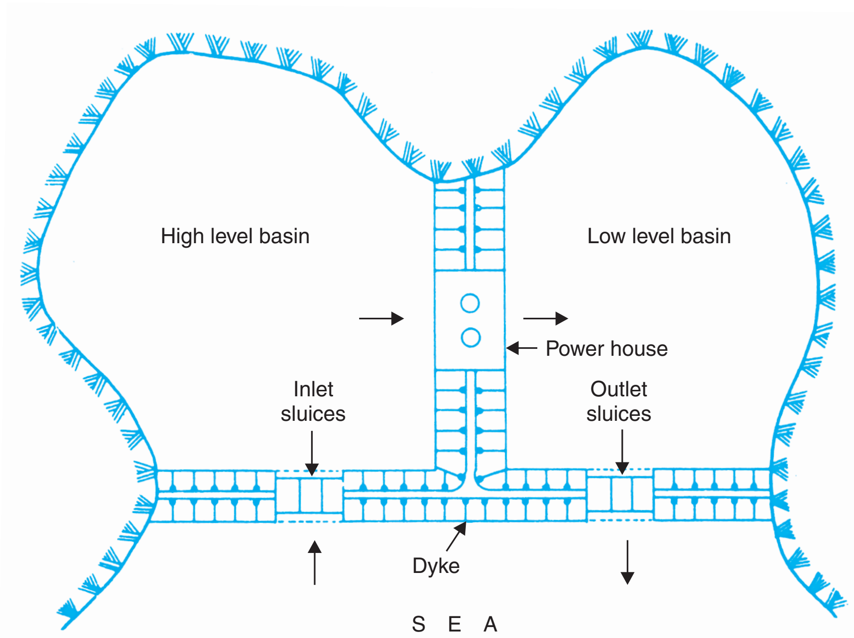


Fig. 1.2 Cooperating Double Basin System

Let us assume that the upper basin is filled with water. The water is allowed to flow to the lower basin through the turbine. Therefore, the level in the upper basin falls and that in the lower basin rises. At an instant when the rising level in the basin is equal to the level of the falling tide, the outlet gates are opened. When the tide reaches its lower most level, the outlet gates are closed. After a while the tide rises. When its level becomes equal to the low level of the upper basin, the inlet gates are opened. As a result, the level of the upper basin starts rising. At the same time, the turbines are fed from the upper basin transferring water to the lower basin, thus raising level of water there. When the tide reaches its peak value, the inlet gates are called again. Thus the cycle is repeated.

1.1.3 Turbines for Tidal Power

Tidal power plants operate using a rapidly varying head of water and, therefore, their turbines must have high efficiency at varying head. The Kaplan type of water turbine operates quite favourably under these conditions. The propeller type of turbine is also suitable because the angle of the blades can be altered to obtain maximum efficiency while water is falling.

A compact reversible horizontal turbine has been developed by French Engineer which acts with equal efficiency both as a pump and as a turbine. The bulb-type turbine (Fig. 1.3) consists of a steel shell completely enclosing the generator which is coupled to the turbine runner. The turbine is mounted in a tube within the structure of the barrage, the whole machine being submerged at all times.

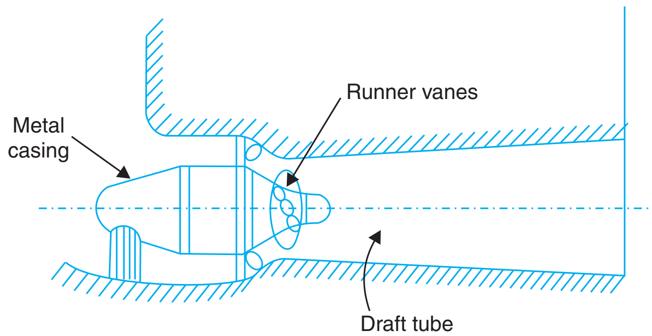


Fig. 1.3 Bulb-Type Turbine

When the power demand on the system is low during the rising tides, the unit operates as a pump to transfer water from sea to the basin. When the load on this system is high, the unit will work as a generator, and deliver the stored energy which is a valuable additional input to the system.

There are two tidal power plants in France now in operation; an experimental one with a capacity of 9 MW at Saint Malo and a 240 MW Plant with a 700 m long dam at the mouth of the Rance River. A large number of tidal power projects have been planned but subsequently abandoned because of the high cost involved and obstruction in navigation.

Even though many problems have to be overcome in tidal power development, this form of power has certain definite advantages. Output of a tidal power station is independent of the seasonal changes and can be predicted well in advance, as it depends on the cosmic phenomenon. It is possible to predict the amount of power and the time at which it will be available throughout the year. This power can, therefore, be utilized at the proper position of the load curve.

More than fifty sites have been identified in the world for possible generation of tidal power. As more and more technological advancement take place, even more sites could be identified for tidal power development. Some of the important sites are:

(*i*) La Rance (France), (*ii*) Severn Barrage (UK), (*iii*) White sea (USSR), (*iv*) Passamaquoddy (USA), (*v*) Gulf of Cambey (India) and (*vi*) Gulf of Kutch (India).

The maximum tidal range in the Gulf of Cambey is about 10.8 m and is quite attractive for a tidal plant. However, the silt charge of the Gulf of Cambey is relatively high and needs a closer study for further development.

The Gulf of Kutch has a maximum spring tide of 7.5 m and the silt charge is relatively low.

1.2 WIND POWER

1.2.1 Introduction

The wind wheel, like the water wheel, has been used by man for a long time for grinding corn and pumping water. Ancient seamen used wind power to sail their ships. With the development of the fossil fuelled and hydro-electric plants, there was decline in the use of wind power due to the less cost involved in the new methods. Another difficulty with wind power was the problem of energy storage. The energy could not be made available, on demands, due to uncertainties of wind. Due to these two reasons, no further attempt was made to develop wind power for large scale power generation.

In recent years, however, as a result of energy crisis in the world, it has been decided to investigate all possible means of developing power, as alternatives to fuel fired plants. The wind could supply a significant portion of the world's energy demand. An estimate by an American Professor indicates the potentialities of wind power. According to him about 350,000 wind mills each rated for about 1250 KW to 2200 KW could develop power of the order of 190,000 MW. With the advancement in the knowledge of aero-dynamics it has been possible to build larger and more efficient wind power plants. A typical example is the 1250 KW installation at Grandpa's Knol in U.S.A. Whereas some success has been achieved in developing small and medium size plants, the prospects of large scale generation *i.e.*, 1 MW or above are not, as yet very encouraging.

1.2.2 Characteristics of Wind Power

Wind as a source of energy is plentiful, inexhaustible and pollution free but it has the disadvantage that the degree and period of its availability are uncertain. Also, movement of large volumes of air is required, to produce even a moderate amount of power. As a result, the wind power must be used as and when it is available, in contrast to conventional methods where energy can be drawn upon when required. Wind power, therefore, is regarded as a means of saving fuel, by injection of power into an electrical grid, or run wind power plant in conjunction with a pumped storage plant.

The power that can be theoretically obtained from the wind, is proportional to the cube of its velocity and thus high wind velocities are most important. The power developed using this law, in atmospheric condition where the density of air is 1.2014 kg/cu metre, is given as

$$\text{Power developed} = 13.14 \times 10^{-6}\, A\, V^3 \text{ KW}$$

where A is the swept area in sq. metre and V the wind velocity in Km/hr. The energy developed is affected by :

The Altitude of the Site

The velocity of the wind increases with the altitude. In general, the higher the wind wheel is placed above ground, the greater will be wind power available.

Velocity Duration Curve

The variation of velocity of wind over the period affects the power output, *e.g.*, let the velocity over the first hour be 30 kmph and the next hour be 20 kmph. The energy developed is proportional to $30^3 + 20^3 = 35{,}000$. On the other hand, if we assume average velocity during these two hours of 25 kmph, the power developed is proportional to $2 \times 25^3 = 33250$. Thus, the relation between the actual energy available, and that available from a steady wind of average velocity, varies considerably and depends on the shape of the velocity-duration curve for the period of generation.

The wind speeds, between which a wind wheel generator operates, are limited. A certain minimum wind velocity is required to overcome frictional and other losses of the machine and, on the other hand, it would be uneconomical to design a plant for very high velocity wind which would occur only for a small period over the year. Therefore, the machine must be designed for a rated wind velocity, for which the output is maximum. Typical wind velocities for some sites may range between 30 kmph to 45 kmph.

The rated wind velocity, for which a plant is designed substantially affects the specific output (K whr generated per annum per KW installed capacity) and also the cost of construction. If the rated velocity is low, the specific output is high as full output will be generated for a relatively longer duration of the year, whereas if the rated velocity is high, the converse will be true. But with low rated wind velocity, a larger diameter wheel will be required for a given KW rating, which in turn increases the cost of the plant. Economic development of wind power, therefore, requires selection of sites where high specific outputs are compatible with reasonable cost of construction of plant. It is, therefore, necessary to obtain wind velocity duration curve for a particular site and to know the output of the machine for varying wind velocities. The maximum efficiency of the wind power plant is found not to exceed 40%.

1.2.3 Design of Wind Wheels

Several types of wind wheels have been used but the advantage of propeller rotating about a horizontal shaft, in a plane perpendicular to the direction of the wind make it the most likely type to realise economic generation on a large scale. A propeller consisting of two or three blades (with an aerofoil section) and capable of running at the high speeds is likely to be the most efficient. Present technology has been able to build systems with 60 m long blades, on towers as high as 305 m. A large tower system, to support many small rotor-generator units, can also be built.

Wind pressure rotates the wind vanes or propellers attached to a shaft. The revolving shaft rotates the rotor of a generator, through a mechanism of gears couplings etc. Thus, electricity is generated.

The wind power plants can be operated in combination with steam or hydro power station, which will lead to saving in fuel and increase in firm capacity, respectively of these plants.

Wind energy can prove to be a potential source of energy for solving the energy problem. It can certainly go a long way to supply pollution-free energy to millions of people, living in the villages all over the world.

The economic viability of wind mills is better in situations where conventional transmission costs are extremely high (because of inaccessiability and small load) or where continuous availability of supply is not essential so that only a limited amount of storage on standby power need be provided.

1.3 GEOTHERMAL POWER

1.3.1 Introduction

Many geothermal power plants are operating throughout the world. Although larger geothermal power plants are in operation in America today, it is to the credit of the Italians that the first impressive breakthrough in geothermal power exploitation was achieved. The oldest geothermal power station is near Larderello in Italy, which has an installed capacity of 380 MW. In Newzealand geothermal power accounts for 40% of the total installed capacity, whereas in Italy it accounts for 6%.

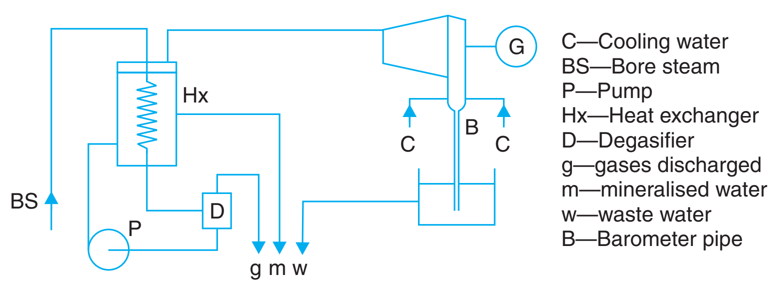
It is a common knowledge that the earth's interior is made of a hot fluid called 'magma'. The outer crust of the earth has an average thickness of 32 Km and below that, is the magma. The average increase in temperature with depth of the earth is 1°C for every 35 to 40 metre depth. At a depth of 3 to 4 Kms, water boils up and at a depth of about 15 Kms, the temperature is, in the range of 1000°C to 1200°C. If the magma finds its way through the weak spots of the earth's crust, it results into a volcano. At times, due to certain reasons the surface water penetrates into the crust, where it turns into steam, due to intense heat, and comes out in the form of springs or geysers. Moveover, the molten magma also contains water, which it releases in the form of steam, which could be utilized for electric power generation.

1.3.2 Principle of Operation

Various types of cycles have been suggested for geothermal power generation. Only two important ones, which are being used in practice, are discussed here.

Indirect Condensing Cycle

While developing Larderello power plant, it was thought, that geothermal steam may corrode the turbines. Therefore, an indirect system was adopted, which involved the use of a heat exchanger by means of which clean steam was raised from contaminated natural steam (Fig. 1.4). In spite of the fact that about 15% to 20% of the steam power potential had to be sacrificed in the heat exchanger, the cycle was considered economical, because of the recovery of minerals and non-condensible gases from the new steam.



(a)

Fig. 1.4 Indirect Condensing Cycle

With the advancement in metallurgy technology and the declining economic attractions of mineral extraction, through this process, this cycle has been rendered obsolete.

Direct Non-Condensing Cycle

This is the simplest, cheapest and most widely used geothermal cycle. Bore steam, either direct from dry bores, or after separation (using centrifugal separator) from wet bores, is simply passed through a turbine and exhausted to atmosphere (Fig.1.5).

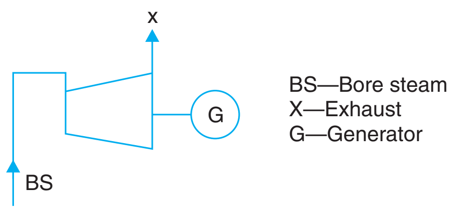


Fig. 1.5 Direct Non-Condensing Cycle

There is a need for utilizing the heat available from the high temperature (about 1000°C) layers of the earth. It has been suggested that water should be pumped into artificial volcanic craters and then turned into useful steam.

Like hydro power stations, geothermal power plants are unattended and do not need full time supervision. Since the units are unattended, the warning alarm can be transmitted to the attended station where appropriate action can be taken.

If a well has been shut down, it requires several hours to get it upto rated flow to clear it of water and debris. Some more time is required to warm up the steam collection system piping the drain condensate from it. No attempt should be made to fast start ups as it results in damage to the turbine blades. Steam temperature and steam line drains should be closely monitored, for any indication of water. If there is any possibility of water coming alongwith the steam, the unit should be tripped to prevent damage to the turbine. Rated turbine throttle pressure is maintained by connecting sufficient number of wells to the supply line of a unit. Whenever a unit trips, the steam should be released to the atmosphere. If a unit is to be shut down for a long time, the wells should also be shut down.

It is important that a systematic schedule of preventive maintenance be observed at these plants. A rigidly planned periodic maintenance schedule must be adhered to. Units should be inspected every three years. An adequate stock of spare parts–especially the turbine blades–must be maintained. With proper maintenance, it is possible to operate these plants at very high annual plant load factor of the order of 90% or even more.

1.3.3 Combined Operation of Geothermal Plant

It is well known that a composite power system can be supplied more economically by a combination of two main types of plants:

(*i*) Base Load Plant which is characterised by high fixed cost and low variable cost.

(*ii*) Peak load Plant which is characterised by low fixed cost and high variable cost.

In case of a geothermal plant, the usual practice is to regard all the production cost as fixed cost, with zero variable cost as no fuel is required for its operation. This is justified by the fact, that once geothermal steam has been made available by means of capital spent on exploitation, drilling and pipe work, it may be regarded as free. Geothermal plants are, therefore, ideally rated as base load plants. Most of the plants today are being used as base load plants as they can achieve annual plant load factor of 90% or more–higher than that obtainable from thermal or nuclear plant.

The commercial viability of a geothermal power plant as compared to other sources, depends upon the cost of alternative power sources and other local factors. As a rule of thumb, the following guidelines may be followed to assess its viability:

(*i*) The fluid temperature at the bottom of the bore should be at least 180°C.

(*ii*) A temperature of 180°C should be available at depths not exceeding 3 Kms.

(*iii*) The yield from a 24 1/2 cm bore should be at least 20 tons/hr of steam.

The following are some of the geothermal power projects in operation :

Larderello	:	Italy
Geysers	:	California (USA)
Cerro Prieto	:	Mexico
Hatchobaru	:	Japan
Matsukawa	:	Japan
Paratunka	:	USSR
Wairakei	:	New Zealand
Pugga Multipurpose Project (Ladakh)	:	India

At present geothermal energy makes a very small, but locally important, contribution to world energy requirements. This situation will not change unless important technological advances are made. Environmentally, it is probably the least objectionable form of power generation available at present, with, the exception of hydroelectric methods.

1.4 WAVE POWER

1.4.1 Introduction

Another source of non-conventional energy generation is the wave power. The major problem with the wave power is that it is not concentrated at a place. If means could be developed for collecting the energy in the wave, spread over a large surface area, and concentrating it into a relatively small volume, the prospects, would be considerably improved.

It has been observed that a typical wave measures 2 to 3 metres in height throughout the year. The energy per square metre of wave surface area is given as $1/2\ \rho\, ga^2$ where ρ is density of sea water, g is acceleration due to gravity and a is the amplitude of the wave. In the Atlantic, the wave period T is around 9s, and the average velocity of propagation of wave is 14 m/s. It has been observed that a power flow of around 70 KW for every metre of wave front, can be obtained. This is a considerable amount of power, especially when we think of the availability of this power throughout the year. If the length of the coast line is, say 1200 Km, the power available is around 84 GW.

1.4.2 Wave Power Conversion Devices

A large number of devices for converting wave power to mechanical power have been suggested in the literature *e.g*. flaps, ramps, floats and converging channels.

A device known as Salter Cam is being used for this purpose which has a high efficiency (75%). A cross section of the device is shown in Fig. 1.6. It simulates the action of a vertical flapping plate at the front where energy is absorbed, but the rear is cylindrical so that the water beyond the device is not disturbed, as it rotates. Due to its asymmetrical shape, the response of this device depends upon its loading and therefore, counter-balancing is necessary.

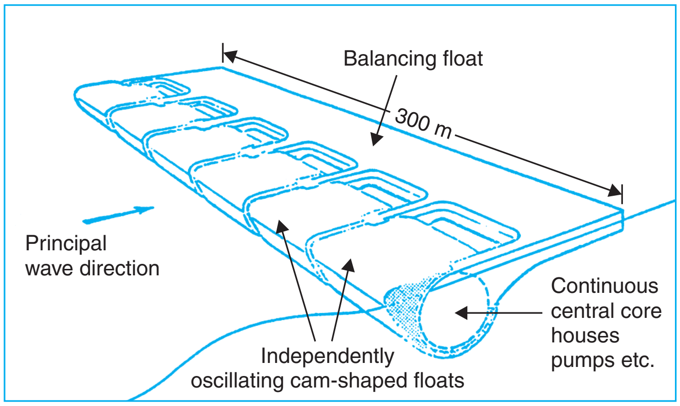


Fig. 1.6 Salter Cam

Another device suggested by Masuda uses a bell shaped chamber filled with air, which is pumped through an air turbine by the rising and falling motion of the water. A large number of such devices are in use, for providing about 60 watt of power for marine buoy lights. Such devices are inherently small in size, but a large number of them could be put together, to provide a large floating structure *e.g.* an arrow-shaped triangular structure (Fig. 1.7) for mounting, near the shore.

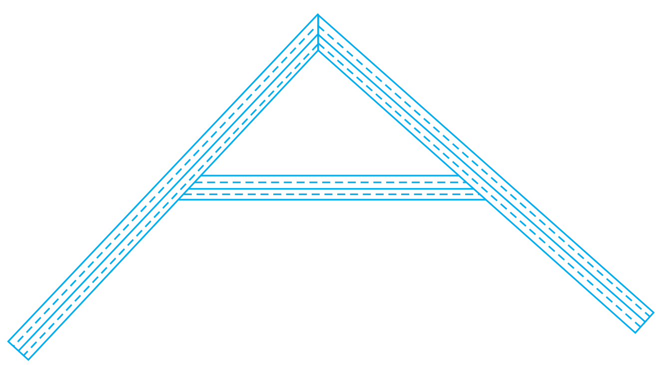


Fig. 1.7 Masuda System of Floating Buoys

Wave power, even though looks to be a single component, but it must be considered in its entirety if it has to make significant contributions. Fig. 1.8 shows various possible ways in which wave power can be used and shows the various links between the sea-waves and the consumer of power.

If the wave power is to be brought off-shore as electrical power, a submarine cable will be required. In recent times a lot of technological developments have taken place in the design and manufacture of submarine cables and it should not be a problem to produce economical submarine cables. A variable frequency generator could feed a rectifying device. The power could be transmitted through the cable to the substation. It could then be inverted and fed into a grid system. Alternatively, the power could be used on-board floating factories. Also, hydrogen could be produced by the d.c. output which could be supplied to the consumer as fuel.

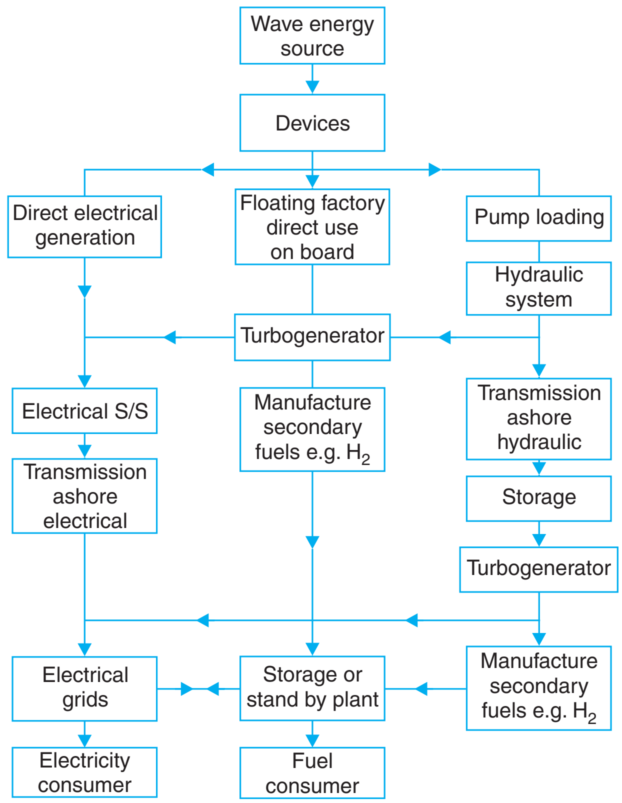


Fig. 1.8 Use of Wave Power

Another possibility is that the energy could be transmitted hydraulically, using a storage system to provide short term storage before transfer to a turbo-generator. The conversion equipment would be inside the cams and the electricity outputs connected to a floating substation by cable.

1.5 MAGNETO HYDRO DYNAMIC (MHD) GENERATION

1.5.1 Introduction

In the conventional steam power plants, the heat released by combustion of fuel is transformed into the internal energy of steam. The temperature and pressure of steam increase in the process. The steam turbine, then, converts steam energy into mechanical energy, which drives a generator. This way, the mechanical energy is converted into electric energy. The repeated conversion of various forms of energy involves losses and, hence, the overall efficiency of thermal power plant decreases. The typical range of effciency of thermal plants is 37 to 40%. The direct conversion of heat to electricity would enable the industry to use the fuel resources more efficiently. MHD generation is one form of energy technology, wherein direct conversion of heat into electric energy has been devised. The technological development in the field of plasma physics and metallurgy etc. and other branches of science and technology has made it possible for this kind of direct transformation of energy.

An ionized gas is used as conducting medium in the MHD generator. The gas can be made electrically conducting when it is maintained at least at a temperature of 2000°C. This fact does not allow MHD generation from being used in the entire temperature range from 3000 K to 300 K. It is therefore, thought beneficial that MHD generators be used in conjunction with steam operated thermal plants utilising the heat of the gas leaving the MHD ducts. The combined operation of MHD generators alongwith the conventional thermal plant, will raise the overall efficiency to nearly 60%, thereby lot of saving in the fuel cost will result.

1.5.2 Principle of Operation of MHD Generator

The basic principle of operation is based on Faraday's law of electro magnetic induction, which states an e.m.f. is induced in a conductor moving in magnetic field. The conductor may be a soild, liquid or a gaseous one. The study of the dynamics of an electrically conducting fluid interacting with a magnetic field, is called magneto hydro dynamics.

In this method (Fig. 1.9) gases at about 2500°C are passed through the MHD duct across which a strong magnetic field has been applied. Since the gases are hot, and partly ionized they form an electrically conducting conductor moving in the magnetic field. An e.m.f. (direct-current) is thus induced, which can be collected at suitable electrodes.

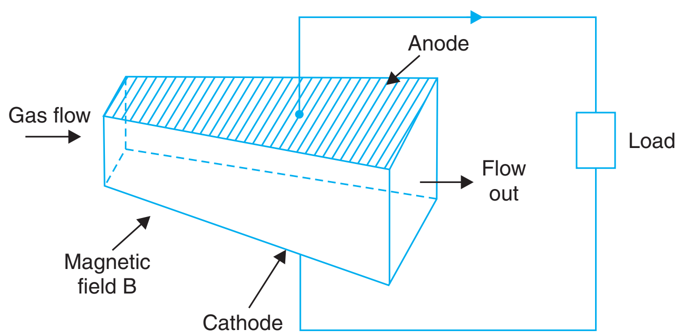


Fig. 1.9 Basic Principle of MHD Generator

Block diagram of a typical open cycle MHD power plant is shown in Fig. 1.10.

1.6 SOLAR ENERGY

1.6.1 Introduction

Sun is the primary source of energy. The earth receives 1.6 × 10^{18} units of energy from the Sun annually, which is 20,000 times the requirement of mankind on the earth. Some of the solar energy causes evaporation of water, leading to rains and creation of rivers etc. Some of it is utilized in photosynthesis which is essential for sustenance of life on earth. Man has tried, from time immemorial, to harness this infinite source of energy, but has been able to tap only a negligibly small fraction of this energy, till today.

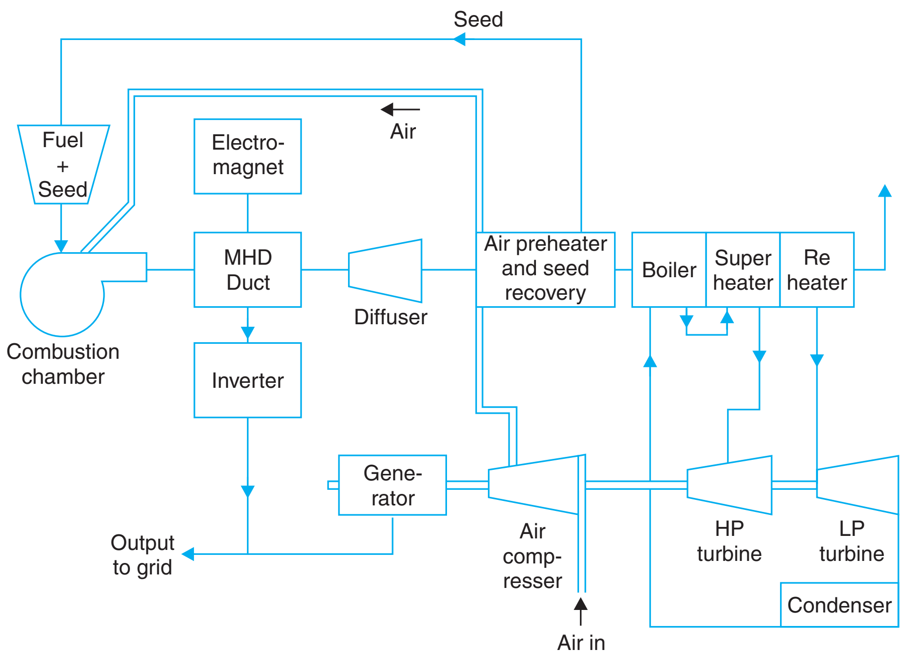


Fig. 1.10 Block Diagram of Open Cycle MHD Power Station

Three broad categories of possible large scale applications of solar power are:

(*i*) The heating and cooling of residential and commercial buildings;

(*ii*) The chemical and biological conversion of organic material to liquid, solid and gaseous fuels; and

(*iii*) Conversion of solar energy to electricity.

The use of solar energy for generation of electricity is costly as compared to conventional methods. However, due to scarcity of fuel, solar energy will certainly find a place in planning the national energy resources.

1.6.2 Residential cooling and heating

A major component of our electricity bill is due to heating and cooling of buildings. This can be achieved using solar energy. A typical solar energy scheme is shown in Fig. 1.11. A flat plate collector is located on the roof of a house, which collects the solar energy. The cooling water is pumped through the tubes of the solar collector. The heat is transferred from the collector to the water and the hot water is stored in a storage tank which may be located at ground level or in the basement of the house. Hot water is then utilized to heat or cool the house by adjusting the automatic valve. A separate circuit is there to supply hot water. Thus all the three requirements *i.e.*, space cooling, heating and water heating are met.

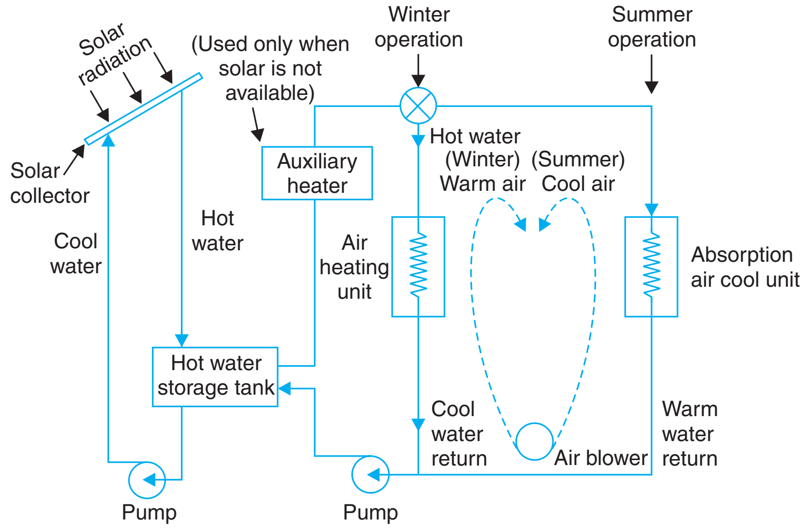


Fig. 1.11 Schematic Diagram of Residential Cooling and Heating with Solar Energy

1.6.3 Photosynthesis Production of Energy Sources

Solar energy can be transformed into chemical energy in the form of plants and trees, through the process of photosynthesis, which is the basis of the world's fossil fuels. It is, now possible, to produce organic matter with high heat content, by using suitable chemical processes.

1.6.4 Solar Power Plant

It is known that only a small fraction of the energy radiated by the Sun reaches the Earth. It would, therefore, be an attractive proposition, if energy could be received from outside the atmosphere and then transmitted to the earth. A man-made satellite revolving around the earth will receive energy for all the 24 hours and will not be affected by the weather conditions.

Fig. 1.12 shows the arrangement and general view of a solar power plant, carried by a man-made satellite. The solar cell panels to be installed on the satellite may vary in area from

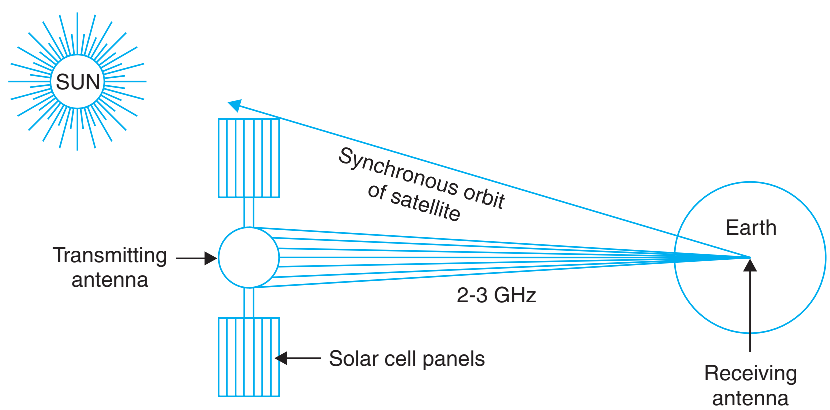


Fig. 1.12 Solar Power Plant

16 to 100 sq km according to the plant capacity. The solar cells arranged in space would generate d.c. electric power and transmit it by means of microwaves (of about 10 cm. wave length), using a transmitting antenna. Microwave transmission may be at 2 to 3 GHz, as this keeps the losses at minimum. On the earth, this energy will be converted into high voltage d.c. or commercial frequency electric power.

The diameter of transmitting antenna would be around 1 km and that of the receiving antenna, 7 to 10 Kms. The effeciency of transmission is estimated to be in the range of 55 to 75%. The overall efficiency, with the present technology, is around 25% but is likely to go upto 60% in the near future.

The solar cells operate on the principle of photo electricity *i.e.*, electrons are liberated from the surface of a body when light is incident on it. Backed by semi-conductor technology, it is now possible to utilize the phenomenon of photo-electricity.

It is known that if an *n*-type semi-conductor is brought in contact with a *p*-type material, a contact potential difference is set-up at the junction (Schottky effect), due to diffusion of electrons. When the *p*-type material is exposed to light, its electrons get excited, by the photons of light, and pass into the *n*-type semi-conductor. Thus, an electric current is generated in a closed circuit. The *pn* junction silicon solar cells have emerged as the most important source of long duration power supply necessary for space vehicles. These cells are actuated by both, direct Sun rays and diffuse light. The efficiency of silicon solar cells increases with decreasing temperature. In cold weather the decreased luminous flux is compensated for, by higher efficiency. The efficiency of these solar cells varies from 15 to 20%.

Although the energy from the Sun is available free of cost, the cost of fabrication and installation of systems, for utilization of solar energy, is often too high to be economically viable. In order to make solar installations economically attractive, plastic materials are being increasingly used for the fabrication of various components of the system.

The efficiency of solar heating/cooling installation depends on the efficiency of collection of solar energy and its transfer to the working fluid (*e.g*. water, air etc.). There are two main classes of collectors. The flat plate collector is best suited for low and intermediate temperature applications (40°–60°, 80°–120°C) which include water heating for buildings, air heating and small industrial applications like agricultural drying etc. The concentrating collectors are usually employed for power generation and industrial process heating.

1.6.5 Solar Concentrators

Solar concentrators are the collection devices which increase the flux on the absorber surface as compared to the flux impinging on the concentrator surface. Optical concentration is achieved by the use of reflecting refracting elements, positioned to concentrate the incident flux onto a suitable absorber. Due to the apparent motion of the Sun, the concentrating surface, whether reflecting or refracting, will not be in a position to redirect the sun rays onto the absorber, throughout the day if both the concentrator surface, and absorber are stationary. Ideally, the total system consisting of mirrors or lenses and the absorber should follow the Sun's apparent motion so that the Sun rays are always captured by the absorber. In general, a solar concentrator consists of the following:

(*i*) a focussing device;

(*ii*) a blackened metallic absorber provided with a transparent cover; and

(*iii*) a tracking device for continuously following the Sun.

Temperatures as high as 3000°C can be achieved with such devices and they find applications in both photo-thermal and photo-voltaic conversion of solar energy. The use of solar concentrators has the following advantages:

(*i*) Increased energy delivery temperature, facilitating their dynamic match between temperature level and the task.

(*ii*) Improved thermal efficiency due to reduced heat loss area.

(*iii*) Reduced cost due to replacement of large quantities of expensive hardware material for constructing flat plate solar collector systems, by less expensive reflecting and/or refracting element and a smaller absorber tube.

(*iv*) Increased number of thermal storage options at elevated temperatures, thereby reducing the storage cost.

Parameters Characterising Solar Concentrators

Several terms as used to specify concentrating collectors. These are:

(*i*) *The aperture area* is that plane area through which the incident solar flux is accepted. It is defined by the physical extremities of the concentrator.

(*ii*) *The acceptance angle* defines the limit to which the incident ray path may deviate, from the normal drawn to the aperture plane, and still reach the absorber.

(*iii*) *The absorber area* is the total area that receives the concentrated radiation. It is the area from which useful energy can be removed.

(*iv*) *Geometrical concentration ratio* or the radiation balance concentration ratio is defined as the ratio of the aperture area to the absorber area.

(*v*) *The optical efficiency* is defined as the ratio of the energy, absorbed by the absorber, to the energy, incident on the aperture.

(*vi*) *The thermal efficiency* is defined as the ratio of the useful energy delivered to the energy incident on the aperture.

Solar concentrators may be classified as point focus or line focus system. Point focus systems have circular symmetry and are generally used when high concentration is required as in the case of solar furnaces and central tower receiver systems. Line focus systems have cylindrical symmetry and generally used when medium concentration is sufficient to provide the desired operating temperature.

A solar concentrator consists of the following components:

(*i*) A reflecting or refracting surface, (*ii*) An absorbing surface *i.e.*, an absorber, (*iii*) A fluid flow system to carry away the heat, (*iv*) a cover around the absorber, (*v*) Insulation for the unirradiated portion of the absorber and (*vi*) A self supporting structural capability and well adjusted tracking mechanism.

1.6.6 Flat Plate Collector

The schematics of a flat plate collector are shown in Fig. 1.13. It usually consists of five main components viz.

(*i*) an absorber plate (metallic or plastic),

(*ii*) tubes or pipes for conducting or directing the heat transfer fluid,

(*iii*) one or more covers,

(*iv*) insulation to minimise the downward heat loss from the absorbing plate,

(*v*) casing which encloses the foregoing components and keeps them free of dust and moisture and also reduces the thermal losses.

Generally flat plate collectors are framed sandwich structures, mounted on roofs or sloping walls. In most of these collectors, the absorber element is made of a metal such as galvanised iron, aluminium, copper etc. and the cover is usually of glass of 4 mm thickness. The back of the absorber is insulated with glass wool, asbestos wool or some other insulating material. The casing, enclosing all the components of the collector is either made of wood or some light metal like aluminium. The cost, with such meterials, is rather too high to be acceptable for common use. As the temperatures needed for space heating are rather low, plastics are being considered as potential material for fabrication of various components of the flat, plate collector. This would make solar energy systems comparable with other energy systems.

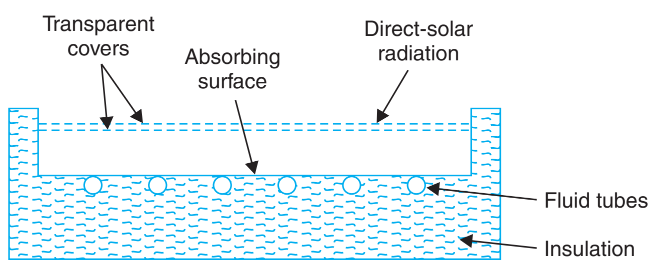


Fig. 1.13 Schematics of a Flat Plate Solar Collector

1.7 CONVENTIONAL SOURCES

1.7.1 Hydro Station

The water wheel, as developed in the early part of 19th century, played an important role in converting water power into mechanical power. With the invention of steam engines, the use of water wheel began to decrease and larger steam engines were developed. Steam engines possessed the advantage of mobility, allowing power to be produced, where it was required and also that of flexibility in its application.

It was only later with the discovery of conversion of mechanical energy into electric energy, and transmission of electric energy being the most efficient method of transporting energy from one place to another, that water wheel was revived. The modern water turbine, is being built in single unit of more than 200 MW. Also, the concept multipurpose project, in which the production of power is included as one of several uses (flood control, navigation, irrigation, water for domestic and industrial purpose, etc.), has led to the development of sites which otherwise could not be harnessed economically for power alone. The capital investment per KW is much higher in case of hydro power as compared to thermal power. This is because in order to store water at sufficient head, it is essential to construct a dam which is a costly affair. However, the running cost of hydro electric energy is much less as no fuel is used.

Water power differs fundamentally from thermal power in that it represents an inexhaustible source of energy which is continually replenished by the direct agency of the Sun; whereas thermal power represents chemical energy which has been created and stored within the earth's crust during past geological ages. The use of chemical energy is thus equivalent to the consumption of capital as the replacement is not so easy. Another important difference between the two is that whereas water power can be developed only where it is present in nature, thermal power (liquid or solid fuel) can be transported for use from one place to another.

1.7.2 Selection of Site

Preliminary investigation regarding catchment area, average rainfall, ground gradient, geology of foundation, availability of raw material for construction work are required. The important factors governing selection are as follows:

1. *Location of Dam*

From the cost point of view smaller the length of dam, the lower will be the cost of construction. Therefore, the site has to be where the river valley has a neck formation. In order to have capacity, a valley which has a large storage capacity on the upstream side of the proposed dam site is probably the best. It is desirable to locate a dam after the confluence of two rivers so that advantage of both the valleys to provide larger storage capacity is available.

2. *Choice of Dam*

The most important consideration in the choice of the dam is safety and economy. Failure of a dam may result in substantial loss of life and property. The proposed dam must satisfy the test of stability for : (*i*) shock loads which may be due to earthquakes or sudden changes in reservoir levels and (*ii*) unusually high floods.

The dam should, as far as possible, be close to the turbines and should have the shortest length of conduit.

3. *Quantity of Water Available*

This can be estimated on the basis of measurements of steam flow over as long a period as possible.

Storage of water is necessary for maintaining continuity of power supply thoughout the year. Sufficient storage of water should be available since rainfall is not uniform thoughout the year and from one year to another.

4. *Accessibility of Site*

The site should be accessible from the view point of transportations of man and material, so that the overall cost for construction, of project is kept low.

5. *Distance from the Load Centre*

The distance should be as small as possible so that the cost of transmission of power is minimum.

Availability of construction material and general knowledge, should also be considered in site selection.