KINGS
ENGINEERING COLLEGE
AUTONOMOUS
Accredited with NAAC, Approved by AICTE & Affliated to Anna University

DEPARTMENT
OF
MECHHANICAL ENGINEERING

Regulation 2021

IV Year – VII Semester

CME365 - RENEWABLE ENERGY TECHNOLOGIES

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UNIT - I

1 Introduction

Syllabus

World Energy Use - Reserves of Energy Resources - Environmental Aspects of Energy Utilisation - Renewable Energy Scenario in Tamil nadu, India and around the World - Potentials - Achievements / Applications - Economics of renewable energy systems.

Contents

1.1 Introduction to Energy

- **Energy** is defined as a property of objects which can be transferred from one object to another objects or converted into different forms of energy.
- Energy is the capacity to do work, generating heat and emitting light.
- Heat is the ability to change the temperature of an object or phase of a substance.
- For example, heat changes from an ice into water or water into water vapor.
- Heat is part of the definition of energy.
- Another part of the definition of energy is radiation, which is the light and energy emitted in the form of waves travels at the speed of light (3×10^8m/s).
- Energy is measured in calorie, erg, and joule units.
- One kilo-calorie is the amount of heat energy required to raise the temperature of 1 kg of water from 14.5 °C to 15.5 °C temperature.
- Any physical activity in this world, whether carried out by human beings or by nature, is cause due to flow of energy in one form or the other.
- The word 'energy' itself is derived from the Greek word 'en-ergon', which means 'in-work' or 'work content'.
- The work output depends on the energy input.
- Energy is one of the major inputs for the economic development of any country.
- In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them.
- The different types of energy are

1. Mechanical Energy (Kinetic and Potential)
2. Nuclear Energy
3. Electrical Energy
4. Thermal Energy
5. Chemical Energy
6. Radiant Energy
7. Gravitational Energy
8. Electromagnetic Energy

1.2 Classification of Energy

- Energy can be classified into several types based on the following criteria :
  1. Primary and Secondary energy
  2. Commercial and Non-commercial energy
  3. Renewable and Non-Renewable energy
  4. Conventional and Non-conventional energy

1. Primary and Secondary Energy

- Primary energy sources are those that are either found or stored in nature.
- Common primary energy sources are coal, oil, natural gas, and biomass (such as wood).
- Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity.

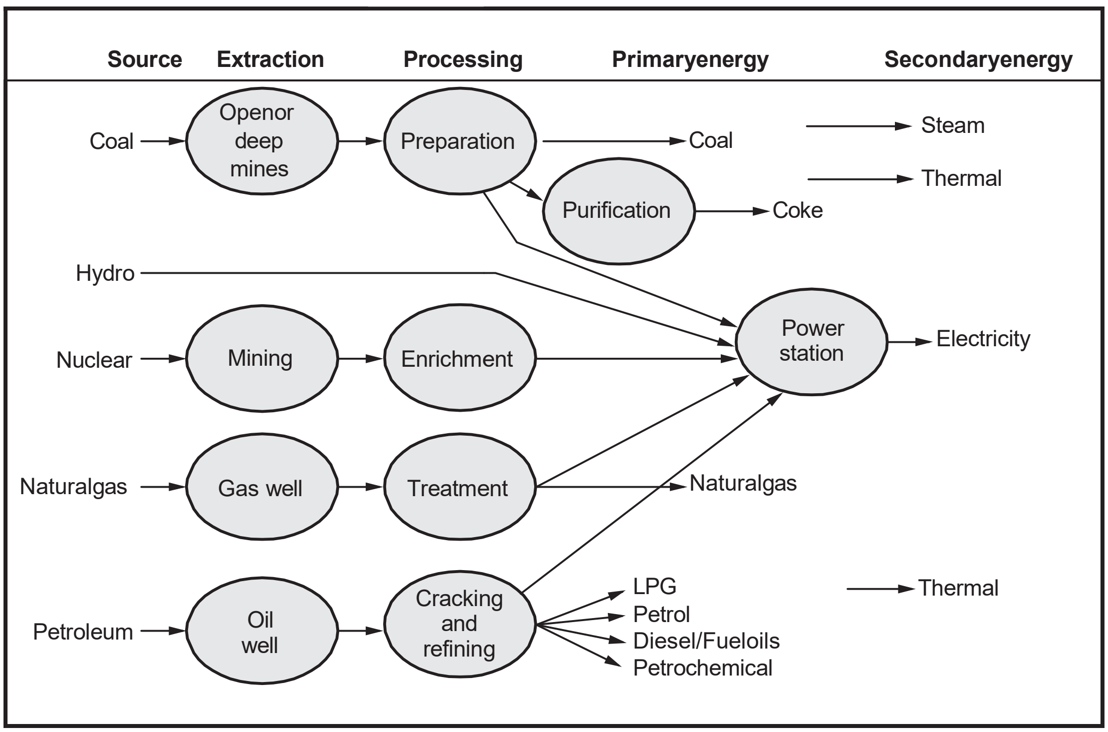

Fig. 1.2.1 Major primary and secondary sources

- The major primary and secondary energy sources are shown in Fig. 1.2.1.

- Primary energy sources are costly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity.
- Primary energy can also be used directly.
- Some energy sources have non energy uses, for example coal or natural gas can be used as a feedstock in fertilizer plants.

2. Commercial Energy and Non Commercial Energy

i. Commercial Energy

- The energy sources that are available in the market for a definite price are known as commercial energy.
- By far the most important forms of commercial energy are electricity, coal and refined petroleum products.
- Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world.
- In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.
- Examples: Electricity, lignite, coal, oil, natural gas etc.

ii. Non-Commercial Energy

- The energy sources that are not available in the commercial market for a price are classified as non-commercial energy.
- Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.
- Example : Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

3. Renewable Energy and Non-Renewable Energy

- Renewable energy is energy obtained from sources that are essentially inexhaustible.
- Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power (See Fig. 1.2.2).

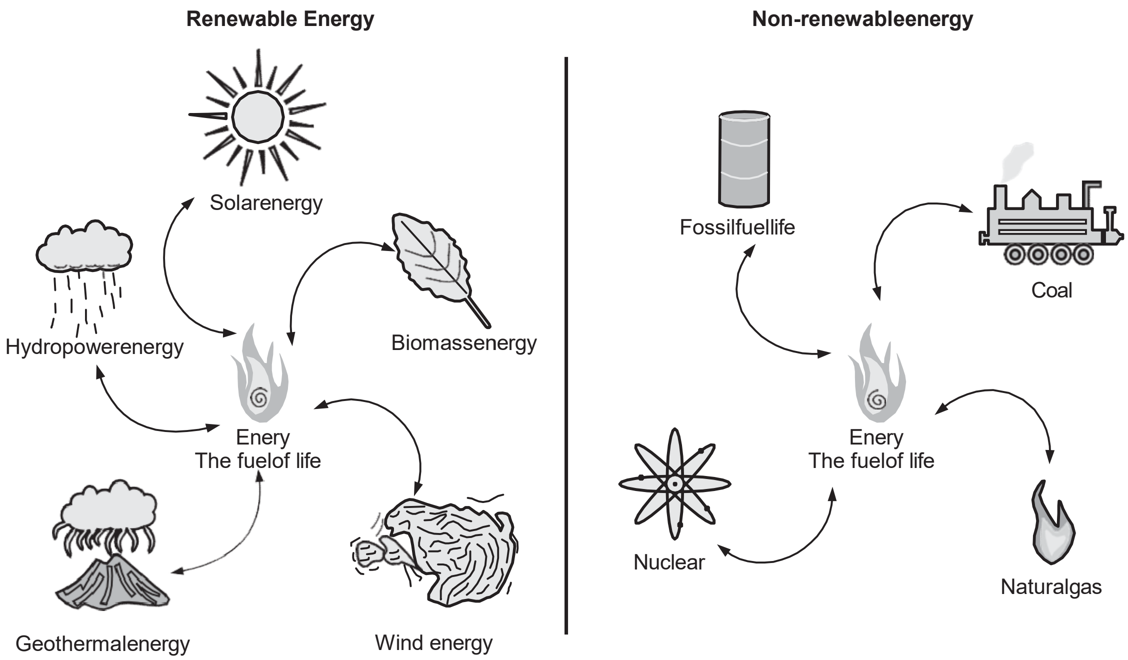

Fig. 1.2.2

- The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.
- Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

4. Conventional Energy & Non-conventional energy

i. Conventional Energy

- Conventional energy resources which are being traditionally used for many decades and were in common use around oil crisis of 1973 are called conventional energy resources, e.g., fossil fuel, nuclear and hydro resources.

ii. Non-conventional energy

- Non-conventional energy resources which are considered for large - scale use after oil crisis of 1973, are called non-conventional energy sources, e.g., solar, wind, biomass, etc.

1.3 Sources of Energy

- In current situation, all country required energy for different applications which is derived from various sources.
- There are six sources of existing energy utilized by human being worldwide.

i) Fossil Fuels including Coal, petroleum products and natural gases which produce thermal, mechanical and electrical energy.

ii) Nuclear energy derived from reactions of the nuclear fuels available on the earth.

iii) Chemical energy derived from reactions between minerals sources.

iv) The Sun which produces solar energy in the form of mechanical or electrical energy.

v) Geothermal energy is the energy that is produced from beneath the earth.

vi) The gravitational potential and planetary motion between sun, moon and earth which creates wave, tidal and wind energies.

- Non renewable energy is derived from sources i) , ii) and iii) whereas renewable energy is obtained from sources iv), v) and vi).

1.3.1 Conventional Energy Resources

- Conventional Energy Resources are as follows:

1. Fossil Fuel Energy
2. Hydraulic Energy
3. Nuclear Energy

1. Fossil Fuel Energy

- Fossil fuels are hydrocarbons, primarily coal, fuel oil or natural gas, formed from the remains of dead plants and animals.
- Fossil fuels provide the power for most of the world, primarily using coal and oil.
- Oil is converted into many products, the most used of which is gasoline.
- Natural gas is starting to become more common, but is used mostly for heating applications although there are more and more natural gas powered vehicles appearing on the streets.
- The issue with fossil fuels is twofold.
- To get to the fossil fuel and convert it to use there has to be a heavy destruction and pollution of the environment.

- The fossil fuel reserves are also limited, expecting to last only another 100 years given are basic rate of consumption.

i) Coal

- Contribution in power generation in India is 58.30 %.
- Coal is expected to remain the dominant fuel for power generation in India for a long time.
- Coal India Ltd is the government coal production company in India. It controls the coal production, distribution of coal to different government and private companies for electricity generation and other purposes.
- If any deficiency of coal is noticed by Coal India Ltd, It will import coal from different countries to fulfill the need.
- Coal consumption in India for electricity generation is shown in Fig. 1.3.1.

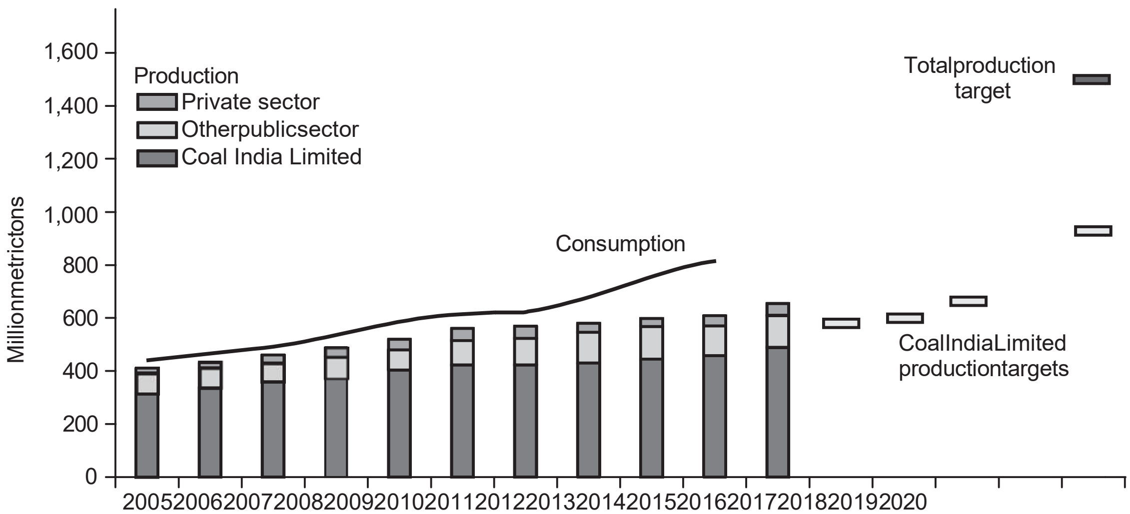

Fig. 1.3.1 India's coal consumption, production and production targets

- Coal consumption in India is more than production and the difference becomes 200 Million metric tons in 2014 and still difference is rising too fast.
- Coal India set targets for future coal production as by 2020 coal production target is 950 Million metric tons.
- To meet expected future demand of electricity, indigenous coal production will have to be greatly expanded.

- Indian coal is typically of poor quality and as such requires being beneficiated to improve the quality of coal or need to develop advance technology to improve the performance of power plants.
- Coal is mainly available in Bihar, West Bengal, Orissa and Madhya Pradesh.
- The big coal mines in our country are at Jharia and Bokaro in Bihar and at Raniganj in West Bengal.

ii) Petroleum

- Petroleum is oil obtained from rocks; particularly sedimentary rocks of the earth. Therefore, it is also called mineral oil.
- Technically speaking, petroleum is an inflammable liquid that is composed of hydrocarbons which constitute 90 to 95 per cent of petroleum and the remaining is chiefly organic compounds containing oxygen, nitrogen, sulphur and traces of organo-metallic compounds.
- Petroleum and petroleum products are mainly used as motive power.
- It is a compact and convenient liquid fuel which has revolutionized transportation on land, in the air and on water.
- It can be easily transported from the producing areas to the consuming areas with the help of tankers and more conveniently, efficiently and economically by pipelines.
- India was a very insignificant producer of petroleum at the time of Independence and remained so till Mumbai High started production on a large scale.
- Seventeen public sector refineries are located at Guwahati, Barauni, Koyali, Haldia, Mathura, Digboi, Panipat, Chennai, Narimanam, Bongaigaon, Mumbai (HPCL), Vishakhapatnam, Mumbai (BPCL), Kochi, Numaligarh, Tatipaka (ONGC) and Bina (M.P.) Bina refinery was inaugurated in June 2003. Aggregate refining capacity of these plants is 75.95 million tonnes per annum.
- Private sector refinery of Reliance Petroleum Limited was commissioned at Jamnagar in 2001. With an installed capacity of 27 million tonnes, it is the biggest refinery in the country.

iii) Natural Gas

- Natural gas is the cleanest fossil fuels among the available fossil fuels.
- It is used as a feedstock in the manufacture of fertilizers, plastics and other commercially important organic chemicals as well as used as a fuel for electricity generation, heating purpose in industrial and commercial units.

- Natural gas is also used for cooking in domestic households and a transportation fuel for vehicles.
- Indian government is motivating peoples to us natural gas (CNG) for their vehicles, demand for natural gas in future highly increases.
- As a vision of Indian government to supply LPG connection to every kitchen in the country, demand of LPG gas is also rapidly increases.
- Demand of natural gas in 2012-13 was 240 MMSCMD (Million Metric Standard Cubic Meter Per Day) and production was 120 MMSCMD and expected to be increase demand to 550 MMSCMD and production to 260 MMSCMD.
- To fulfill the demand of natural gas is imported by India from other countries.

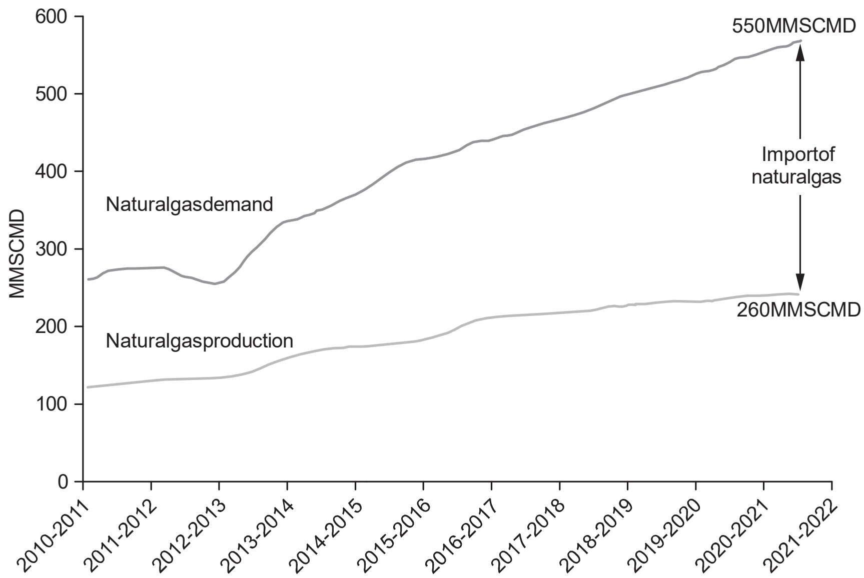

Fig. 1.3.2 Natural gas production and consumption in India

2. Hydraulic Energy (Hydro Power)

- Water-energy is most conventional renewable energy source and obtained from water flow, water falling from a height.
- Hilly and highland areas are suitable for this purpose, where there is continuous flow of water in large amounts falling from high slopes.
- Hydro- power is a clean, non-polluting source of energy.
- It can be transmitted to long distance through wires and cables.
- The flowing water and the tides in the sea are sources of energy.
- India is endowed with large hydropower potential of 1,45,320 MW.

- Heavy investments are made on large projects.
- In recent years, hydel energy (through mini and small hydel power plants) is also used to reach power to remote villages which are unelectrified.
- The estimated potential of Small Hydro Power is about 15,000 MW in the country.
- As on May 2019, the installed capacity of Small hydro projects (upto 3MW) amounts to 4603.75 MW.

3. Nuclear Energy

- This is of course a main source of energy, when the fossil fuel reserves are depleting very fast.
- A small quantity of radioactive material can produce an enormous amount of energy.
- For example, one tonne of Uranium would provide as much energy as by three million tonnes of coal or 12 million barrels of oil.
- Besides electricity, atomic power is also used as fuel for marine vessels, heat generation for chemical and food processing plants and for space-crafts.
- For atomic energy, we need a nuclear reactor.
- The decay of fissionable matter produces enormous heat.
- This is used to make steam and channeled through a turbine connected to an electric generator.
- There are different types of nuclear reactions.
- The Indian government is committed to growing its nuclear power capacity as part of its massive infrastructure development programme.
- The government has set ambitious targets to grow nuclear capacity.

1.3.2 Non-Conventional Energy Sources

- Natural resources like wind, tides, solar, biomass, etc generate energy which is known as "Non-conventional resources".
- These are pollution free and hence we can use these to produce a clean form of energy without any wastage.
- Some of these sources as follows :

a) Solar Energy b) Wind Energy

c) Tidal Energy d) Wave Energy

e) Geothermal Energy f) Biomass Energy

a) Solar Energy

- Solar energy is the most readily available and free source of energy since prehistoric times.
- It is estimated that solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year.
- Solar energy can be utilized through two different routes, as solar thermal route and solar electric (solar photovoltaic) routes.
- Solar thermal route uses the sun's heat to produce hot water or air, cook food, drying materials etc.
- Solar photovoltaic uses sun's heat to produce electricity for lighting home and building, running motors, pumps, electric appliances, and lighting.
- In solar thermal route, solar energy can be converted into thermal energy with the help of solar collectors and receivers known as solar thermal devices.

b) Wind Energy

- Wind energy describes the process by which wind is used to generate electricity.
- As the wind increases, power output increases up to the maximum output of the particular turbine.
- Wind farms prefer areas, where winds are stronger and constant.
- These are generally located at high altitudes.
- Wind turbines use wind to make electricity.
- There is no pollution because no fossil fuels are burnt to generate electricity.
- One of India's largest windmill farm is in Kanyakumari which generates 380 mW of electricity.
- India now has the 4^{th} largest wind power installed capacity in the world which has reached 36089.12 MWp (as on May, 2019). Private agencies own 95 % of the wind farms in India.

c) Tidal Energy

- The tidal cycle occurs every 12 hours due to the gravitational force of the moon.
- The difference in water height from low tide and high tide is potential energy.
- Similar to traditional hydropower generated from dams, tidal water can be captured in a barrage across an estuary during high tide and forced through a hydro-turbine during low tide.
- The capital cost for tidal energy power plants is very high due to high civil construction and high power purchase tariff.

- To capture sufficient power from the tidal energy potential, the height of high tide must be at least five meters (16 feet) greater than low tide.
- Total identified potential of Tidal Energy is about 12455 MW, with potential locations identified at Khambat & Kutch regions, and large backwaters, where barrage technology could be used.
- India may take up "ocean thermal level conversion" by which it will be able to generate 50,000 mW of electricity to meet the power requirements.

d) Wave Energy

- Wave energy is generated by the movement of a device either floating on the surface of the ocean or moored to the ocean floor.
- Wave conversion devices that float on the surface have joints hinged together that bend with the waves.
- This kinetic energy pumps fluid through turbines and creates electric power.
- Stationary wave energy conversion devices use pressure fluctuations produced in long tubes from the waves swelling up and down.
- This bobbing motion drives a turbine when critical pressure is reached.
- Other stationary platforms capture water from waves on their platforms.
- This water is allowed to runoff through narrow pipes that flow through a typical hydraulic turbine.
- The total theoretical potential of wave energy in India along the country's coast is estimated to be about 40,000 MW - these are preliminary estimates.
- This energy is however less intensive than what is available in more northern and southern latitudes.

e) Geothermal Energy

- Geothermal energy is the heat energy that we get from hot rocks present in the earth's crust.
- So Geothermal wells release greenhouse gases trapped within the earth and but these emissions are much lower per energy unit than the fossil fuels.
- This energy generally involves low running costs since it saves 80 % on fossil fuels.
- Due to this, there is an increase in the use of geothermal energy.
- It helps in reducing global warming and does not create pollution.

- The availability of geothermal power is most environment-friendly power, round the year 24 × 7 basis, not affected by the severity of climate during 6 to 7 winter months like hydro and like dependence on sun in solar PV.

f) Biomass Energy

- Biomass is the organic matter that originates from plants, animals, wood, sewage.
- These substances burn to produce heat energy which then generates electricity.
- The chemical composition of biomass varies in different species but generally, biomass consists of 25 % of lignin, 75 % of carbohydrates or sugar.
- Biomass energy is also applicable for cooking, lighting, and generation of electricity.
- The residue left after the removal of biogas is a good source of manure.
- Biomass is an important energy source contributing to more than 14 % of the global energy supply.

1.3.3 Advantages and Disadvantages of Non Conventional Energy Resources

Advantages

1. They do not pollute the atmosphere.
2. They are available in large quantities.
3. They are inexhaustible.
4. They do not deplete natural resources.
5. They can sustain energy supply for many generations.
6. Non-conventional Sources of Energy less expensive
7. Non-conventional Sources of Energy meet our requirement on a limited scale.

Disadvantages

1. They have little regulation and thus can become much more environmentally impactful than existing sources.
2. It can be harder to obtain and less widely available.
3. It can be more expensive.
4. Because of it newness may have hidden consequences not yet known.

1.4 World Energy Use

- Energy is an important ingredient in all phases of society.
- We live in a very interdependent world, and access to adequate and reliable energy resources is crucial for economic growth and for maintaining the quality of our lives.
- But current levels of energy consumption and production are not sustainable.
- About 40 % of the world's energy comes from oil, and much of that goes to transportation uses.
- Oil prices are dependent as much upon new (or foreseen) discoveries as they are upon political events and situations around the world.
- The U.S., with 4.5 % of the world's population, consumes 24 % of the world's oil production per year; 66 % of that oil is imported!

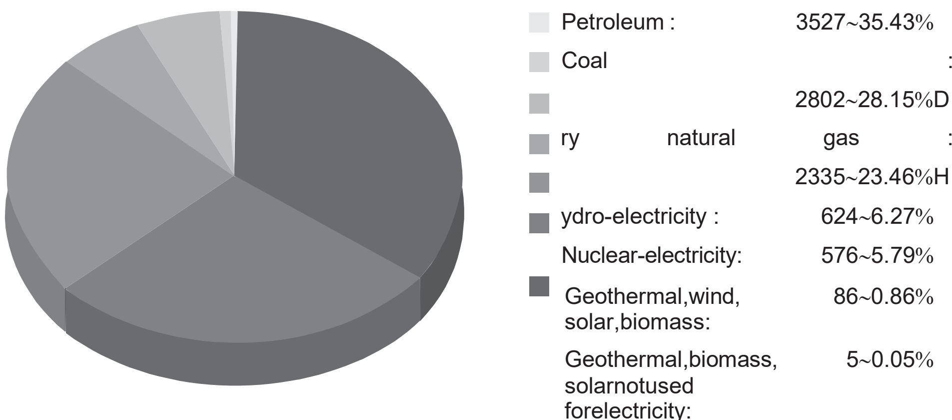

Fig. 1.4.1 Energy resources used in world

- The principal energy resources used in the world are shown in Fig.1.4.1.
- The fuel mix has changed over the years but now is dominated by oil, although natural gas and solar contributions are increasing.
- Renewable forms of energy are those sources that cannot be used up, such as water, wind, solar, and biomass.
- About 85 % of our energy comes from nonrenewable fossil fuels oil, natural gas, coal.
- The likelihood of a link between global warming and fossil fuel use, with its production of carbon dioxide through combustion, has made, in the eyes of many scientists, a shift to non-fossil fuels of utmost importance but it will not be easy.
- World energy consumption by source, in billions of kilowatt-hours: 2006. (credit : KVDP)

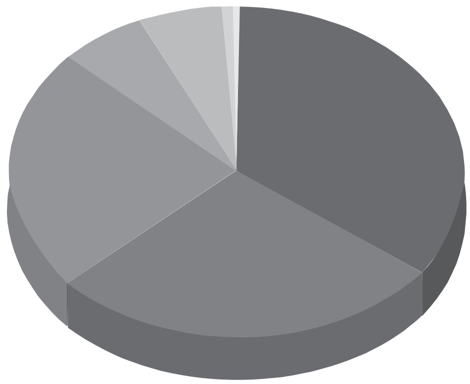

Fig. 1.4.2 Energy resources used in world

- World energy consumption continues to rise, especially in the developing countries.
- Global demand for energy has tripled in the past 50 years and might triple again in the next 30 years.
- While much of this growth will come from the rapidly booming economies of China and India, many of the developed countries, especially those in Europe, are hoping to meet their energy needs by expanding the use of renewable sources.
- Although presently only a small percentage, renewable energy is growing very fast, especially wind energy.
- For example, Germany plans to meet 20 % of its electricity and 10 % of its overall energy needs with renewable resources by the year 2020.
- Energy is a key constraint in the rapid economic growth of China and India.
- In 2003, China surpassed Japan as the world's second largest consumer of oil.
- However, over 1/3 of this is imported.
- Unlike most Western countries,coaldominates thecommercial energy resources of China, accounting for 2/3 of its energy consumption.
- In 2009 China surpassed the United States as the largest generator of CO_2
- In India, the main energy resources are biomass (wood and dung) and coal.
- Half of India's oil is imported.
- About 70 % of India's electricity is generated by highly polluting coal.
- Yet there are sizeable strides being made in renewable energy.
- India has a rapidly growing wind energy base, and it has the largest solar cooking program in the world.

- Past and projected world energyuse(source:BasedondatafromU.S.Energy Information Administration, 2011)

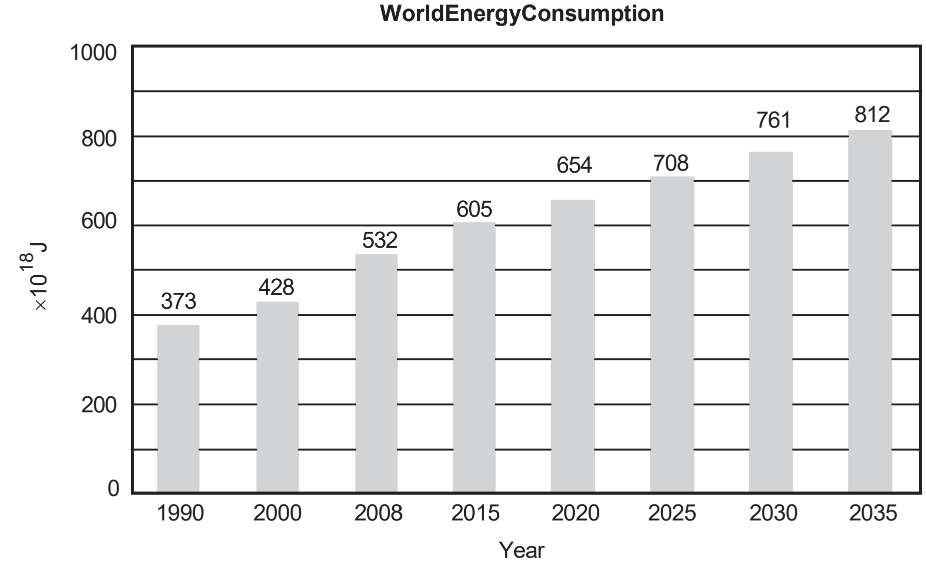

Fig. 1.4.3

Country	Consumption, in EJ (10^{18} J)	Oil	Natural Gas	Coal	Nuclear	Hydro	Other Renewables	Electricity Use per capita (kWh/yr)	Energy Use per capita (GJ/yr)
Australia	5.4	34 %	17 %	44 %	0 %	3 %	1 %	10000	260
Brazil	9.6	48 %	7 %	5 %	1 %	35 %	2 %	2000	50
China	63	22 %	3 %	69 %	1 %	6 %		1500	35
Egypt	2.4	50 %	41 %	1 %	0 %	6 %		990	32
Germany	16	37 %	24 %	24 %	11 %	1 %	3 %	6400	173
India	15	34 %	7 %	52 %	1 %	5 %		470	13
Indonesia	4.9	51 %	26 %	16 %	0 %	2 %	3 %	420	22
Japan	24	48 %	14 %	21 %	12 %	4 %	1 %	7100	176
New Zealand	0.44	32 %	26 %	6 %	0 %	11 %	19 %	8500	102
Russia	31	19 %	53 %	16 %	5 %	6 %		5700	202
U.S.	105	40 %	23 %	22 %	8 %	3 %	1 %	12500	340
World	**432**	**39 %**	**23 %**	**24 %**	**6 %**	**6 %**	**2 %**	**2600**	**71**

- While non-renewable sources dominate, some countries get a sizeable percentage of their electricity from renewable resources.
- For example, about 67 % of New Zealand's electricity demand is met by hydroelectric.
- Only 10 % of the U.S. electricity is generated by renewable resources, primarily hydroelectric.
- It is difficult to determine total contributions of renewable energy in some countries with a large rural population, so these percentages in this table are left blank.
- A new report by the U.S. Energy Information Agency predicts that worldwide energy consumption will surge 53 percent between 2008 and 2035, with China and India accounting for about half of the growth.

1.5 Reserves of Energy Resources

- Nearly 90 % of the world's primary energy supply is comprised of non-renewable energies (oil, natural gas, coal, uranium).
- The International Energy Agency predicts that demand for all types of non-renewable energy will increase further.
- Except for traditional oil, world reserves seem to adequately cover long-term energy demand.
- Fig. 1.5.1 shows fossil fuel extraction remaining for future as on 2016.

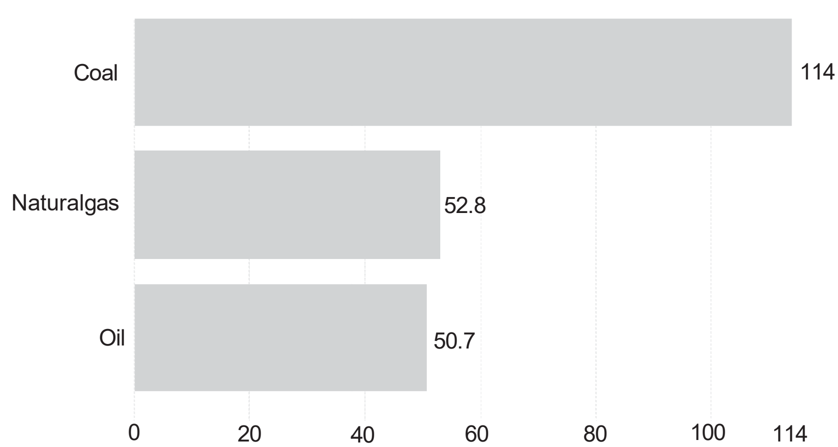

Fig. 1.5.1 Years of fossil fuel extraction remaining for future as on 2016

- Oil is very important for the transportation, heat generation and chemical industries.
- Natural gas is essential not only for the production of heat and electricity, but also for the chemical industry.
- Coal is needed for electricity and steel production, and uranium is needed for power generation.
- Therefore, it is important to keep track of the reserves of these energy resources.

1.5.1 Oil Reserves

- **Proven** reserves are those reserves claimed to have a *reasonable certainty* (normally at least 90 % confidence) of being recoverable under existing economic and political conditions, with existing technology.
- In 2018, there were 1.73 trillion barrels of oil in the world.
- That's enough to last another 50 years since the world uses 95 million barrels per day. Only proven reserves are counted in the total world reserves.
- This number changes only slightly every year.
- India holds 4,728,790,000 barrels of proven oil reserves as of 2016, ranking 24th in the world and accounting for about 0.3 % of the world's total oil reserves of 1,650,585,140,000 barrels.
- India has proven reserves equivalent to 2.9 times its annual consumption.
- This means that, without imports, there would be about 3 years of oil left (at current consumption levels and excluding unproven reserves).
- Most of the big fields in the proved oil reserves are in the Middle East, Venezuela, Canada, and Russia.
- Here's the number of barrels of proven oil reserves in 2018 for the top 15 countries according to the BP Statistical Review.

2018 Top 10 Oil Producers by Country			
Rank	**Country**	**Production (mbd)**	**Share of World Total**
1	United States	17.9	18 %
2	Saudi Arabia	12.4	12 %
3	Russia	11.4	11 %

4	Canada	5.3	5 %
5	China	4.8	5 %
6	Iraq	4.6	5 %
7	Iran	4.5	4 %
8	UAE	3.8	4 %
9	Brazil	3.4	3 %
10	Kuwait	2.9	3 %
	Sum Top 10	**70.9**	**70 %**
	World Total	**100.6**	

1.5.2 Natural Gas Reserves

- Natural gas reserves refer to large deposits of natural gas which, based on geological surveys and engineering studies, are thought to exist to a very high degree of certainty.
- In addition to the knowledge of their existence, these reserves are also accessible and economically viable to extract.
- Natural gas reserves are spread worldwide; however, some countries have more natural gas than others.
- It is estimated that the total world reserves amount to around 6 quadrillion cubic feet.
- Rough estimates suggest that this large reserve is equal to around 6000 exajoules of energy.
- Russia has the world's largest natural gas reserves, followed closely by Iran and Qatar.
- Recently, natural gas has become more and more important as a fuel source as its reserves are so vast.
- In addition to reserves that exist currently, there is huge potential for more reserves to be found.

- Fig.1.5.2 shows an interactive graph showing what regions have major natural gas reserves.
- Note that despite natural gas generally forming along with crude oil, Saudi Arabia has massive oil reserves but is comparable to the United States in its gas reserves.

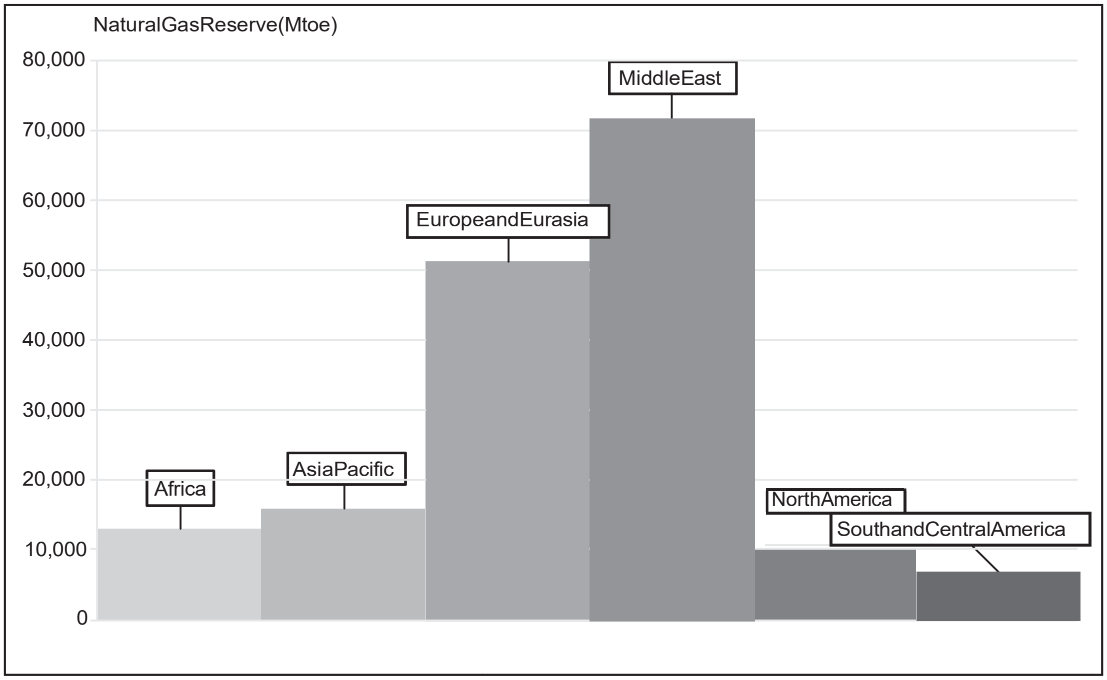

Fig. 1.5.2

1.5.3 Coal Reserves

- Coal is one of the most important energy resources of the world, and it was the first of the fossil fuels to be used by mankind as a major source of energy.
- Coal is defined as having more than 50 percent by weight (or 70 percent by volume) carbonaceous matter produced by the compaction and hardening of altered plant remains namely, peat deposits.
- Coal is a key commodity for India from an energy security perspective, because it is the country's most abundant non-renewable energy source.
- India is the third largest coal producing country in the world.
- India has the world's fifth largest proved recoverable reserves of coal, at an estimated 101 billion tonnes (See Fig. 1.5.3 on next page).
- Most of India's coal reserves are located in the east, with the states of Jharkhand, Odisha, Chhattisgarh and West Bengal accounting for most of total proved reserves

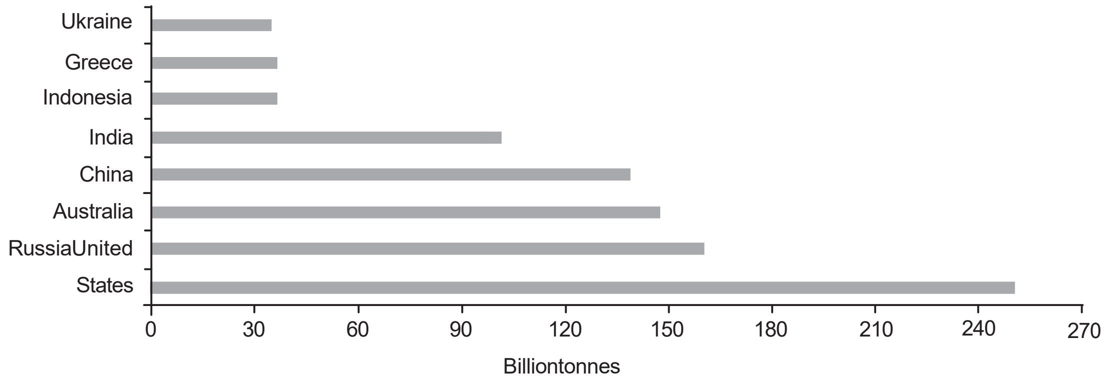

Fig. 1.5.3 Proved reserves of coal at end 2018

1.6 Environmental Aspects of Energy Utilization

- Getting the energy we need affects our environment in many different ways. Some energy sources have a greater impact than others.
- Energy is lost to the environment during any energy transformation, usually as heat. Notice the heat from your computer or car after it has been in use for a while.
- Nothing is completely energy efficient.
- Fortunately, the energy industry has become increasingly aware of the importance of environmental protection and is working to reduce its long-term impact.
- The usage of energy resources in industry leads to environmental damages by polluting the atmosphere.

1. Air Pollution

- A variety of air pollutants have known or suspected harmful effects on human health and the environment.
- These air pollutants are basically the products of combustion from fossil fuel use.
- Air pollutants from these sources may not only create problems near to these sources but also can cause problems far away.
- Air pollutants can travel long distances, chemically react in the atmosphere to produce secondary pollutants such as acid rain or ozone.

- Many air pollutants and their sources are listed below:

i) Carbon Monoxide (CO) :

- Carbon monoxide (CO) is a toxic gas, which is emitted into the atmosphere as a result of combustion processes, and from oxidation of hydrocarbons and other organic compounds.
- In urban areas, CO is produced almost entirely (90 %) from road traffic emissions.
- CO at levels found in ambient air may reduce the oxygen-carrying capacity of the blood.
- It survives in the atmosphere for a period of approximately 1 month and finally gets oxidized to carbon dioxide (CO_2)

ii) Carbon Dioxide (CO_2)

- The primary causes are deforestation and the burning of fossil fuels such as coal.
- As carbon dioxide levels have risen, so have its effects on air pollution.
- Carbon dioxide accounts for less than 1 percent of the atmospheric gases.
- However, a delicate balance exists between carbon dioxide and other gases.
- The concern over carbon dioxide is the significant change over a relatively short period of time.

iii) Chlorofluorocarbons (CFCs)

- Chlorofluorocarbons (CFCs), once described as "miracle chemicals," cause the breakdown of the ozone layer that protects the earth from the sun's ultraviolet (UV) radiation.
- CFCs have been used as **refrigerants** in air conditioners and refrigerators, in aerosol spray cans, in manufacturing foams as industrial **solvents** and as cleaning agents in the manufacture of electronics.
- CFCs are now recognized as harmful chemicals because of their ozone-depleting properties.

iv) Heavy Metals and Lead

- Particulate metals in air result from activities such as fossil fuel combustion (including vehicles), metal processing industries and waste incineration.
- There are currently no emission standards for metals other than lead.

- Lead is a cumulative poison to the central nervous system, particularly detrimental to the mental development of children.
- Lead is the most widely used non-ferrous metal and has a large number of industrial applications.
- Its single largest industrial use worldwide is in the manufacture of batteries and it is also used in paints, glazes, alloys, radiation shielding, tank lining and piping.

v) Ozone (O_3)

- **Ozone (O_3)** is not emitted directly into the atmosphere, but is a secondary pollutant produced by reaction between nitrogen dioxide (NO_2), hydrocarbons and sunlight.
- Ozone can irritate the eyes and air passages causing breathing difficulties and may increase susceptibility to infection.
- It is a highly reactive chemical, capable of attacking surfaces, fabrics and rubber materials.
- Ozone is also toxic to some crops, vegetation and trees.

vi) Nitrogen Oxide (NOx)

- **Nitrogen oxides** are formed during high temperature combustion processes from the oxidation of nitrogen in the air or fuel.
- The principal source of nitrogen oxides - nitric oxide (NO) and nitrogen dioxide (NO_2), collectively known as NOx is road traffic. NO and NO_2 concentrations are greatest in urban areas where traffic is heaviest.
- Other important sources are power stations and industrial processes.
- Nitrogen oxides are released into the atmosphere mainly in the form of NO, which is then readily oxidized to NO_2 by reaction with ozone.
- Elevated levels of NOx occur in urban environments under stable meteorological conditions, when the air mass is unable to disperse.
- Nitrogen dioxide has a variety of environmental and health impacts.
- It irritates the respiratory system and may worsen asthma and increase susceptibility to infections.
- In the presence of sunlight, it reacts with hydrocarbons to produce photochemical pollutants such as ozone.

vii) Sulphur dioxide

- **Sulphur dioxide** is a corrosive acid gas, which combines with water vapour in the atmosphere to produce acid rain.
- Both wet and dry depositions have been implicated in the damage and destruction of vegetation and in the degradation of soils, building materials and watercourses.
- SO_2 in ambient air is also associated with asthma and chronic bronchitis.
- The principal source of this gas is power stations and industries burning fossil fuels, which contain sulphur.

2. Acid Rain

- Acid rain is caused by a chemical reaction that begins when compounds like sulfur dioxide and nitrogen oxides are released into the air.
- These substances can rise very high into the atmosphere, where they mix and react with water, oxygen, and other chemicals to form more acidic pollutants, known as acid rain.
- Sulfur dioxide and nitrogen oxides dissolve very easily in water and can be carried very far by the wind.
- As a result, the two compounds can travel long distances where they become part of the rain, sleet, snow, and fog that we experience on certain days.
- Human activities are the main cause of acid rain.
- Over the past few decades, humans have released so many different chemicals into the air that they have changed the mix of gases in the atmosphere.
- Power plants release the majority of sulfur dioxide and much of the nitrogen oxides when they burn fossil fuels, such as coal, to produce electricity.
- In addition, the exhaust from cars, trucks, and buses releases nitrogen oxides and sulfur dioxide into the air.
- These pollutants cause acid rain.
- The effects of acid rain are as follows :

i. Acidification of lakes, streams, and soils

ii. Direct and indirect effects (release of metals, For example : Aluminum which washes away plant nutrients)

iii. Killing of wildlife (trees, crops, aquatic plants, and animals)

iv. Decay of building materials and paints, statues, and sculptures

v. Health problems (respiratory, burning- skin and eyes)

3. Ozone Layer Depletion

- The ozone layer is the layer present in the Stratosphere. It absorbs the harmful ultraviolet rays that come from the sun.
- Moreover, it causes harmful radiation that has a high concentration of ozone (O_3) which is harmful to living beings on the earth.
- The ozone layer is basically present in the lower stratosphere that is near about 20 to 35 kilometers above the earth.
- Moreover, the thickness of the ozone layer may differ depending upon the seasonal and geographical changes.
- The ozone layer is important for the earth because it protects the earth from the harmful ultraviolet radiation.
- This radiation comes from the sun and is harmful to the earth's surface.
- The formation of chlorine and bromine takes place and these chemicals cause the depletion of the ozone layer at a very high speed.
- They are capable of breaking down the molecules of the ozone layer.
- One chlorine molecule has a capacity to breakdown thousands of molecules present in the ozone layer; therefore, it results in the depletion of the ozone layer.

4. Greenhouse Effect

- The greenhouse effect is one of the main factors determining the temperature of a planet.
- It's the phenomenon by which certain gases - so-called greenhouse gases - in the atmosphere trap heat that would otherwise escape to space, thereby keeping the planet warm.
- The greenhouse effect is not a man-made phenomenon.
- The Earth's atmosphere has always contained greenhouse gases, such as CO_2 and they proportion of greenhouse gases in the air. have always caused warming.
- If there was no greenhouse effect, the planet would be uninhabitably cold - more than 30 °C colder than the hospitable current average of 15 °C.
- However, humans are changing the strength of the greenhouse effect by increasing the
- For example, CO_2 concentration in the atmosphere has increased from around 315 parts per million (ppm) to 387 ppm since 1959.

1.7 Renewable Energy Scenario in Tamilnadu

- Tamil Nadu, India's sixth-most populous state, has emerged as a major hub for renewable energy over the last decade.
- More than one-third of its installed capacity about 9,000 megawatts now comes from renewable energy sources like wind and solar.
- The state is blessed with various forms of renewable energy
- The state is blessed with various forms of renewable energy sources viz., Wind, Solar, Biomass, Biogas, Small Hydro, etc. Municipal and Industrial wastes could also be useful sources of energy while ensuring safe disposal.
- Renewable Energy (RE) sources provide a viable option for on/off grid electrification & wide industrial applications in Tamilnadu.

Establishment of TEDA

- The Government of Tamil Nadu realized the importance and need for renewable energy, and set up a separate Agency, as registered society, called the Tamil Nadu Energy Development Agency (TEDA) as early as 1985 with the following specific objectives :-

1. To promote the use of new and renewable sources of energy (NRSE) and to implement projects therefore.
2. To promote energy conservation activities.
3. To encourage research and development on renewable sources of energy.

1.7.1 Renewable Energy Potentials in Tamilnadu

- In India, Tamil Nadu is the only state where one-third of the installed power comes from renewable sources.
- The present installed capacity of 17,868.37 MW mostly consists of

i. Coal (35 %),

ii. Hydro (12 %) and

iii. Renewable Energy (42 %)

- Tamil Nadu's higher percentage of renewable energy comes from the fact that State has geographic conditions that are suitable for harnessing such sources of energy.
- The government is also supporting by taking proactive steps to tap various sources of energy through policy framework and research (see Fig. 1.7.1 and 1.7.2 on next page).

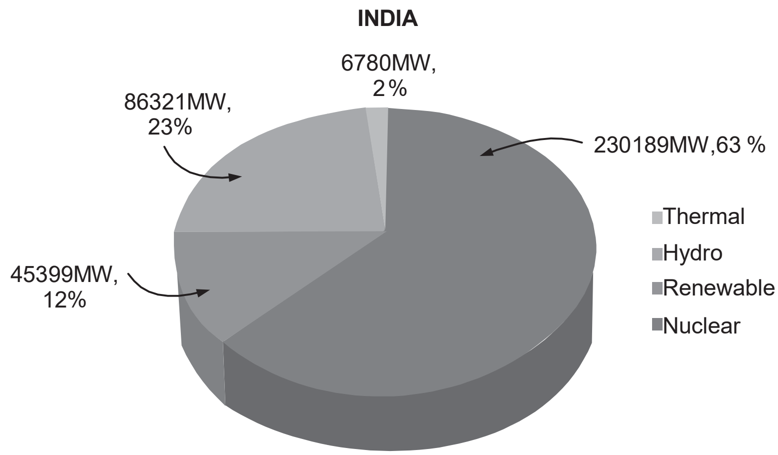

Fig. 1.7.1

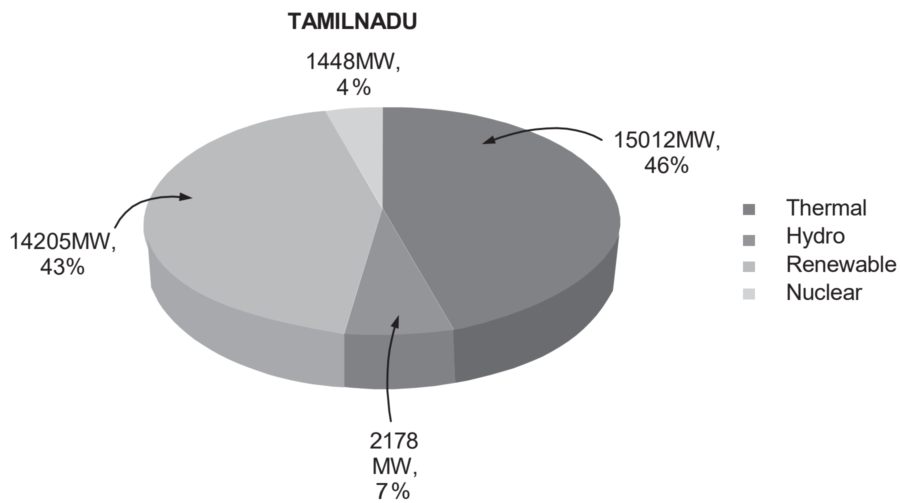

Fig. 1.7.2

- Tamil Nadu constitutes 9 % of the total installed electricity generation capacity of India, which is mainly from fossil fuels.
- Table 1.7.1 show the power sector at a glance in India and Tamil Nadu respectively.

Sr. No.	Technology	Achievement in (MW) as on 31.01.2020	
		Tamil Nadu	Tamil Nadu
1	Thermal	15,012	230189
2	Hydro	2178	45399

3	Renewable	14205	86321
4	Nuclear	1448	6780
	Total	32843	368689

Table 1.7.1 Power Production in Tamil Nadu and Tamil Nadu

1.7.2 Renewable Energy Achievement in Tamil nadu

- The southern Indian state of Tamil Nadu is one of the top nine markets globally to have achieved an exceptionally large share of renewable power generation, according to a report by US-based think-tank Institute for Energy Economics and Financial Analysis (IEEFA).
- The IEEFA studied the top 15 countries or power markets worldwide by their share of wind and solar energy-the percentage of net energy needs met by these sources in these nations. Denmark leads the pack with 53 % in 2017, followed by southern Australia and Uruguay.
- Tamil Nadu, which gets 14 % of its energy needs from renewables, is the only Asian market on the list. This comes at a time when India is embarking on a major tran sition towards clean energy, targeting 175 gigawatts (1 GW = 1,000 megawatts) by 2022.

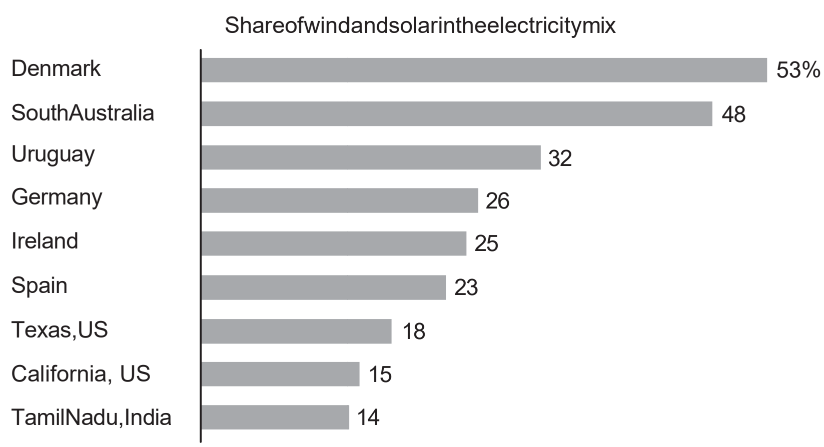

Fig. 1.7.3

1.7.3 Wind Energy Potential in Tamil Nadu

- Tamil Nadu has high wind potential due to the tunneling effect during South West Monsoon.
- The wind installed capacity of the state is 7134 MW, which is a whopping 40 % of the country's total wind installed capacity.
- This makes wind the single largest power generation technology in Tamil Nadu in terms of installed base.
- In 2011-12, over 1,000 MW of wind generation capacity was added but in the current year, only about 200 MW was added.
- Last summer, wind energy had contributed to nearly one-third of the power supplied to the grid.
- A study commissioned by CII and Sakthi Foundation, along with WISE found out that there is potential to add over 2,000 MW of wind energy in Tamil Nadu.
- The state could also take a lead in harnessing its offshore wind resources.
- It is in the process of installing a 100-metre must for wind measurements in Dhanushkodi.
- According to Centre for Wind Energy Technology (C-WeT), Tamil Nadu has a potential of about 1 GW in the north of Rameswaram and another 1 GW in the south of Kanyakumari.
- Various surveys were conducted to assess this potential.

1.7.4 Small Hydro Potential in Tamil Nadu

- Tamil Nadu has been a pioneer State in the field of hydro power development in India.
- It is the only State in India where all of its economically exploitable hydro power potential has been harnessed.
- In Tamil Nadu, small hydro has an estimated potential of 659.51 MW through 197 sites.
- As of November 2011, 94.05 MW was installed. Many small micro hydro projects are being set up in remote and isolated areas.
- A number of tea garden owners are also setting up micro hydel projects to meet their captive requirement of power.

- Organizations such as the Water Mill Associations, Cooperative Societies, NGOs, etc. are being encouraged to install watermills in their areas for electricity generation to meet small scale electrical requirements of villages.
- Apart from wind, solar, biomass and small hydro, waste to energy plants are also under operation, but there are roughly about three projects that are running now.

1.7.5 Solar Energy

- Tamil Nadu has the 5th highest operating solar-power capacity in India in May 2018.
- The 648-MW Kamuthi Solar Power Project is the biggest operating project in the state.
- The Tamil Nadu Solar Policy 2019 was issued by the Government of Tamil Nadu on 04.02.2019.
- The Policy has set a target of 9000 MW to be achieved by 2023 of which 40 % is earmarked for consumer category solar energy systems.
- Some of the major objectives of Tamil Nadu's Solar Policy 2012

i. To project Tamil Nadu as a Solar Hub

ii. To generate 3000 MW of solar energy by 2015

iii. To achieve grid parity by 2015

iv. To encourage indigenous solar manufacturing facilities in the State

- The Tamil Nadu Generation and Distribution Corporation tied up with over 90 investors to supply a total of 226 MW of solar power

1.8 Renewable Energy Scenario in India

- Renewable energy sources and technologies have potential to provide solutions to the long-standing energy problems being faced by the developing countries.
- The renewable energy sources like wind energy, solar energy, geothermal energy, ocean energy, biomass energy and fuel cell technology can be used to overcome energy shortage in India.
- To meet the energy requirement for such a fast growing economy, India will require an assured supply of 3-4 times more energy than the total energy consumed today.
- The renewable energy is one of the options to meet this requirement.

- Today, renewable account for about 33 % of India's primary energy consumption.
- India is increasingly adopting responsible renewable energy techniques and taking positive steps towards carbon emissions, cleaning the air and ensuring a more sustainable future.
- In India, from the last two and half decades there has been a vigorous pursuit of activities relating to research, development, demonstration, production and application of a variety of renewable energy technologies for use in different sectors.
- Modern biomass encompasses a range of products derived from photosynthesis and is essentially chemical solar energy storage.
- Renewable energy supplies 18 % of the world's final energy consumption, counting traditional biomass, large hydro-power, and nonrenewable (small hydro, modern biomass, wind, solar, geothermal, and bio-fuels).

1.8.1 Initiative for Development of Renewable Energy in India

- The relevance of the increasing use of renewable energy sources in the transition to a sustainable energy base was recognized in India even in the early 1970s.
- Since the early 1980s, a significant thrust has been given to the development, trial and induction of a variety of renewable energy technologies for use in different sectors.
- To begin with, the endeavors were steered and overseen by the Commission for Additional Sources of Energy (CASE) set up in 1981.
- In 1982, a separate Department of Non-Conventional Energy Sources (DNES) was created in the Ministry of Energy and was entrusted with the charge of promoting non-conventional energy sources.
- A decade later, this was upgraded and thus MNES (Ministry of Non-Conventional Energy Sources) started funding as a separate Ministry from 1992 to develop all areas of renewable energy.
- India was the first country in the world to set up a ministry of non-conventional energy resources (Ministry of New and Renewable Energy (MNRE)), in the early 1980s, and its public sector undertakings the Solar Energy Corporation of India is responsible for the development of solar energy industry in India.
- According to its mandate, the MNES has been implementing a broad-based programme covering the whole spectrum of renewable energy technologies.

- The aim of the programme is to

(a) Increase me share of renewables in the overall installed capacity power generation

(b) Meet the energy needs of rural and remote areas for a variety of applications

(c) Minimize the drudgery and health hazards faced by rural women in following the age-old practice of cooking with fuel-wood collected from long distances and in traditional chulhas which emit a lot of smoke and

(d) Extract energy from urban and industrial waste besides chemical, ocean and geo-thermal sources. The underlying idea of the programme is not to substitute but to supplement the conventional energy generation in meeting the basic energy needs of the community at large.

- India has the world's largest programmes for renewable energy.
- Several renewable energy technologies have been developed and deployed in villages and cities of India.
- The Ministry of Non-Conventional Energy Sources (MNES) was created in 1992 for all matters relating to non-conventional/renewable energy.
- The government of India also created the Indian Renewable Energy Development Agency Limited (IREDA) to assist and provide financial assistance in the form of subsidy and low interest loan for renewable energy projects.
- The IREDA covers a wide spectrum of financing activities including those that are connected to energy conservation and energy efficiency.
- At present, IREDA's lending is mainly in the following areas :

1. Solar energy technologies, utilization of solar thermal and solar photo voltaic systems.
2. Wind energy setting up grid connected wind farm projects.
3. Small hydro setting up small, mini and micro hydel projects.
4. Bio-energy technologies biomass based co-generation projects, biomass gasification, energy from waste and briquetting projects.
5. Hybrid systems.
6. Energy efficiency and conservation.

1.8.2 Renewable Energy Potential in India

- It is not hidden anymore that India has a vast supply of renewable resources and it has one of the largest programs in world for deploying renewable energy products and systems.
- India is the only country in the world to have an exclusive ministry for renewable energy development, the Ministry of New and Renewable Energy (MNRE) which has launched one of the world's largest and ambitious programs on renewable energy.
- Over the years, renewable energy sector has emerged as a significant player in India especially affecting the power generation capacity.
- This supports the government's agenda of sustainable development while becoming an integral part in meeting the nation's energy needs.
- For past two years, the Indian Government has taken several initiatives such as introduction of the concept of solar parks, organizing RE-Invest 2015 a global investors' meet, launching of a massive grid connected rooftop solar programme, earmarking of ₹ 38,000 crore (Euros 4 billion) for a Green Energy Corridor, eight-fold increase in clean environment cess from ₹ 50 per tonne to ₹ 400 per tonne (Euro 0.62 to Euros 5 per tonne), solar pump scheme with a target of installing 100,000 solar pumps and programme to train 50,000 people for solar installations under the Surya Mitra scheme, no inter-state transmission charges and losses to be levied for solar and wind power, compulsory procurement of 100 per cent power from waste to energy plants, and Renewable Generation Obligations on new thermal and lignite plants, etc.

Advantages of India :

1. **Robust Demand :** With the growing Indian economy, the electricity consumption is projected to reach 15,280 TWh by 2040.
2. **Increasing Investments :** With Indian government's ambitious targets, the sector has become quite attractive to foreign and Indian investors. It is expected to attract investments upto USD 80 billion (Euros 70 billion) in next four years.
3. **Competitive Advantage :** Indian has sunlight available throughout the year and has a large hydropower potential.

Renewable Energy Targets:

- The Indian Government has increased the target of renewable energy capacity to 175 GW by the year 2022 which includes 100 GW from solar, 60 GW from wind, 10 GW from bio-power and 5 GW from small hydro-power.

Installed grid interactive renewable power capacity (excluding large hydropower) as of 31 March 2018 (RES MNRE)

Source	Total Installed Capacity (MW)	2022 Target (MW)
Wind Power	34,046	60,000
Solar Power	21,651	1,00,000
Biomass Power (Biomass & Gasification and Bagasse Cogeneration)	8,701	10,000
Waste-to-Power	138	
Small Hydro Power	4,486	5,000
TOTAL	**69,022**	**1,75,000**

1.8.3 Different Renewable Energy Sources (RES):

1. Solar Power :

- Solar energy is a clean energy as it produces no harmful solid, liquid or gas wastes and does not create pollution.
- Solar power can be produced through PV cell which is made of semiconductor and Energy Collectors classified into parabolic trough, parabolic, tower and parabolic disc system etc.
- With 300 clear sunny days, India receives around 5,000 trillion kWh/year, which is far more than the total energy consumption of the country today.
- The solar power on the surface of the earth is 10^{16}W whereas the total worldwide power demand for all needs of civilization is 10^{13}W.
- Therefore, the sun gives us 1000 times more power than we actually need.

2.WindPower:

- Wind energy is turning out to be a very promising alternative energy technology of the future.
- Over the years, there has been considerable increase amount of energy produced by wind-driven turbines due to recent advancement in the turbine technologies.
- Although India is a relative newcomer to the wind industry compared with Denmark or the US, domestic policy support for wind power has led India to become the country with the fourth largest installed wind power capacity in the world.
- As of 30 June 2018, the installed capacity of wind power in India was 34,293 MW. Wind power accounts for 10 % of India's total installed power capacity.
- India has set an ambitious target to generate 60,000 MW of electricity from wind power by 2022.
- MNRE announced a new wind-solar hybrid policy in May 2018 which means that the same piece of land will be used to house both wind farms and solar panels.

3. Bio Energy :

- Biomass is a resource of renewable energy that is derived from carbonaceous waste of various human and natural activities.
- Bio energy encompasses biomass power, bagasse cogeneration, waste to energy, biomass gasifier, bio ethanol, bio diesel etc.
- Biomass takes carbon out of the atmosphere while it is growing, and returns it as it is burned.
- Given its tropical location and abundant sunshine and rains, India is an ideal environment for Biomass production.
- It is estimated that the potential for biomass energy in India includes 16,000 MW from biomass energy and a further 3,500 MW from bagasse cogeneration.

4. Small Hydro Power (SHP) :

- India is the 7^{th} largest producer of hydroelectric power in the world.
- Hydro projects in India under 25 MW capacity are classified as 'Small Hydro Power' and is considered as a 'renewable energy'.
- SHP units with a total capacity of 4,380 MW have been installed up till now.

1.8.4 Government initiatives

- Some initiatives by the Government of India to boost the Indian renewable energy sector are as follows :

1. A new Hydropower policy for 2018-28 has been drafted for the growth of hydro projects in the country.
2. The Government of India has announced plans to implement a US$ 238 million (Euros 210 million) National Mission on advanced ultra-supercritical technologies for cleaner coal utilization.
3. The Ministry of New and Renewable Energy (MNRE) has decided to provide custom and excise duty benefits to the solar rooftop sector, which in turn will lower the cost of setting up as well as generate power, thus boosting growth.
4. Around 4.96 million household size biogas plants were installed in the country under the National Biogas and Manure Management Programme (NBMMP) by 2016-17.
5. The Indian Railways is taking increased efforts through sustained energy efficient measures and maximum use of clean fuel to cut down emission level by 33 per cent by 2030.

1.9 World Renewable Energy Scenario

- Global population growth and improvement of living standards cause high energy demand .
- This global energy demand is increasing faster than the population growth rate.
- Approximately 80 % of the total primary energy is being supplied by fossil fuels.
- World energy consumption projection from 2002 to 2030 shows the increase of energy demand by almost 60 % (1.6 % per year).
- The energy demand will be approximately 16.5 billion tons of oil equivalents (toe) by 2030 compared with 10.3 billion in 2002.
- Tables 1.9.1 and 1.9.2 present the projection of the world primary energy demand from 2002 to 2030.

Table 1.9.1 world primary energy demand

Energy sources	2002	2010	2020	2030	2002-2030
Coal	2389	2763	3193	3601	1.50 %
Oil	3676	4308	5074	5766	1.60 %

Gas	2190	2703	3451	4130	2.30 %
Nuclear	692	778	776	764	0.40 %
Hydro	224	276	321	365	1.80 %
Biomass and waste	1119	1264	1428	1605	1.30 %
Others renewable	55	101	162	256	5.70 %
	10345	12193	14405	16487	1.70 %

Table 1.9.2 world primary energy demand (%) from 2002 to 2030

Energy sources	2002	2010	2020	2030
Coal	23 %	23 %	22 %	22 %
Oil	36 %	35 %	35 %	35 %
Gas	21 %	22 %	24 %	25 %
Nuclear	7 %	6 %	5 %	5 %
Hydro	2 %	2 %	2 %	2 %
Biomass and waste	11 %	10 %	10 %	10 %
Others renewable	0.53 %	0.83 %	1.12 %	1.55 %

- The global primary energy consumption projection shows that fossil fuels will solely contribute the largest amount of energy, not taking into consideration if its share will slightly decrease from 36 % in 2002 to 35 % in 2030.
- In most parts of the world, natural gas is expected to remain as a main competitive fuel in the new power station because of its high efficiency.
- The share of coal in fulfilling the total primary energy demand will decrease from 30 % in 2012 to 27 % by 2035.
- The nuclear energy will decrease to 5 % by 2030 from 7 % in 2002.
- The intensities in different regions will continue to vary because of levels of variation in economic growth, energy use of different users, energy prices, geography, economic arrangement, culture, lifestyle, and climate.

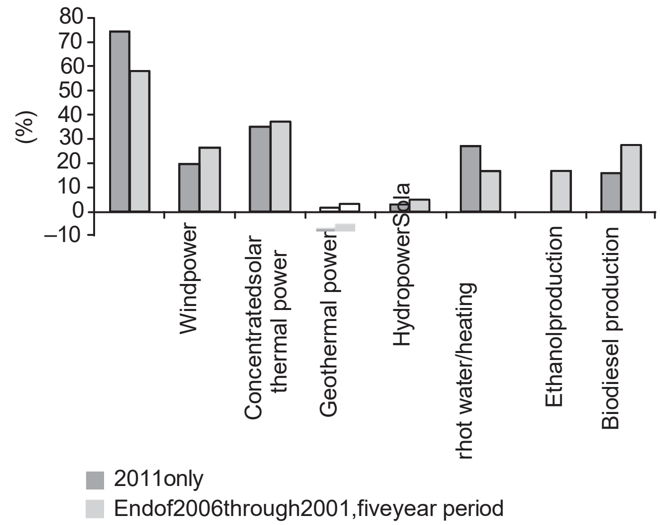

Fig. 1.9.1 Renewable energy capacity growth rate, 2006-2011

1.10 Applications of Renewable Energies

- Application potential of commercially viable renewable energy sources such as solar, wind, bio and hydro energy in India is discussed below.

1.10.1 Applications of Solar Energy

- Solar energy is the most readily available and free source of energy since prehistoric times.
- It is estimated that solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year.
- Solar energy can be utilized through two different routes as solar thermal route and solar electric (solar photovoltaic) routes.
- Solar thermal route uses the sun's heat to produce hot water or air, conk fond, drying materials etc.
- Solar photovoltaic uses sun's heat to produce electricity for lighting home and building, running motors, pumps, electric appliances and lighting.

1. Solar thermal energy application :

- In solar thermal route, solar energy can be converted into thermal energy with the help of solar collectors and receivers known as solar thermal devices.
- The Solar-Thermal devices can be classified into three categories :

i. Low-Grade Heating Devices - up to the temperature of 100 °C.

ii. Medium-Grade Heating Devices - up to the temperature of 100 ° - 300 °C

iii. High-Grade Heating Devices - above temperature of 300 °C

- Low-grade solar thermal devices are used in solar water heaters, air-heaters, solar cookers and solar dryers for domestic and industrial applications.
- A few industrial application of solar water heaters are listed below :

iv. Hotels : Bathing, kitchen, washing, laundry applications

v. Dairies : Ghee (clarified butter) production, cleaning and sterilizing, pasteurization

vi. Textiles : Bleaching, boiling, printing, dyeing, curing, ageing and finishing

vii. Breweries & Distilleries : Bottle washing, wort preparation, boiler feed heating

viii. Chemical /Bulk drugs units : Fermentation of mixes, boiler feed applications

ix. Electroplating/Galvanizing units : Heating of plating baths, cleaning, degreasing applications

x. Pulp and paper industries : Boiler feed applications, soaking of pulp.

2. Solar Electricity Generation Solar Photovoltaic (PV) :

- Photovoltaic is the technical term for solar electric. Photo means "light" and voltaic means "electric".
- Some applications for PV systems are lighting for commercial buildings, outdoor (street) lighting, rural and village lighting etc.
- Solar electric power systems can offer independence from the utility grid and offer protection during extended power failures.
- Solar PV systems are found to be economical especially in the hilly and far flung areas where conventional grid power supply will be expensive to reach.

1.10.2 Applications of Wind Energy

- Wind energy is basically harnessing of wind power to produce electricity.
- The kinetic energy of the wind is converted to electrical energy.
- When solar radiation enters the earth's atmosphere, different regions of the atmosphere are heated to different degrees because of earth curvature.
- This heating is higher at the equator and lowest at the poles.
- Since air tends to flow from warmer to cooler regions, this causes what we call winds, and it is these airflows that are harnessed in windmills and wind turbines to produce power.

- Some of the potential applications of wind energy are listed below :

i. Utility interconnected wind turbines generate power which is synchronous with the grid and are used to reduce utility bills by displacing the utility power used in the household and by selling the excess power back to the electric company.

ii. Wind turbines for remote homes (off the grid) generate DC current for battery charging.

iii. Wind turbines for remote water pumping generate 3 phase AC current suitable for driving an electrical submersible pump directly. Wind turbines suitable for residential or village scale wind power range from 500 Watts to 50 kilowatts.

1.10.3 Applications of Bio Energy

- Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities.
- It is derived from numerous sources, including the by-products from the wood industry, agricultural crops, raw material from the forest, household wastes etc.
- Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel.
- Its advantage is that it can be used to generate electricity with the same equipment that is now being used for burning fossil fuels.
- Biomass is an important source of energy and the most important fuel worldwide after coal, oil and natural gas.
- Bio-energy, in the form of biogas, which is derived from biomass, is expected to become one of the key energy resources for global sustainable development.
- Biomass offers higher energy efficiency through form of Biogas than by direct burning.
- Some of the potential applications of bio energy are: cooking, mechanical applications, pumping, power generations.
- Biomass gasifiers convert the solid biomass (basically wood waste, agricultural residues etc.) into a combustible gas mixture normally called as producer gas.
- Gasification of biomass and using it in place of conventional direct burning devices will result in savings of atleast 50 % in fuel consumption. The gas has been found suitable for combustion in the internal combustion engines for the production of power.

Applications :

1. Water pumping and Electricity generation :

- Using biomass gas, it possible to operate a diesel engine on dual fuel mode-part diesel and part biomass gas.
- Diesel substitution of the order of 75 to 80 % can be obtained at nominal loads.
- The mechanical energy thus derived can be used either for energizing a water pump set for irrigational purpose or for coupling with an alternator for electrical power generation - 3.5 kW - 10 MW

2. Heat generation :

- A few of the devices, to which gasifier could be retrofitted, are dryers - for drying tea, flower, spices, kilns for baking tiles or potteries, furnaces for melting non-ferrous metals, boilers for process steam, etc.
- Direct combustion of biomass has been recognized as an important route for generation of power by utilization of vast amounts of agricultural residues, agro-industrial residues and forest wastes.
- Gasifiers can be used for power generation and available up to a capacity 500 kW.
- The Government of India through MNES and IREDA is implementing power-generating system based on biomass combustion as well as biomass gasification.

3. High Efficiency Wood Burning Stoves

- These stoves save more than 50 % fuel wood consumption.
- They reduce drudgery of women saving time in cooking and fuel collection and consequent health hazards.
- They also help in saving firewood leading to conservation of forests.
- They also create employment opportunities for people in the rural areas.

4. Bio fuels

- Unlike other renewable energy sources, biomass can be converted directly into liquid fuels biofuels for our transportation needs (cars, trucks, buses, airplanes, and trains).
- The two most common types of biofuels are *ethanol and biodiesel.*

1.10.4 Applications of Hydro Energy

- The potential energy of falling water, captured and converted to mechanical energy by waterwheels, powered the start of the industrial revolution.

1. Small Hydro

- Small Hydro Power is a reliable, mature and proven technology.
- It is non-polluting, and does not involve setting up of large dams or problems of deforestation, submergence and rehabilitation.
- India has an estimated potential of 10,000 MW.

2. Micro Hydel

- Hilly regions of India, particularly the Himalayan belts, are endowed with rich hydel resources with tremendous potential.
- The MNES has launched a promotional scheme for portable micro hydel sets for these areas.
- These sets are small, compact and light weight.
- They have almost zero maintenance cost and can provide electricity/power to small cluster of villages.
- They are ideal substitutes for diesel sets run in those areas at high generation cost.
- Micro (upto 100 kW) mini hydro (101 - 1000 kW) schemes can provide power for farms, hotels, schools and rural communities, and help create local industry.

1.10.5 Applications of Ocean Energy

- Oceans cover more than 70 % of Earth's surface, making them the world's largest solar collectors.
- Ocean energy draws on the energy of ocean waves, tides, or on the thermal energy (heat) stored in the ocean.
- The sun warms the surface water a lot more than the deep ocean water, and this temperature difference stores thermal energy.
- The ocean contains two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves.
- Ocean thermal energy is used for many applications, including electricity generation.

1.11 Economics of Renewable Energy Systems

- The world currently receives about 80 % of its energy supply from fossil fuels because these sources generally provide energy at the lowest cost.
- However, the cost advantage of fossil fuels over renewable energy sources has been diminishing in recent years, and a designated renewable resource can already compete with fossil fuels only in financial terms.
- Non- renewable energy costs are expected to decline further while fossil fuel prices will likely rise.
- Thus even without policies to promote a transition toward renewable source, economic factors are currently moving us in that direction.
- The cost of non-renewable energy is expected to decrease further, while the price of fossil fuels may rise.
- So even without policies that promote the transition to renewable energy, economic factors are still pushing us in this direction.
- Techno-economic analysis of renewable energy system mainly depends on the following factors :
- Techno-economic analysis of renewable energy system mainly depends on the following factors :

i) Initial investment/ present value/first cost for construction of renewable energy system

ii) Annual operating cost of renewable energy system

iii) Annual maintenance cost

iv) Annual energy output either in terms of thermal energy or electrical energy.

v) Rate of interest

vi) Overhauling cost of renewable energy system if any, during life of the system

vii) Life of the system and its salvage value

- In addition to the above points, it is also necessary to consider the following points for the economic analysis:

i) An impact on the environment due to CO_2 emission by embodied energy (one time) of renewable energy system

ii) The energy used to operate it (annually) and pre-treatment, etc.and

iii) CO_2 credit (CC) earned due to use of renewable energy system

1.11.1 Terms used in Renewable Energy Cost Analysis

- When evaluating renewable power plant or new renewable energy projects on an economic basis or comparing the economics of different technologies, the following measures provide insights :

1. Capital costs ($/kWp)
2. Operating costs ($/kWp per annum)
3. Capacity factor (%)
4. Cost of capital (%)
5. Levelised cost of energy ($/kWh)
6. Marginal cost ($/kWh)

1. Capital Costs

- **Capital costs** are the upfront costs to construct the plant and major maintenance work that needs to be carried out during the lifetime of the plant beyond typical operating expenses.
- To compare different technologies, capital costs are divided by the peak power (or "name plate power") of the plant to get the **specific capital cost,** where the peak power is the maximum electric power that the plant can deliver.

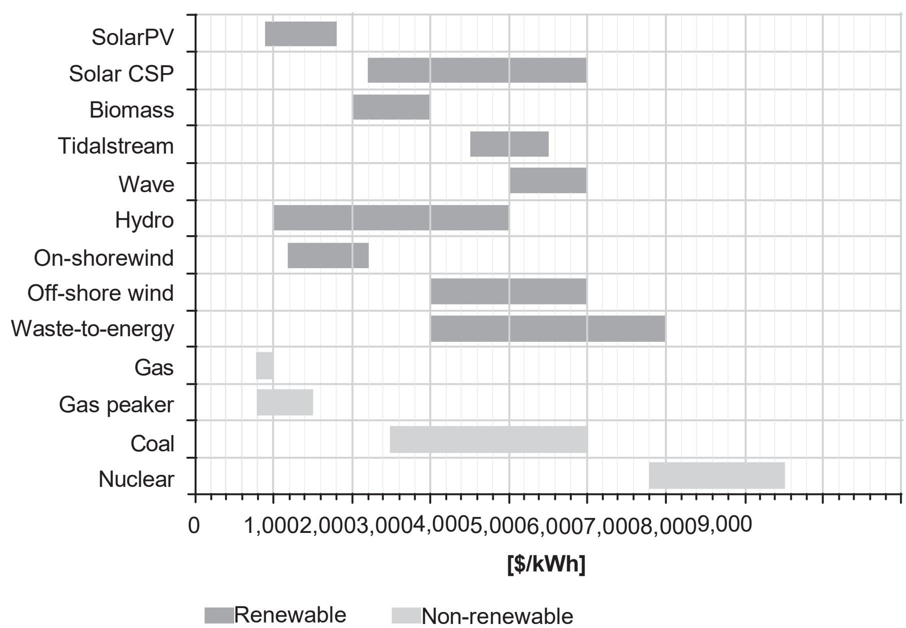

Fig.1.11.1 Capital cost of energy by technology

- As the cost for most plant components, especially electric, rises withthe required power, the specific capital cost is useful to compare the upfrontcosts of different technologies.
- Fig. 1.11.1 shows the capital cost of different forms and technologies of energy with its sensitivity range.
- Among renewable energy sources, solar is now one of the least expensive technologies on a "per MW" basis.

2. Operating Costs

- **Operating costs** cover operations, maintenance and, where appropriate, costs for fuels.
- Renewable energy plants tend to be very low on operating costs in comparison with fossil fuel generators.

3. Capacity Factor

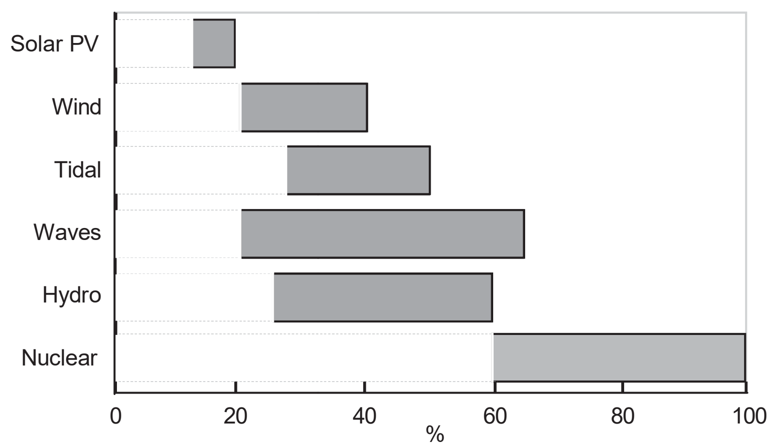

Fig. 1.11.2 Capacity factor by power plant by technology

- The capacity factor of a power station is the ratio of average output power to peak power that the station could deliver.
- Due to fluctuations in the availability of the primary energy source and outages due to maintenance of the equipment, the capacity factor is never 100 %.
- In fact, for renewable energy sources, it is mostly below 50 %.
- The capacity factors of solar plants are particularly low as shown in Fig. 1.11.2.
- After all, the sun is only half of the time above the horizon.

- Why is this important ?
- All electrical components have to be sized such that they can deliver peak power, which is more cost-efficient when the plant runs at high capacity.
- Higher capacity factors imply less fluctuation.

4. Cost of Capital

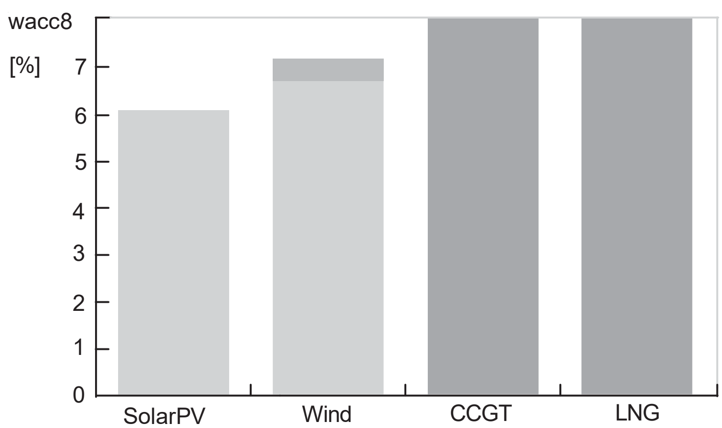

Fig. 1.11.3

- The weighted average cost of capital is measure of how much money the plant has to pay banks and investors in order to provide them with their expected return on the assets.
- The returns are shared by debt providers (banks) and investors.
- This expected return also reflects the risk associated with the business, or in this case, technology.
- According to figures published by *Zelya Energy,* solar photovoltaics are considered a lower risk than wind or liquid gas turbines (LNG).
- The wacc is impacted by level of maturity of technology, predictability of the energy yield, fuel supply risk and also policy risk.
- The expectation of rising carbon prices could increase the cost of capital for coal-fired power plants in future.
- The risk of solar PV is particularly low because the forecast of energy yields of solar modules is more accurate than for other sources.

5. Levelised Cost of Energy

- The Levelised Cost of Energy (LCOE) is the price (per kWh) for generated electricity that makes the net present value of the installation zero.
- In other words : If the sales price is lower than the LCOE, the plant does not provide the required return.
- It is a measure of the **cost of ownership** of the plant.

$$LCOE = \frac{\sum_{i=0}^{N} \left[\frac{I_i + O_i + F_i - ITC_i - PTC_i}{(1+r)^i} \right]}{\sum_{i=0}^{N} \left[\frac{E_i}{(1+r)^i} \right]}$$

I_i	Investment costs in year i
O_i	O and M costs in year i
F_i	Fuel costs in year i
ITC_i	Investment tax credits in year i
PTC_i	Production tax credits in year i
E_i	Energy generated in year i
r	wacc
N	Lifetime of project (years)

- We are deducting tax credits from costs in this formula, as they are benefits independent from the sales price level.
- It is particularly important to take into account any capital allowances (investment tax credits), as their availability may be limited to certain technologies.
- In the absence of availability of tax credits, and assuming that the investment is all made in the first year with constant operating costs and annual energy yield, the formula becomes

$$LCOE = \frac{1}{E_0} \left[\frac{r I_0}{1 - \frac{1}{(1+r)^N}} + O_0 \right]$$

- The levelised cost of energy is a very sophisticated measure, as it takes into account the capital costs, operating costs, cost of capital, capacity factor, generated electricity as well as the timing of all flows.
- The Fig. 1.11.4 shows indicative values for levelized cost of energy for different technologies.

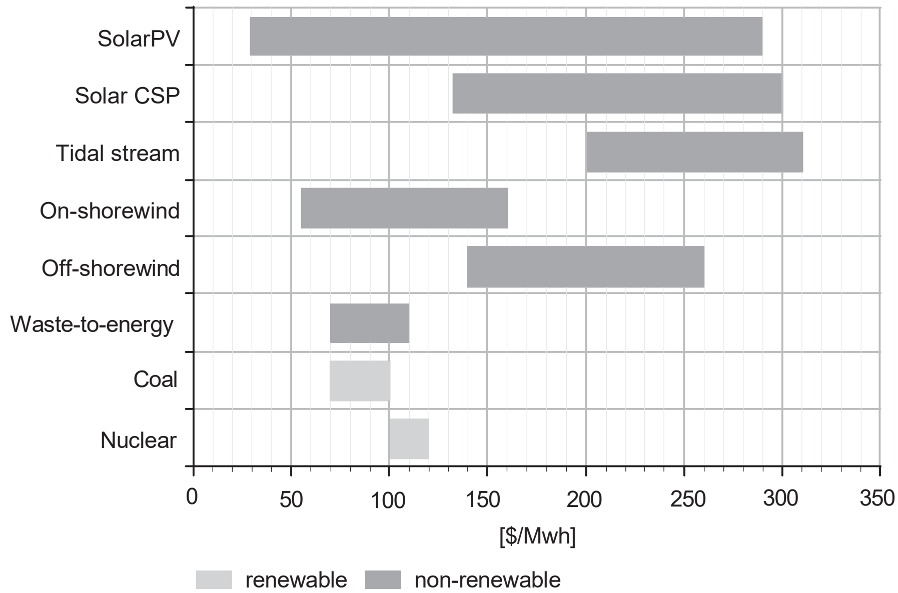

Fig. 1.11.4 Levelized cost of energy by technology

6. Marginal Cost

- The **marginal cost** of a power plant is the dollar amount that needs to be spent to generate an additional kWh, over and above the fixed costs associated with the initial investment and operation.
- With no fuel requirements and very little maintenance, the marginal cost of solar parks is virtually zero, whilst fuel and regular maintenance costs drive up marginal costs for other technologies.
- When considering which generators to use in order to meet the electricity demand, generators with the lowest marginal costs should have priority, thus contributing to lower overall cost of providing electricity.

1.12 Energy Storage System

- Energy storage systems are an essential part of the renewable power generation system.
- The renewable power sources like solar, wind, and hydro are fluctuating resources.
- To supply a smooth output power to the power grid, energy storage systems are installed to the power generation system.

- Again the renewable sources (wind and solar) are unreliable, and in the case of the wind energy, the wind velocity sometimes drops below the power generation level, and sunlight may only be available 6-8 h per day to generate electricity.
- When the power generation becomes zero or the energy demand is high, the energy storage systems can deliver power to the consumers.
- Common forms of renewable energy storage include the following

1. Pumped Hydro Storage
2. Compressed air storage
3. Flywheel storage
4. Battery Storage
5. Hydrogen storage

- These storage systems are based on the viable means of storing electricity and widely available.
- At the same time each method has its own characteristics and features such as response time and storage efficiency.

1.12.1 Pumped Hydro Storage (PHS)

- Pumped storage hydroelectricity is a type of hydroelectric power storage used by some power plants for load balancing.
- The method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation.
- Low-cost off-peak electric power is used to run the pumps.
- During periods of high electrical demand, the stored water is released through turbines.
- The main advantage of this technology is that it is readily available.
- It uses the power of water, a highly concentrated renewable energy source.
- The Pumped Hydro Storage technology is currently the most used for high-power applications.
- Pumped hydroelectric systems have conversion efficiency, from the point of view of a power network, of about 65-80%, depending on equipment characteristics.
- The main shortcoming of this technology is the need for a site with different water elevations.

1.12.2 Compressed Air Energy Storage (CAES)

- Compressed Air Energy Storage (CAES) refers to the compression of air to be used later as energy source.
- At utility scale, it can be stored during periods of low energy demand (off-peak), and for use in meeting periods of higher demand (peak load).
- Compressed air energy storage (CAES) can be used to store off-peak electricity from wind farms or other sources to pump air underground.
- The high pressure air acts like a huge battery that can be released on demand to turn a gas turbine and make electricity.
- CAES relies on relatively mature technology with several high-power projects in place.
- A power plant with a standard gas turbine uses nearly two-thirds of the available power to compress the combustion air.
- It therefore seems possible, by separating the processes in time, to use electrical power during off-peak hours (storage hours) in order to compress the air, and then to produce power during peak hours (retrieval hours) by expanding the air in a combustion chamber before feeding it into the turbines.
- However, a good portion of the input energy is lost in this process, making CAES one of the least efficient storage technologies available.

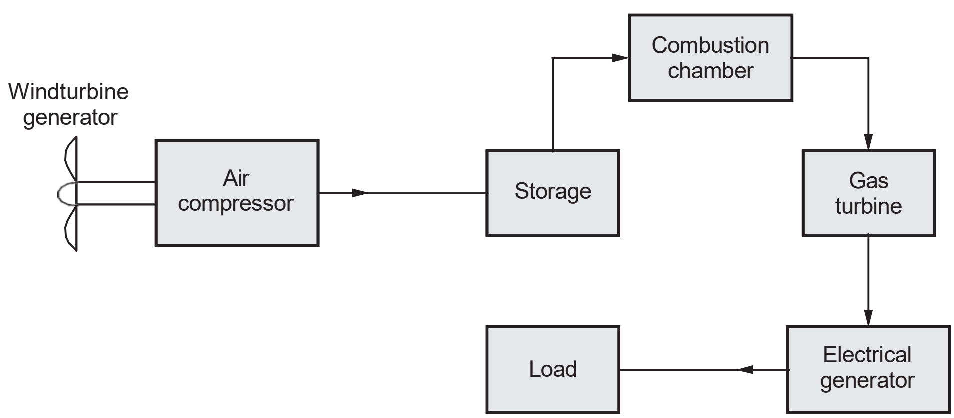

Fig. 1.12.1 Compressed Air Energy Storage

1.12.3 Flywheel Energy Storage (FES)

- Flywheel Energy Storage (FES) works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy.

- When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of conservation of energy; adding energy to the system correspondingly results in an increase in the speed of the flywheel.
- Most FES systems use electricity to accelerate and decelerate theflywheel,but devices that directly use mechanical energy are being developed.
- Advanced FES systems have rotors made of high strength carbon-composite filaments, suspended by magnetic bearings, and spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure.
- Flywheels are today used in specific cases of road and rail transportation, where they eliminate many of the disadvantages of existing battery power systems, such as low capacity, long charge times, heavy weight, and short usable lifetimes.
- They have also been used as uninterrupted power supply systems in data centres.
- They also find applications in laboratories where circuit-breakers and similar devices are tested (that is, where the enormous transient loads produced by deliberately forcing such devices to demonstrate their ability to interrupt simulated short circuits would have unacceptable effects on the local grid if these tests were done directly off building power).
- In addition, they find applications in providing pulsed power and in niche areas in motor sports.

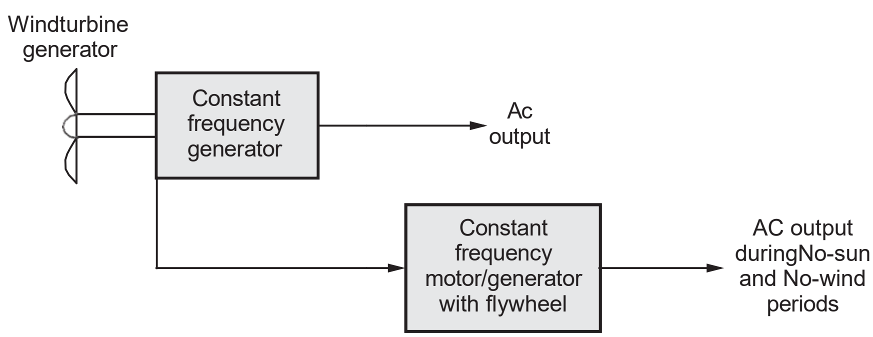

Fig. 1.12.2 Energy Storage in Flywheel

1.12.4 Energy Storage Using Flow Batteries (FBES)

- A flow battery is a form of rechargeable battery in which electrolyte containing one or more dissolved electro active species flows through an electrochemical cell that converts chemical energy directly to electricity.
- An additional electrolyte is stored externally, generally in tanks, and is usually pumped through the cell (or cells) of the reactor, although gravity feed systems are also known.

- Flow batteries can be rapidly "recharged" by replacing the electrolyte liquid (in a similar way to refilling fuel tanks for internal combustion engines) while simultaneously recovering the spent material for re-energization.
- These batteries overcome the limitations of standard electrochemical accumulators (lead-acid or nickel-cadmium for example) in which the electrochemical reactions create solid compounds that are stored directly on the electrodes on which they form, limiting their capacity.
- Various types of electrolytes have been developed using bromine as a central element: with zinc (ZnBr), sodium (NaBr), vanadium (VBr) and, more recently, sodium polysulfide.

1.12.5 Fuel Cells-Hydrogen Energy Storage (FC- HES)

- Fuel cells are a means of restoring spent energy to produce hydrogen through water electrolysis.
- The storage system proposed includes three key components: electrolysis which consumes off-peak electricity to produce hydrogen, the fuel cell which uses that hydrogen and oxygen from air to generate peak-hour electricity, and a hydrogen buffer tank to ensure adequate resources in periods of need.
- There are many types of fuel cells, such as: Alkaline Fuel Cell (AFC), Polymer Exchange Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC).
- The basic differences between these types of batteries are the electrolyte used, their operating temperature, their design, and their field of application.
- Moreover, each type has specific fuel requirements.
- There are several hydrogen storage modes, such as: compressed, liquefied, metal hydride, etc.
- Fuel cells can be used in decentralized production (particularly low-power stations-residential, emergency, etc.), mid-power cogeneration (a few 100 kW), and centralized electricity production without heat upgrading.
- They can also represent a solution for isolated areas where the installation of power lines is too difficult or expensive (mountain locations, etc.).

Advanced Renewable Energy Systems

Questions bank

Chapter 1

Introduction

Q.1 Explain the impact of renewable energy generation on environment in detail.

Q.2 How does environment get affected by the use of the renewable energy? And also discuss GHG emissions from the various energy sources.

Q.3 Explain the influence of different renewable energy sources with special reference to the global warming context.

Q.4 Explain the consequences of greenhouse effect.

Q.5 Explain the Importance of renewable sources of energy

Q.6 Summarize about Indian energy scenario

Q.7 Summarize about World energy scenario

Q.8 Explain about the Environmental consequences of fossil fuel

Q.9 Explain in detail about the Types of renewable energy systems

Q.10 List the Advantage and Disadvantages of conventional energy systems

Q.11 List the Advantage and Disadvantages of non – conventional energy systems

UNIT - II

2 Solar Energy

Syllabus

Solar Radiation - Measurements of Solar Radiation - Flat Plate and Concentrating Collectors - Solar direct Thermal Applications - Solar thermal Power Generation - Fundamentals of Solar Photo Voltaic Conversion - Solar Cells - Solar PV Power Generation - Solar PV Applications.

Contents

2.1 Introduction

- Without the sun, living life on earth is indeed impossible.
- Sun as we known is a ball of fire that gives us light and heat.
- The energy that we receive from the sun is called as the solar energy.
- With the help of this energy serious problems regarding energy that is needed everyday can be solved.
- Solar energy means capturing the rays of the sun and storing and its heat.
- This heat can be converted with the help of solar panels into heat or electrical energy.
- When we talk about solar energy, there are two kinds of solar energy namely, thermal energy and electrical energy.
- Thermal energy is something which we can find everywhere and is totally free of cost.
- It helps us ding our daily chores like dries things, clothes, heats water, and many other things.
- Water can basically be heated in two ways i.e. actively and passively.
- In active method, when a heating element inside the solar hot water system heats the water during hot season.
- In the passive method the water is pre heated and flows through a cold inlet that of a conventional electric geezer.
- Talking about electric energy, the power of the sun is used to produce electricity with the help of solar cells.
- It can be used through a solar home system that helps in conducting electricity where there is no power supply.
- Apart from that it can be used a system where the electricity supplying utility is connected to the property and lastly it can be used as a backup system where there are frequent load shedding problems.

2.1.1 Importance of Solar Energy

- As mentioned before solar energy is required and is important for survival of life on earth.
- Not only human beings, plants, animals everyone requires solar energy every day.
- Plants require solar energy to produce oxygen, prepare food i.e. photosynthesis.

- Solar energy is required to produce both pure and saltwater in oceansasitisthe only source of melting the frozen ice formed on the mountain caps.
- Apart from that the electricity which we get to run various machines is all gained from the solar energy, thus its importance and existence is very important on a planet where there is life.
- Solar energy is a clean and renewable energy.
- Also it's versatile and can help in producing power for watches and calculators that do not run on batteries.
- It's a clean energy because it is received directly from the sun.
- The fossil fuels and other gas and oil that are extracted from the mines are non renewable energy.
- Also they are costly and cause lot of pollution.
- But solar energy is something that is renewable and can be used for lots of activities. Also it is available free of cost.
- As fossil fuels and other oils are soon going to disappear solar energy which is available in abundant should be utilized well and hence is important.
- One major concern is the cost of solar power. Solar panels (accumulators) are not cheap; and because they are constructed from fragile materials (semiconductors, glass, etc.), they must constantly be maintained and often replaced.
- As mentioned before solar energy is required and is important for survival of life on earth.
- Not only human beings, plants, animals everyone requires solar energy every day.
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- But solar energy is something that is renewable and can be used for lots of activities. Also it is available free of cost.
- As fossil fuels and other oils are soon going to disappear solar energy which is available in abundant should be utilized well and hence is important.

2.1.2 Advantages of Solar Energy

1. It's a renewable and clean source of energy that will last forever (well, as long as the sun is around)
2. It reduces energy usage in homes and businesses and ultimately lessens utility bills
3. Diverse applications across many different industries including transport, heating buildings, and so on
4. Low maintenance costs as solar panels last over 30 years and experience very little wear and tear
5. Technology is always developing, improving and becoming cheaper and more efficient
6. It is available almost every day as some power can still be produced even on cloudy days
7. Using solar power reduces our dependence on fossil fuels and foreign oil
8. Solar power is pollution-free and emits no greenhouse gases after installation
9. It provides a great return on your investment, instead of paying for energy bills every month
10. It helps the economy by creating jobs for solar manufacturers, solar installers, and so on.
11. Any surplus power that is generated can be exported back to the grid and sold to the power company.
12. Solar energy gives residents the options and ability to live grid-free if they want to
13. It can be installed almost anywhere from buildings to fields, as long as you have space for it
14. Extra power can be stored in batteries for use in the night
15. Solar power can be used to not only power homes, but even cars as well
16. It is safer to use than traditional electric current

2.1.3 Disadvantages of Solar Energy

1. Initial costs for material and installing are relatively high
2. Power is harnessed intermittently depending on the weather
3. Storing the surplus energy generated can be costly
4. Solar power is associated with pollution (when creating the solar panels)
5. Exotic materials are sometimes required for the manufacture of solar technology
6. It can take a long time to see a return on the initial investment
7. A lot of space is required for harnessing sufficient solar power for homes or businesses
8. There is a need for large battery banks since there's no solar power at night
9. Solar panels are fragile and can be easily damaged therefore extra insurance costs are needed
10. Appliances and devices running directly on DC power are more expensive
11. The size of solar panels vary for the same power generation depending on geographical location
12. Not much power can be produced on cloudy days or when there is a storm
13. Solar technology isn't being mass produced (this could lower the cost enough to be more affordable)
14. Lack of material and technology inhibits consistent production of solar panels
15. Cars that are solar-powered don't have the same speed and power as traditional gas-powered cars
16. Lower power production during the winter months

2.2 Applications of Solar Energy

- The applications of solar energy are categorized in different sectors :

1. **Residential application :** Use of solar energy for homes has number of advantages. The solar energy is used in residential homes for heating the water with the help of solar heater. The photovoltaic cell installed on the roof of the house collects the solar energy and is used to warm the water.
2. **Industrial application :** Sun's thermal energy is used in office, warehouse and industry to supply power. Solar energy is used to power radio and TV stations. It is also used to supply power to lighthouse and warning light for aircraft.

3. **Poolheating:** Solar heating system can be used to heat up water in pool during cold seasons.
4. **Transportation :** Solar energy is also used for public transportation such as trolleys, buses and light-rails.
5. **Remote application :** Solar energy can be used for power generation in remotely situated places like schools, homes, clinics and buildings. Water pumps run on solar energy in remote areas.

2.3 Solar Radiation

- Solar radiation is the radiant energy emitted by the Sun in the form of electromagnetic waves.
- The sun emits vast amount of radiant energy.
- The earth intercepts only a fraction of it.
- It is essential to drive directly or indirectly all biological and physical processes on the Earth.
- The earth is the only planet in the solar system, which receives an optimum amount of solar radiation that makes life sustainable on it.
- Solar spectrum resembles to that of a black body at approximately 5800 K.
- 98 % of the total emitted energy lies in the spectrum ranges from 0.25 μm to 3.00 μm.
- About half of the radiation is in the visible short-wave part of the electromagnetic spectrum.
- The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum.
- Solar radiation having wavelength less than 0.286 μm (called ultraviolet) is absorbed by ozone layer in stratosphere.
- The ultraviolet radiation not absorbed by the atmosphere is responsible for the change of color in skin pigments.
- The solar radiation, that traverses the atmosphere further, is subjected to scattering, reflection and absorption by air molecules, aerosols, gases and clouds.
- The radiation budget represents the balance between incoming energy from the Sun and outgoing thermal (longwave) and reflected (shortwave) energy from the Earth.

- Globally, the budget is balanced. Otherwise the temperature would rise constantly. Locally, the budget is not balanced.
- Tropical areas get more than they release, while higher latitudes of the winter hemisphere release more than they receive.
- **Solar irradiance** is the power per unit area (watt per square metre, W/m^2), received from the Sun in the form of electromagnetic radiation as reported in the wavelength range of the measuring instrument.
- Solar irradiance is often integrated over a given time period in order to report the radiant energy emitted into the surrounding environment (joule per square metre, J/m^2), during that time period.
- This integrated solar irradiance is called **solar irradiation, solar exposure, solar insolation, or insolation.**
- Irradiance may be measured in space or at the Earth's surface after atmospheric absorption and scattering.

2.3.1 Solar Isolation

- Solar isolation is the amount of solar radiation incident on the surface of the earth at a particular instant of time.
- This refers to the amount of sunlight shining down on the area under consideration.
- The values are generally expressed in $kWh/m^2/day$
- This is the amount of solar energy that strikes a square meter of the earth's surface in a single day.
- This value is averaged to account for differences in the day's length.
- It depends upon below listed parameters :

i. Atmospheric clarity

ii. Hour angle

iii. Seasonal variation and Geographic location of the particular surface.

iv. Degree of latitude of the location

v. Area of exposed surface, m^2

vi. Angle of tilt of solar panel

vii. Shadow of trees, tall structures, adjacent solar panels, etc.

2.3.2 Terms and Definitions used in Solar Radiation

1. Beam or Direct Radiation (I_b)

- The directions of the sun coming on the earth's surface without any change are known as "direct radiation" or "beam radiation".

2. Diffuse Radiation (I_d)

- The radiations of the sun received by the earth after the change in direction by reflection and scattering effect by the atmosphere such radiations are known as the diffuse radiations".

3. Total Radiation (I_T)

- "It is the sum of beam radiations and the diffuse radiations such radiations are known as the total radiations".
- Total Radiations are given by the following equation

$$I_T = I_b + I_T$$

- All these three diffuse, direct, and total radiation are shown in Fig. 2.3.1.

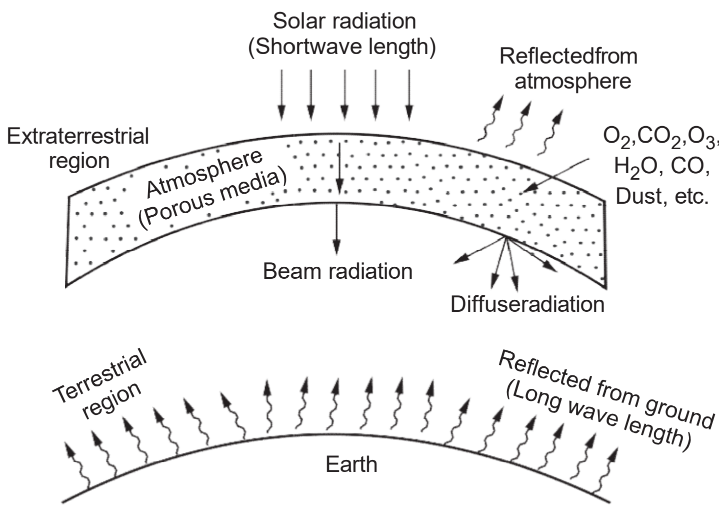


Fig. 2.3.1 Diffuse, Direct, and Total radiation

4. Clarity Index (Ci)

- "It is defined as the ratio of the radiation received on the earth's surface over given period of time to the radiation on the equal surface area beyond earth's atmosphere in perpendicular direction to the beam is known as the clarity index."
- The value of the clarity index is in between 0.1 to 0.7.

5. Concentration Ration (Cr)

- "It is the ratio of solar power per unit area of the concentrator surface to the power per unit area on the line focus or point focus".

6. Air Mass (ma)

- "It is defined as the path length of the radiation through the atmosphere by assuming vertical path as level of unity".
- Value of the air mass depends on the zenith angle.
- Unity value is considered when sun is at the zenith.

ma = 2 when zenith angle is 60°.

ma = 0 just above earth's atmosphere.

2.3.3 Solar Radiation Outside the Earth's Atmosphere and at the Earth's Surface

- "Solar radiation incident outside the earth's atmosphere is called extra-terrestrial radiation".
- On average the extra-terrestrial irradiance is 1367 Watts/meter^2 (W/m^2).

2.3.1.1 Solar Constant (Gsc)

- *"The amount of solar energy received per unit time per unit area at the mean distance of the earth from the sun on a surface normal to the sun is called the solar constant Gsc."*
- This quantity is difficult to measure from the surface of the earth because of the effect of the atmosphere.
- When the sun is closest to the earth, on December 21 the solar heat on the outer edge of the earth's atmosphere is about 1400 W/m^2 and when the sun is farthest away on June 21 is about 1310 W/m^2.

2.3.1.2 Solar Radiation at the Earth's Surface (Terrestrial Radiation)

- The solar radiation incident on the Earth's atmosphere is relatively constant, the radiation at the Earth's surface varies widely due to :
  a. Atmospheric effects, including absorption and scattering.
  b. Local variations in the atmosphere, such as water vapour, clouds, and pollution.
  c. Latitude of the location; and the season of the year and the time of day.

- The above effects have several impacts on the solar radiation received at the Earth's surface.
- These changes include variations in the overall power received, the spectral content of the light and the angle from which light is incident on a surface.
- In addition, a key change is that the variability of the solar radiation at a particular location increases dramatically.
- The variability is due to both local effects such as clouds and seasonal variations, as well as other effects such as the length of the day at a particular latitude.
- Desert regions tend to have lower variations due the amount of energy reaching the surface of the earth every hour is greater than the amount of energy used by the earth's population over an entire year to local atmospheric phenomena such as clouds.
- Equatorial regions have low variability between seasons.

2.3.4 Solar Radiation Geometry

2.3.4.1 Declination, δ

- "The solar declination is the angular distance of the sun's ray's north (or south) of the equator, north declination designated as positive."
- It is the angle between the sun and earth centre line and the projection of this line on the equatorial plane.
- The declination angle ranges from 0° at the spring equinox, to + 23.45° at the summer solstice, to 0° at the fall equinox, to – 23.45° at the winter solstice.
- The variation of the solar declination angle throughout the year is shown in Fig. 2.3.2 (See Fig. 2.3.2 on next page).
- The declination angle δ, in degrees, for any day of the year (n) can be calculated approximately by the equation:

$$\delta = 23.45 \sin [360 / 365 (284 + n)]$$

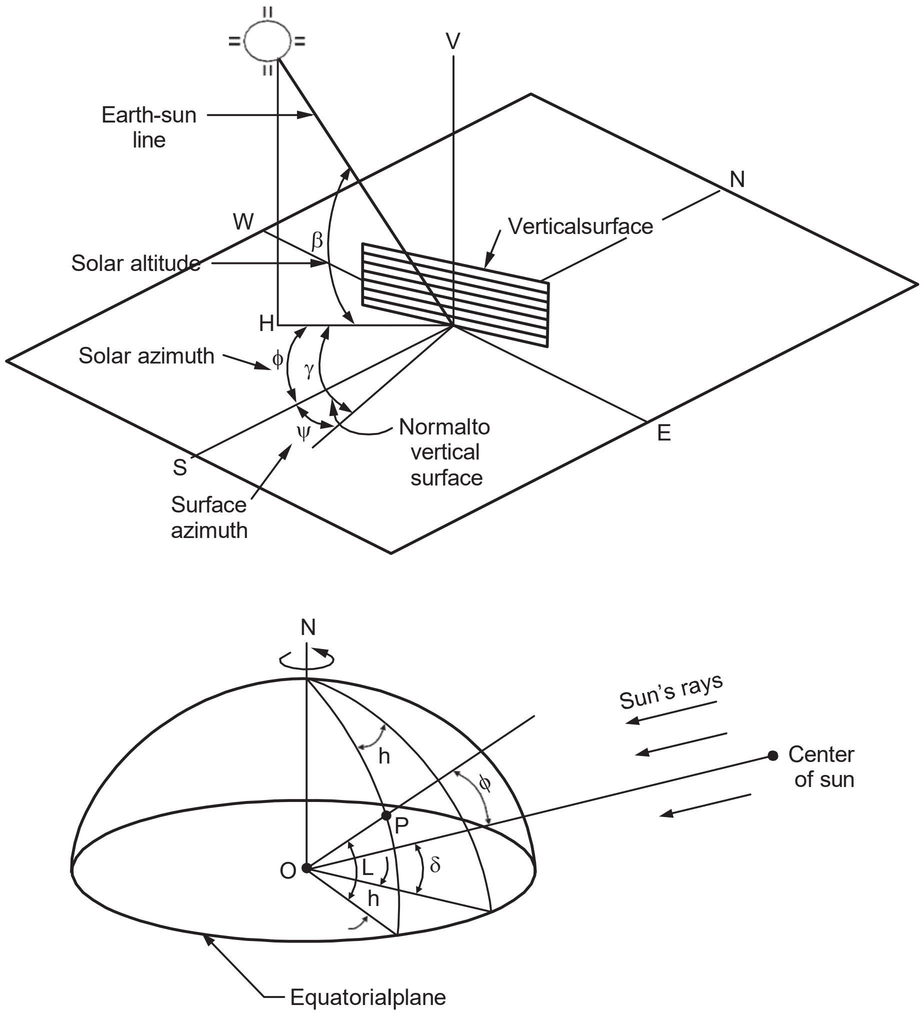


Fig. 2.3.2 : Solar radiation geometry

2.3.4.2 Hour Angle (h)

- The hour angle h, of a point on the earth's surface is defined as the angle through which the earth would turn to bring the meridian of the point directly under the sun.
- The hour angle at local solar noon is zero, with each 360/24 or 15 degrees of longitude equivalent to one hour, afternoon hours being designated as positive.
- Expressed symbolically, the hour angle in degrees is :

$$h = \pm 0.25 \text{ (number of minutes from local solar noon)}$$

Where, the + sign applies to afternoon hours and the − sign to morning hours.

- The hour angle can also be obtained from the Apparent Solar Time (AST),i.e.,the corrected local solar time : h = (AST – 12)15

  At local solar noon AST = 12 and h = 0°.

- Therefore, the Local Standard Time (the time shown by our clocks at local solar noon) is :

  LST = 12 – ET ± 4 (SL – LL)

- For the city in Germany: LST = 12 – ET – 9.2 [min]

Solar Altitude (β)

- It is defined as the vertical angle to the sun position.

Solar Azimuth Angle (γ_c)

- It is defined as horizontal bearing angle from south.

Surface Azimuth : ψ (psi)

- It is defined as, surface horizontal bearing angle from south.

Surface Solar Azimuth : γ (gamma)

- Angle between solar and surface azimuths.
- It is given by the equation -

$$\gamma = \phi - \psi$$

Angle of Incidence (θ)

- The solar incidence angle, θ is the angle between the sun's rays and the normal on a surface.
- For a horizontal plane the incidence angle, θ and the zenith angle ϕ are the same.

Sun Rise and Set Times and Day Length

- The sun is said to rise and set when the solar altitude angle is zero.
- So the hour angle at sunset, hss, can be found from solving the equation for the altitude angle for h when $\alpha = 0°$.
- Thus :

  $\sin(\alpha) = \sin(0) = 0 = \sin(\phi)*\sin(\delta) + \cos(\phi)*\cos(\delta)*\cos(hss)$

  which reduces to : $\cos(hss) = -\tan(\phi)\tan(\delta)$

  where, hss is taken as positive at sunset.

- Since the hour angle at localsolar noon iszero,with each 15 degrees of longitude equivalent to one hour, the sunrise and sunset time in hours from local solar noon is then :

  $Hss = -Hsr = 1/15 \cos - 1[\tan(\phi) \tan(\delta)]$

- The local standard time at sunset for the city of Germany is :
- Sunset Standard Time = Hss – ET – 9.2 (min)
- The day length is twice the sunset hour since the solar noon is at the middle of the sunrise and sunset hours.
- Thus the length of the day in hours is :

  $$\text{Day Length} = 2/15 \cos^{-1} [1 - \tan(\phi) \tan(\delta)].$$

2.3.4.3 Solar Time

- Solar Time is also known as the 'Local Solar Time (LST) or Local Apparent Time (LAT).
- Solar time is generally used to compute the hour angle.
- Solar time can be obtained from the standard time observed from the clock.
- Following corrections are need to make in the solar time in order to obtain the solar time.

a) correction in the longitude between the location and the meridian which is the basis of standard time.

b) Correction in the equation of time which is obtained from the experimental observations.

Hence, we can write the equation for the solar time in terms of the standard time as -

$$\text{LST orLAT} = ST \pm [4\times(L_{st}-L_{local})]+T_c \quad \text{...(a)}$$

where,

LST or LAT = Solar time

ST = Indian standard time

L_{st} = Standard time longitude

L_{local} = Longitude at location

T_c = Time correction equation

- Sign conventions used are 'Positive (+)' value is generally considered for 'western region or hemisphere and (– ve) value for 'Eastern hemisphere.

Numericals on Solar Time

Example 2.3.1 : *Calculate Local Apparent Time (LAT) and declination at a location latitude 25°21′ N, longitude 78° 30′ E at 12.40 IST on July 25 Equation of time corredian = (1′ 07″).*

Solution : Given data,

Latitude = 25° 21′ N, Longitude = 78°30′E

Day of July 25

IST = 12.40 $-12^h 40' T_c$ = – 1′ 07″, LST = 82.5° = 82°30′

Day of July 25

No. of days [n = Jan + Feb + March + April + May + June + July]

[n = 31 + 28 + 31+ 30 + 31 + 30 + 25]

∴ n = 206 ... **Ans.**

Step 1 : Calculate LAT or LST

To calculate LAT or LST we can use following equation.

$$LAT = IST \pm [4 \times (L_{st} - L_{local})] + Tc \qquad ...(1)$$

Step 2 : As longitude is 78°32′ E we have to use –ve value.

$$\therefore \quad LAT = IST - [4 \times (L_{st} - L_{local})] + Tc \qquad ...(2)$$

∴ Equation (2) after putting the values

$$LAT = 12^h 40' - [4 \times (82°30' - T8°30')] - 1'07''$$

$$-12^h 40' - (4 \times 4) - 1'07''$$

$$\therefore \quad LAT = 12^h 2253'' \qquad ... \textbf{Ans.}$$

Local Apparent Time is 12:22:53 (i.e. 12 hour 22 min 53 seconds)

Step 3 : Declination(δ)

Cooper has given equation of δ as -

$$\delta = 23.45 \sin\left[\frac{360}{365}(284n) + \right] \qquad ...(3)$$

where, δ = Declination

η = 206

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+206)\right]$$

$$\delta = 23.45 \sin\left[\frac{360}{365}(490)\right]$$

$$\delta = 23.45 \sin(483.2876)$$

$$\delta = 23.45 \times 0.8359$$

$\therefore$ $\boxed{\delta = 19.60^\circ}$ ...Ans.

> **Example 2.3.2 :** *Determine the number of day light hours in Srinagar (Latitude (36º05′) on 5*th *January and 5*th *July.*

Solution : Given data,

Latitude $\phi = 36^\circ 05'$

number of days 5^{th} January

n=5

Step 1 : Declination (δ) is given by the cooper's equation as,

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+n)\right]$$

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+5)\right]$$

$$\delta = 23.45 \sin\left[\frac{360 \times 289}{365}\right]$$

$$\delta = 23.45 \sin(285.04)$$

$$\delta = 23.45 \times -0.9657$$

$\therefore$ $\boxed{\delta = -22.64^\circ}$ ... Ans.

Step 2 : Calculation of days length.

Day length can be given as -

$$\text{Day length} = \frac{2}{15}\left[\cos^{-1}(-\tan\phi \tan\delta)\right]$$

$$t_{dl} = \frac{2}{15}\left[\cos^{-1}(-\tan(36^o05')\tan(-22.64^o)\right]$$

$$t_{dl} = \frac{2}{15}\left[\cos^{-1}(-0.7287\times-0.4169)\right]$$

$$= \frac{2}{15}\times\cos^{-1}(0.3037)$$

$$= \frac{2}{15}\times 72.3143$$

$$\therefore \quad \boxed{t_{dl} = 9.61 \text{ hours}}$$

Step 3 : Declination at 5th July

To calculate declination (δ) we have to first find the number of days up to 5th July.

$$\therefore \quad n = \text{Jan + Feb + March + April + May + June + 5July}$$

$$n = 31 + 28 + 31 + 30 + 31 + 30 + 5 = 186$$

$$\therefore \quad \delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$

$$= 23.45\sin\left[\frac{360}{365}\times(284+186)\right]$$

$$= 23.45 \sin\left[\frac{360}{365}\times 470\right]$$

$$= 23.45\sin(463.56)$$

$$\therefore \quad \boxed{\delta = 22.79^o}$$

Declination at 5th July is **22.79º**

Step 4 : Day length is -

$$t_{dl} = \frac{2}{15}\cos^{-1}[-\tan\phi\tan\delta]$$

$$= \frac{2}{15}\cos^{-1}\left[-\tan(36^o05')\times\tan(22.79^o)\right]$$

$$= \frac{2}{15}\cos^{-1}(-0.30619)$$

$$= \frac{2}{15} \times 107.830 = 14.37$$

$$\boxed{t_{dl} = 14.37 \text{ hour}}$$

Day length on 5th July is 14.37 hours.

Example 2.3.3 : *Calculate number of daylight hours in Delhi on 22 December 1995. Take latitude* 28º35′ *N.*

Solution : Given data,

Latitude : 28º35′N

∴ ϕ–28º35′

Number of days n on 22 Dec.

∴ n = Jan + Feb. + March + April + May + June + July + Aug. + Sept. + Oct + Nov.+ 22 Dec.

= 31 + 28 + 31 + 30 + 31 + 30 + 31 + 30 + 31 +30 + 31 + 22

$$\boxed{n = 356}$$

Step 1 : Angle of declination (δ)

According to cooper.

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$

$$= 23.45 \sin\left[\frac{360}{365}(284 + 356)\right]$$

$$= 23.45 \sin\left[\frac{360 \times 640}{365}\right]$$

$$\delta = 23.45 \sin(631.23)$$

$$\boxed{\delta = -23.44^{\circ}}$$

Step 2 : Day length as on 22 Dec. 1995.

$$t_{dl} - \frac{2}{15}\cos^{-1}[-\tan\phi \tan\delta]$$

$$= \frac{2}{15}\cos^{-1}[-\tan(28^{\circ}05') \times \tan(-23.44^{\circ})]$$

$$= \frac{2}{15}\cos^{-1}(0.2362)$$

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right]$$

$$= 23.45\sin\left[\frac{360}{365}\times(284+186)\right]$$

$$= 23.45\sin\left[\frac{360}{365}\times 470\right]$$

$$= 23.45\sin(463.56)$$

$$\boxed{\delta = 22.79^{\circ}}$$

Declination 5th July **22.79º**

Step 3 : Day length is

$$t_{dl} = \frac{2}{15}\cos^{-1}[-\tan\phi\tan\delta]$$

$$= \frac{2}{15}\cos^{-1}[-\tan(36^{\circ}05')\tan(22.79^{\circ})]$$

$$= \frac{2}{15}\cos^{-1}(-0.30619)$$

$$= \frac{2}{15}\times 107.830 = 14.37$$

$$\boxed{t_{dl} = 14.37 \text{ hour}}$$

Day length on 5th July is 14.37 hours.

> **Example 2.3.4 :** *Calculate solar Insolation on the top of atmosphere on 23 March and 19 June 2011. Take solar constant =* $1353 W/m^2$

$$GSC - 1353 W/m^2$$

Solution : Given : Solar constant

To find :

i) Solar Isolation for 23 March

ii) Solar Isolation on 19 June 2011

Step 1 : No. Days as on 23 March

$$n = Jan + Feb + 23 \text{ March}$$

$$= 31 + 28 + 23 = 82 \text{ days.}$$

Step 2 : Solar Isolation on 23 March

$$G = GSC\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]$$

$$G = 1353\left[1 + 0.033\cos\left(\frac{360 \times 82}{365}\right)\right]$$

$$G = 1353\ [1 + 0.033 \times \cos\ (80.87)]$$

$$\boxed{G = 1360.07\ W/m^2}$$

Solar Isolation on 23 March is 1360.07

Step 3 : Number of days on June 19

$$n = Jan + Feb + March + April + May + 19 \text{ June}$$

$$= 31 + 28 + 31 + 30 + 31 + 19$$

$$\boxed{n = 170}$$

Step 4 : Solar Isolation on June 19

$$G = GSC\left[1 + 0.033\cos\left(\frac{360 \times n}{365}\right)\right]$$

$$= 1353\left[1 + 0.033\cos\left(\frac{360 \times 170}{365}\right)\right]$$

$$= 1353\ [1 + 0.033\ \cos\ (167.67)]$$

$$= 1353\ [1 + 0.033 \times (-\ 0.9769)]$$

$$= 1353 \times 0.9677$$

$$\boxed{G = 1309.38\ W/m^2}$$

Example 2.3.5 : *Calculate the day length in hours at Chennai (latitude=13°)* **on** 15*th* *May.*

Solution : Day-length can be calculated by the equation

$$t_d = \frac{2}{15}[\cos^{-1}(-\tan\phi_1 \tan\delta)] \text{ hours}$$

The value of δ can be calculated by the equation

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right]$$

where n = Number of days from 1^{st} Jan. to 15^{th} May

= 31 + 28 + 30 + 31 + 15 = 135 days

$\therefore$ $$\delta = 23.45\sin\left[\frac{360}{365}(284+135)\right] = 18.79^\circ$$

Hence, $$t_d = \frac{2}{15}[\cos^{-1}(-\tan 13^\circ \tan 18.79^\circ)]$$

= 12.6 hours **...Ans.**

Example 2.3.6 : *Determine the angle made by beam radiation with the normal to* **a** *flat plate collector, pointing the south location in Chennai (13°N, 80.27°E) at 11.00 hour solar time* **on** 17*th* *April. The collector is tilted at* **an** *angle of 32° with the horizontal.*

Solution : Since the surface is facing south, $\gamma = 0$

To calculate incident angle equation is,

$$\cos\theta = \sin\delta\sin(\phi_1-\beta)+\cos\delta\cos\omega\cos(\phi_1-\beta)$$

where ϕ_1 – Latitude = 13°

δ = Declination angle

β = Slope or tilt angle = 32°

ω = Hour angle

The value of δ can be calculated by the equation

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right]$$

where n = Number of days from 1^{st} Jan. to 17^{th} April

= 31 + 28 + 30 + 17 = 106 days

$$\therefore \quad \delta = 23.45 \sin\left[\frac{360}{365}(284 + 106)\right] = 9.78^\circ$$

Hour angle, $\omega = 15(12 - LST) = 15(12 - 11) = 15^\circ$

Substituting these values in the above equation

$$\cos\theta = \sin 9.78^\circ \sin(13^\circ - 32^\circ) + \cos 9.78^\circ \cos 15^\circ \cos(13^\circ - 32^\circ)$$

$$= 0.955$$

$\therefore \quad \theta = \mathbf{17.19^\circ}$ **...Ans.**

2.4 Solar Radiation Measurements

- It is important to measure solar radiation, due to the increasing number of solar heating and cooling applications, and the necessity for accurate solar radiation data to predict performance.
- Solar radiation needed instrument which will calculate the heating effect of direct solar radiation and diffuse solar radiation.
- Solar radiation can be measured using the following instruments :

1. Pyranometer 2. Pyro heliometers 3. Sunshine recorder

2.4.1 Pyranometer

Principal

- A pyranometer is used to measure global solar radiation falling on a horizontal surface. Its sensor has a horizontal radiation-sensing surface that absorbs solar radiation energy from the whole sky and transforms this energy into heat.
- Global solar radiation can be ascertained by measuring this heat energy.

Construction and Working

- The pyranometer was constructed using a silicon photodiode which was chosen for its local availability and high sensitivity.
- This silicon photodiode is a solid-state device that converts light energy (photons) to electric current.

- When radiation at a specific energy level that is capable of ionizing the atoms is incident on the P-N junction photodiode, an electrical current arises from the continuous movement of excess electrons and holes.
- Electric current produced by the photodiode is directly proportional to the amount of global solar radiation reaching its surface.
- The sensor element is mounted on a wooden base, covered with a transparent plastic material to protect the sensor from absorbing dirt.

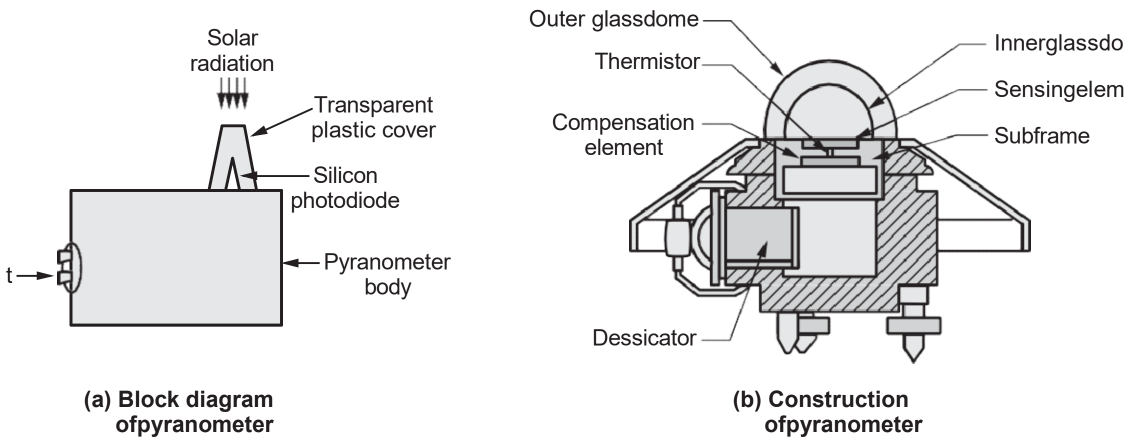


Fig.2.4.1:Solar pyranometer

- The developed pyranometer generates an electrical signal proportional to the irradiance received.
- The pyranometer was constructed in parts and then assembled.
- A hole was drilled about one quarter distance from one end in the top of a wood case of 10 mm thickness with a dimension of 165 mm by 120 mm by 80 mm where a diode holder was inserted and super glued.
- The photo detector was inserted into the diode holder.
- The exposed surface of the photodiode was covered with a transparent plastic material in order to protect it from dust and other weather attack.
- A pair of wires was soldered to the anode and cathode terminals of the photodiode which was then connected to the terminals of a digital multi-meter through which the output readings indicating the amount of solar radiation was obtained.

Advantage of the pyranometer

- The temperature coefficient is extremely small
- Standardized to ISO standards
- Measurements of performance ration & performance index are accurate.
- Response time is longer compare to PV cell

Disadvantage of the pyranometer

- The disadvantage of the pyranometer is, its spectral sensitivity is imperfect, so it does not observe the complete spectrum of the sun. So errors in measurements can occur.

Applications of pyranometer

The applications are

- The solar intensity data can be measured.
- Climatological & Meteorological studies
- PV systems design
- Locations of the greenhouse can be established.
- Expecting the requirements of insulation for building structures

2.4.2 Pyroheliometers

- A pyrheliometer is a device used to measure "beam or direct radiations".
- It collimates the radiation to determine the beam intensity as a function of incident angle.
- This instrument uses a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun at normal incidence.

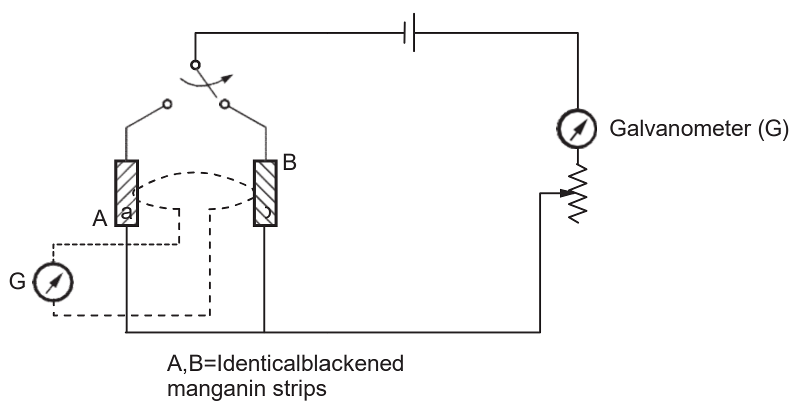


Fig. 2.4.2 Circuit diagram for the thermoelectric type pyroheliometer

Construction of Pyrheliometer:

- In this instrument, two identical blackened manganin strips A and B are arranged in such a way that either can be exposed to radiation at the base of collimating tubes by moving a reversible shutter.

Working of Pyrheliometer :

- One strip is placed in radiation and a current is passed through the shaded strip to heat it to the same temperature as the exposed strip.
- When there is no difference in temperature the electrical energy supplied to shaded strip must equal the solar radiation absorbed by the exposed strip.
- Solar radiation is then determined by equating the electrical energy to the product of incident solar radiation, strip area and absorptance.

2.4.3 Sunshine Recorder

- A sunshine recorder is a device used to measure the **"hours of bright sunshine in a day".**

2.4.3.1 Campbell-Stokes Sunshine Recorder

- A Campbell-Stokes sunshine recorder concentrates sunlight through a glass sphere onto a recording card placed at its focal point.
- The length of the burn trace left on the card represents the sunshine duration.
- The device's structure is shown in Fig. 2.4.3 (a).
- A homogeneous transparent glass sphere L is supported on an arc XY, and is focused so that an image of the sun is formed on recording paper placed in a metal bowl FF' attached to the arc.
- The glass sphere is concentric to this bowl, which has three partially overlapping grooves into which recording cards for use in the summer, winter or spring and autumn are set (Fig. 2.4.3 (b)).
- Three different recording cards (Fig. 2.4.3 (c)) are used depending on the season.
- The focus shifts as the sun moves, and a burn trace is left on the recording card at the focal point.
- A burn trace at a particular point indicates the presence of sunshine at that time, and the recording card is scaled with hour marks so that the exact time of sunshine occurrence can be ascertained.

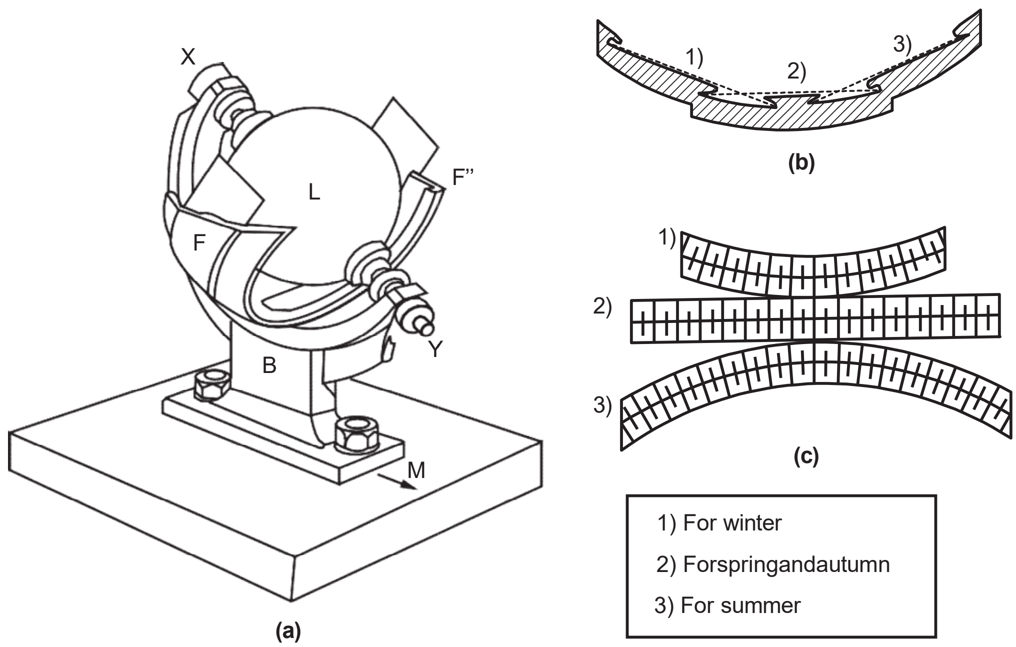


Fig. 2.4.3 Campbell stokes sunshine recorder

- Measuring the overall length of burn traces reveals the sunshine duration for that day.
- For exact measurement, the sunshine recorder must be accurately adjusted for planar levelling, meridional direction and latitude.
- Campbell-Stokes and Jordan sunshine recorders mark the occurrence of sunshine on recording paper at a position corresponding to the azimuth of the sun at the site, and the time of sunshine occurrence is expressed in local apparent time.

2.4.3.2 Jordan Sunshine Recorder

- A Jordan sunshine recorder lets in sunlight through a small hole in a cylinder or a semi cylinder onto photosensitized paper set inside the cylinder on which traces are recorded.
- One common type has two hollow semi cylinders arranged back to back with their flat surfaces facing east and west (Fig. 2.4.4 (a)).
- Each flat surface has a small hole in it.
- The Jordan sunshine recorder used by JMA is the same in principle, but consists of a hollow cylinder with two holes as shown in Fig. 2.4.4 (b).

- The instrument has its cylinders inclined to the relevant latitude and their axes set in the meridional direction. Photosensitized paper with a time scale printed on it is set in the cylinders in close contact with the inner surface. When direct solar radiation enters through the hole, the paper records the movement of the sun as a line.
- Sunshine duration is ascertained by measuring the length of time the paper was exposed to sunlight.

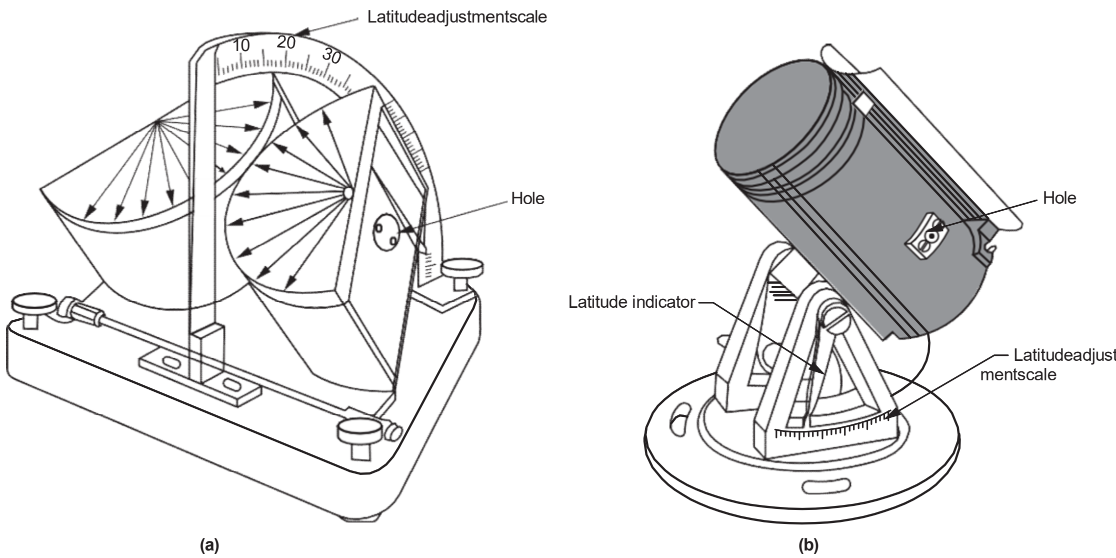


Fig. 2.4.4 Jordan sunshine recorders

2.4.3.3 Rotating Mirror Sunshine Recorder

- A rotating mirror is used to reflect sunlight onto the photo sensor, and the occurrence of sunshine is detected by measuring the intensity of the light received.
- The rotating mirror sunshine recorder used by JMA has a mirror that rotates once every 30 seconds and a photo sensor to receive the reflected sunlight.
- Once the instrument is set to an angle corresponding to the latitude at the site by adjusting the scale on the body at installation, the double-surfaced mirror reflects sunlight as required throughout the year regardless of changes in the sun's elevation.
- Although the radiation received by the photo sensor contains both direct solar radiation and diffuse sky radiation, the latter is removed by differentiating the output signal for time electrically, and only direct solar radiation can be detected at the peak of the maximum differential coefficient.

- The instrument emits a pulse when the signal exceeds the threshold value of 120 W/m^2 corresponding to the definition of direct solar irradiance, andthe processing unit counts two minutes of sunshine for every four pulses.

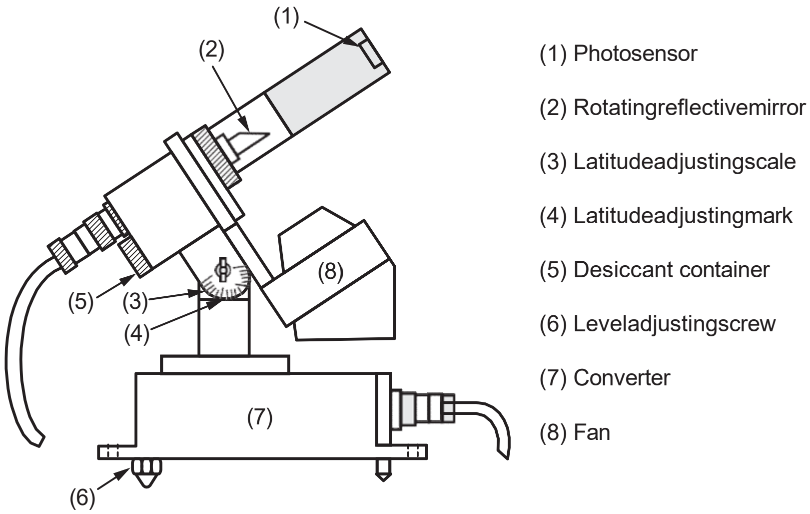


Fig. 2.4.5 : Rotating mirror sunshine recorder

2.5 Solar Radiation Data

- When designing a solar energy system, the appropriate method to forecast its energy-production performance would be to identify what the minute by-minute solar irradiance levels will be, over the lifetime of the system and at the precise location where the system will be built.

- While weather patterns are somewhat random in time and place and they are extremely complex to predict, the system designer is forced to accept historical data and recorded at a different location with value reconstructed from incomplete data records.

- Historical records are an extremely useful analytical tool and appropriate for a wide range of applications.

- However, the designer must not be mistaken to believe that system performance predicted using even the best historical data will represent the future output of the system.

2.5.1 Information Contained in Solar Radiation Data

- Solar radiation data for different locations in the world is available in different forms.
- The radiation data is usually measured on a horizontal surface on the earth.
- However, before using the data, the designer must clearly know the following information.

1. Whether the measurements are of beam, diffuse or total radiation
2. Whether it is hourly, daily or monthly
3. Whether it is measured or computed
4. What type of instrument is used for measurement ?
5. Whether it is averaged ? If averaged, the period over which they are averaged.
6. What is the time or time period of the measurements;
7. Whether it is incident on a horizontal or inclined surface
8. What is the azimuth of the surface ?

2.5.2 Measurement of Solar Radiation Data

- An instrument called **Solariometer** is used to measure most of the data on solar radiation received on the surface of the earth.
- It gives readings for instantaneous measurements at rate throughout the day for total radiation on a horizontal surface.
- Spectral distribution of the sun is plotted by integrating the rate of radiation received on a horizontal surface.
- Samuel Langley who made by the first measurement of the spectral distribution of the sun in 1884.
- Hence, to honour Samuel Langley, solar radiation flux is adopted in Langleys per hour or per day.
- The unit, $1 \text{ langley} = 1 \text{ cal/cm}^2$

2.5.3 Types of Solar Radiation Data

- The solar radiation data is collected for various locations in the world on the basis of :

1. Solar power calculations with reference to the movement of the sun, latitude of the location etc.

2. Hourly measurements of solar radiation at the location and calculation of :

a. "Daily average" global radiation (H_{dg}) at the location for the month (kJ/m^2 July);

b. "Monthly average" global radiation (H_{mg}) at the location for various months ($kJ/m^2 \cdot$ month); (iii) "Yearly average" global radiation (H_{yg}) at the location for a few years (kJ/m^2 year)

2.5.4 Solar Radiation Data for India

- **Solar Radiation** data in terms of kJm^2/day or $kWhm^2$ / day for various days/months/an year can be readily used for calculating :

(i) Available solar energy at the location;

(ii) Determining the surface area of the solar collectors;

(iii) Determining rating of solar plant.

- India is in the **"northern hemisphere"** within latitudes of 7° and 37.5° N.
- The average solar radiation values for India are between 12.5 and 22.7 MJ/m. day.
- The peak solar radiation in India occurs in some parts of Rajasthan and Tamilnadu and is equal to 25 MJ/m^2 .
- The solar radiation reduces to about 60 percent during monsoon months.

2.5.5 Estimation of Average Solar Radiation

- To estimate the amount of solar radiation falling on a solar collector at a given time and location, the direct or beam radiation and diffuse radiation should be either measured or estimated using empirical equations.
- The Angstrom-Prescott regression model was given by Igbal (1983).
- The monthly average daily global radiation on a horizontal surface H_{ga} is

$$\frac{H_{ga}}{H_{oa}} = a + b\left[\frac{S_a}{S_{max\,a}}\right] \quad \text{...(a)}$$

- Where, H_{oa} = Monthly average extra-terrestrial solar radiation at horizontal surface S_a = Monthly average daily sunshine hours S_{maxa} = Maximum possible daily sunshine hours at a given location. a and b are constants.
- In eqaution (a), one needs to have a value of H_{oa} which can be estimated from the instantaneous value of extra-terrestrial solar radiation.

- "Integration of extra-terrestrial radiation over a day will give the daily value of extra-terrestrial solar radiation, H_o (= H_{oa} if it is estimated for a given day of a month), which can be written as

$$H_a = S_t \int \cos\theta \, dt$$

$$= S\left[1+0.033\cos\frac{360\,n}{365}\right]\int_{sunrise}^{sunset}(\sin\phi\sin\delta+\cos\phi\cos\delta\cos\omega)\,dt \qquad \text{...(b)}$$

- Here t is time in hours. It can be converted to time in angles ω (radians) as:

$$dt = \frac{180}{15\pi}\,d\omega \qquad \text{...(c)}$$

$$H_0 = \frac{12}{\pi} S\left[1+0.033\cos\frac{360\,n}{365}\right]\int_{-\omega_s}^{\omega_s}(\sin\phi\sin\delta+\cos\phi\cos\delta\cos\omega)\,dt \qquad \text{...(d)}$$

- The integration in equation (d) will give us the following

$$H_0 = \frac{24}{\pi} S\left[1+0.033\cos\frac{360\,n}{365}\right]\int_{-\omega_s}^{\omega_s}(\sin\phi\sin\delta+\cos\phi\cos\delta\sin\omega_s) \qquad \text{...(e)}$$

- If S is in W/m², H_o will be in W-h/m². Multiplying term ω_s in equation (e) should be in radians. Equation (e) can be used to calculate the daily value of H_o.
- Here, the declination angle in the equation represents the day of the year.
- It has been shown by Klein (1977) that of H_o is calculated for a particular day of the month, its value will be equal to its average value over the month (i.e., H_{oa}).
- The dates at which H_o is equal to H_{oa} are : January 17, February 16, March 16, April 15, May 15, June 11, July 17, August 16, September 15, October 15, November 14 and December 10.

2.5.6 Solar Radiation on an Inclined Surface

- In practice, the solar collectors are installed tilted for better energy collection.
- The radiation falling on tilted surface will be the sum of direct radiation, diffuse radiation and reflected radiation.
- These can be estimated as follows :

2.5.7 Direct Radiation

- The ratio of the direct solar radiation falling on tilted surface to that falling on a horizontal surface is called the tilt factor rb for the beam or direct radiation.
- The rb for the collector surface facing south ($\gamma = 0°$) will be given as

$$r_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\sin\delta \sin(\phi-\beta) + \cos\delta \cos(\phi-\beta)\cos\omega}{\sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega}$$

- Similarly, the rb can be written for a situation where the collection is not facing the south direction, i.e., $\gamma \neq 0°$
- The beam radiation falling on a tilted surface will be given by Ib × rb, where Ib is the instantaneous value of beam radiation.

2.5.8 Diffuse Radiation

- The diffuse part of solar radiation is one of the elements necessary for the design and evaluation of energy production of a solar system.
- Similar to the tilt factor for the direct radiation, tilt factor for the diffuse radiation rd is defined as the ratio of the radiation flux falling on the tilted surface to the diffuse radiation falling on the horizontal surface.
- If the sky is considered as isotropic source of diffuse radiation (it may not be true in all conditions), the rd can be written as

$$r_d = \frac{1+\cos\beta}{2}$$

- The diffuse radiation falling on a tilted surface will be given by Idrd, where Id is the instantaneous value of diffuse radiation.

2.5.9 Reflected Radiation

- The reflected radiation from the ground and surrounding area can also reach the collector with tilted surface.
- The tilt factor for the reflected radiation r_r is given by the following equation.

$$r_r = \rho \frac{1-\cos\beta}{2}$$

2.5.10 Total Radiation on Tilted Surface

- The total radiation on a tilted surface of the collector will be the sum of direct, diffuse and reflected radiations.

- It will be given by

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$$

- Where I_b, I_d and I_r are the instantaneous values of beam, diffuse and reflected radiations, respectively.
- And r_b, r_d and r_r are the tilt factor for the beam, diffuse and reflected radiations, respectively.

Numericals on Solar Radiation

> **Example 2.5.1 :** *Calculation of all parameters for a particular day in March for Madurai location :*
> *Latitude : 16.5 N,*
> *Longitude : 80.64 E,*
> *Assume values for a = 0.28, b = 0.47*

Solution :

Case 1 :

On horizontal surface

Assume sunshine hours per day is 11.9051

For March 20,

Day number n = 31 + 28 + 20 = 79

$\delta = 23.34 \sin((360/365) \times (284 + 79)) = -2.406^\circ$

The sunshine hour angle is :

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$$

$$= \cos^{-1}(-\tan(16.5)\tan(-2.406)) =$$

$$89.288^\circ$$

$$\text{Day length} = (2/15)\times\omega_s$$

$$= (2/15)\times(89.288) = 11.9 \text{ h}$$

The extra - terrestrial solar radiation can be calculated as :

$$H_0 = \frac{24}{\pi} S\left[1 + 0.033 \cos\frac{360n}{365}\right](\omega_s \sin\phi\sin\delta + \cos\phi\cos\delta\sin\omega_s)$$

$$H_0 = \frac{24}{\pi} 1.367 \times 3600\left[1 + 0.033\cos\frac{360\times79}{365}\right](1.5575\sin16.5\sin(-2.406))$$

$$+\cos16.5\cos(-2.406)\sin 89.283)$$

H_0=35560.06694kJ/m^2 – dayor9.87kWh/m^2

Now, the global solar radiation on the horizontal plane can be estimated using equation as :

$$\frac{H_{ga}}{H_{oa}} = a+b\left(\frac{S_a}{S_{maxa}}\right)$$

$$\frac{H_{ga}}{35560.06694} – 0.28+0.47 \left(\frac{11.9051}{11.9}\right)$$

$$H_{ga}=26677.21302 \text{ kJ/m}^2 \text{or} 7.410 \text{ kWh /m}^2\text{-day}$$

The monthly average daily diffuse radiation on the horizontal surface, H_{da}canbe calculated by :

$$\frac{H_{da}}{H_{ga}} = 1.311–3.022\ K_T+3.427K^2_T – 1.821\ K^3_T$$

K_t–(H_{ga}/H_{oa}) = (26677.21302/35560.06694) = 0.75H_{da}=

(1.321–3.022 (0.75) + 3.427(0.75) 2 – 1.821 (0.75)3) × (26677.21302)

= 5707.67kJ/m^2

Example 2.5.2 : *Calculate monthly average of daily global solar radiation on a horizontal surface located in Chennai Tamilnadu state (22°.00′ N, 73°.10′ E) for the month of April. Average Solar day hours are 10 hrs. Amstrom's constants for Ahmedabad, a = 0.28, b = 0.48*

Solution : Given :

ϕ = 22°

Avg. solar day hours = 10 hrs.

∴ smxa = 10 hrs.

Number of days on April

n = Jan + Feb + March + April

= 31 + 28 + 31 + 30

n = 120

Amstrong's constants

$$a = 0.28 \text{ and } b = 0.48$$

Monthly average of global radiation are -

$$\frac{H_{ga}}{H_{oa}} = a+b \left(\frac{sa}{smxa}\right)$$

$$\therefore \quad H_{ga} = H_{oa}\left[a+b\left(\frac{sm}{smxa}\right)\right] \quad \ldots (1)$$

Where,

$$H_{ga} = \frac{24}{\pi} S\left[1+0.033\cos\frac{360\,n}{365}\right] \quad \ldots (2)$$

Calculation of δ and ω_s

i) According to coopers equation,

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right]$$

$$\delta = 23.45\sin\left[\frac{360}{365}(284+120)\right]$$

$$\therefore \quad \boxed{\delta = 14.58^o}$$

ii) Hour angle(ω_s):

$$\omega_s – \cos^{-1}(–\tan\phi \tan\delta)$$

$$–\cos^{-1}(– \tan 22^o \tan 14.58)$$

$$–83.96^o (1.4654 \text{ rad})$$

iii) Now,

$$smxa = \frac{2}{15}\times\omega_s$$

$$= \frac{2}{15}\times 83.96 = 11.19 \text{ hours}$$

From equation (2)

iv) $$H_{oa} = \frac{24}{\pi}\times 4870.8\left[\left\{1+0.033\cos\left(\frac{360\times120}{365}\right)\right\}\right]$$

$$= (1.4654\sin 22^o \sin 14.58+\cos 22^o \cos 14.58 \sin 83.96)$$

$$=37211.26[(0.9843)\ (0.1354 + 0.8935)]$$

$$H_{oa} = 37687.307 \text{ kJ/ m}^2\text{day}$$

v) Equation (1) becomes

$$H_{ga} – 37687.307 \left[0.28 + 0.48 \left(\frac{10}{11.19}\right)\right]$$

$$H_{ga} – 26718.58 \text{ kJ/m}^2\text{day}$$

$$H_{ga} – 26718.58 \times \left(\frac{1353}{4870.8}\right) = 7421.82 \text{ w/m}^2\text{day}$$

2.6 Solar Thermal Collectors

- Solar thermal energy is the most readily available source of energy.
- The Solar energy is most important kind of non-conventional source of energy which has been used since ancient times, but in a most primitive manner.
- The abundant solar energy available is suitable for harnessing for a number of applications.
- The application of solar thermal energy system ranges from solar cooker of 1 kW to power plant of 200 MW.
- These systems are grouped into low temperature (<150 °C), medium temperature (150-300 °C) applications.
- Solar collectors are used to collect the solar energy and convert the incident radiations into thermal energy by absorbing them.
- This heat is extracted by flowing fluid (air or water or mixture with antifreeze) in the tube of the collector for further utilization in different applications.

Types of solar collectors

- The collectors are classified as;
  1. Non concentrating collectors
  2. Concentrating (focusing) collectors.

2.6.1 Performance Indices of Solar Thermal Collectors

- The performance indices or vital aspects of solar collector system are

1. Concentration Ratio (CR)
2. Temperature range

3. Absorption / Reflection ratio (α/ε)

4. Collector efficiency.

1. Concentration Ratio (CR) :

- Concentration ratio is defined as the ratio of the area of aperture of the system to the area of the receiver.
- The aperture of the system is the projected area of the collector facing (normal) the beam.

$$CR = \frac{kW/m^2 \text{ insolar radiation on surface}}{kW/m^2 \text{ on surface focus of collector}}$$

Flat plate collectors have Concentration Ratio = 1

2. Temperature Range :

- Temperature range is the range of temperature to which the heat transport fluid is heated up by the collector.
- The resulting temperature of heat transfer fluid by the solar collector is less than 150 °C.
- Focusing the collectors attains higher temperature concentration ratios of the order of 1000.
- It can be obtained with heliostats with sun tracking in two planes.
- Concentration ratios up to 100 can be achieved by parabolic through collectors with sun tracking in one plane.

3. Absorption / Reflection Ratio (α / ε)

- It has significant effect on the temperature attained by the heat transport fluid.
- Absorption / Reflection ratios are in the range of 1 to 40.

4. Collector efficiency :

- The performance of a collector is evaluated in terms of its collector efficiency.
- Collector efficiency is defined as the ratio of the energy actually absorbed and transferred to the heat transport fluid by the collector (useful energy) to the energy incident on the collector.

$$\text{Collector efficiency} = \frac{\text{Energy collected by the collector (J)}}{\text{Energy incident on the collector (J)}}$$

2.6.2 Factors Affecting Solar Collectors Systems Efficiency

- The efficiency of solar collector system is unfavorably affected by the shadow, cosine loss, dust etc.
- These aspects have an important influence on the design of the collector layout.

1. **Shadow effect :** Shadows of some of the neighbor panel fall on the surface of the collector where the angle of elevation of the sun is less than 15° (sun-rise and sunset).

$$\text{Shadow factor} = \frac{\text{Surface of the collector recieving light}}{\text{Total surface of the collector}}$$

- Shadow factor is less than 0.1 during morning and evening.
- The effective hours of solar collectors are between 9 AM and 5 PM.

2. Cosine loss factor :

- For maximum power collection, the surface of collector should receive the sun rays perpendicularly.
- If the angle between the perpendicular to the collector surface and the direction of sun rays is θ, then the area of solar beam intercepted by the collector surface is proportional to cos θ.

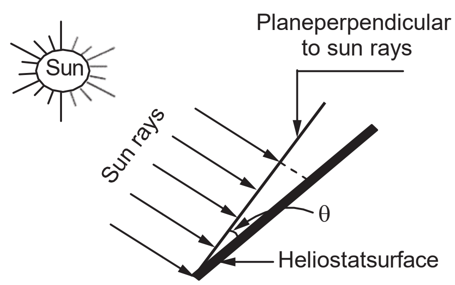


Fig. 2.6.1

3. Reflective loss factor :

- The collector glass surface and the reflector surface collect dust, dirt, moisture etc.
- The reflector surface gets rusted, deformed and loses the shine.
- Hence, the efficiency of the collector is reduced significantly with passage of time.

2.6.3 Physical Principle of the Conversion of Solar Radiation into Heat

- Energy is not a good unto itself; it is valued rather as a means of satisfying important needs of a society.

- In classical thermodynamics, energy is defined as the capacity to do work; but from a more practical point of view, energy is the main stay of any industrial society.
- To maintain our present social structure, it is desirable, therefore, that we supply an increasing portion of our energy needs from renewable sources.
- Approximately 30 percent of the solar energy impinging on the earth is reflected back into space.
- The remaining 70 percent, approximately 120,000 terawatts [l terawatt is equal to 1012 watts], is absorbed by the earth and its atmosphere.
- Solar radiation reaching the earth consists of the beam radiation that casts a shadow and can be concentrated and the diffuse radiation that has been scattered along its path in space from sun to earth.
- The solar radiation reaching the earth degrades in several ways.
- Some of the radiation is directly absorbed as heat by the atmosphere, the ocean, and the ground.
- Another component produces atmospheric and oceanic circulation.
- A third component evaporates, circulates, and precipitates water in the hydrologic cycle.
- Finally, a very small fraction is captured by green plants and drives the photosynthetic process.
- The thermal conversion process of solar energy is based on well-known phenomena of heat transfer (Kreith 1976).
- In all thermal conversion processes, solar radiation is absorbed at the surface of a receiver, which contains or is in contact with flow passages through which a working fluid passes.
- As the receiver heats up, heat is transferred to the working fluid which may be air, water, oil, or a molten salt.
- The upper temperature that can be achieved in solar thermal conversion depends on the insolation, the degree to which the sunlight is concentrated, and the measures taken to reduce heat losses from the working fluid.
- Since the temperature level of the working fluid can be controlled by the velocity at which it is circulated, it is possible to match solar energy to the load requirements, not only according to the amount but also according to the temperature level, i.e., the quality of the energy required.

- In this manner, it is possible to design conversion systems thatareoptimized according to both the first and the second laws of thermodynamics.
- The collection and conversion of the solar radiation to thermal energy depends on the collector design and the relative amounts of direct beam and diffuse radiation absorbed by the collector (Kreider and Kreith 1981).
- As indicated in the following discussion of solar thermal collectors, the collectors used for higher temperature applications can collect only the direct radiation from the sun.
- High temperature heat is needed by industry for process heat and by utilities for electricity.

2.7 Non Concentrating Collectors

- In these collectors the area of collector to intercept the solar radiation is equal to the absorber plate and has concentration ratio of 1.

2.7.1 Flat Plate Collector

- The flat-plate solar collectors are probably the most fundamental and most studied technology for solar-powered domestic hot water systems.

2.7.1.1 Principle

- The basic principle for this device is that the sun heats a dark flat surface, which collects as much energy as possible, and then the energy is transferred to water, air, or other fluid for further use.

2.7.1.2 Construction and Working

- These are the main components of a typical flat-plate solar collector :

1. **Black surface :** Absorber plate that absorbs the incident solar energy (copper or aluminium sheet coated with selective coating)
2. **Glazing cover :** Transparent layer that transmits radiation to the absorber, but prevents radiative and convective heat loss from the surface (plastic or glass)
3. **Tubes :** Contain heating fluid to transfer the heat from the collector
4. **Support structure :** Protect the components and hold them in place
5. **Insulation :** Cover sides and bottom of the collector to reduce heat losses (polymeric material)

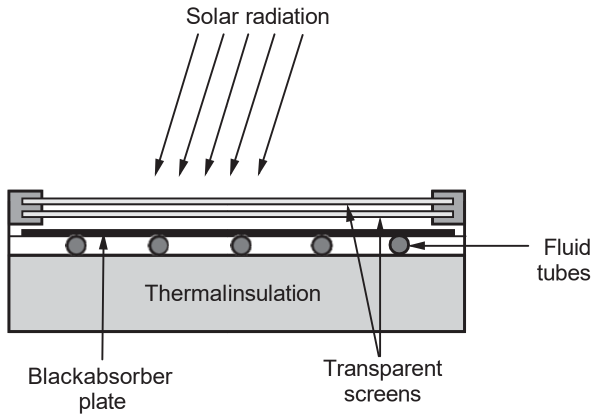


Fig.2.7.1Schematic of a flat plate solar collector withliquid transport medium

- The schematic of a flat plate solar collector with liquid transport medium is given here.
- The black absorber plate absorbs radiant heat from sunlight.
- The black absorber plate is covered by transparent screens to reduce the heat loss due to convection and radiation to the atmosphere.
- There are tubes carrying water, which gets heated due to the heat absorbed.
- The thermal insulation prevents heat loss during heat transfer.
- The flat-plate systems normally operate and reach the maximum efficiency within the temperature range from 30 °C to 80 °C, however some new types of collectors that employ vacuum insulation can achieve higher temperatures (up to 100 °C).
- Due to introduction of selective coatings, stagnant fluid temperature in flat-plate collectors has been shown to reach 200 °C.
- Flat-plate collectors need to face the sun to obtain maximum sunlight exposure.
- The installation angle should be equal to or up to 15 ° higher than the latitude of the location.
- This angle ensures optimal heat output throughout the year.
- The flat plate solar collectors are highly useful for low temperature heating.
- The main use of this technology is in residential buildings where the demand for hot water has a large impact on energy bills.
- Commercial applications include car washes, military laundry facilities and eating establishments.

2.7.1.3 Advantages of the Flat-Plate Collectors

- Some advantages of the flat-plate collectors are that they are :

1. It is easy to manufacture
2. It has low cost
3. It can collect both beam and diffuse radiation
4. Permanently fixed (no sophisticated positioning or tracking equipment is required)
5. It requires little maintenance.

2.7.1.4 Disadvantages of the Flat-Plate Collectors

1. Initial cost of installation is high.
2. Heavy in weight.
3. Low temperature is achieved
4. Large heat losses by conduction due to large area

2.7.1.5 Applications of the Flat-Plate Collectors

1. It is used in domestic solar water heating
2. It is suitable in low temperature power generation
3. It is used in solar heating dryers
4. It is used in solar space heating and cooling systems.
5. Solar water heating systems for residence, hotels, industry.
6. Desalination plant for obtaining drinking water from sea water.

2.7.1.6 Factors Affecting the Performance of a Flat-Plate Collector

- The following factors affect the performance of a flat-plate collector :

1. Incident solar radiation
2. Number of cover plates.
3. Spacing between absorber plate and glass cover.
4. Tilt of the collector.
5. Selective surface.
6. Fluid inlet temperature.
7. Dust on cover plate.

2.7.2 Evacuated Tube Collector

- The **Evacuated tube collector** consists of a number of rows of parallel transparent glass tubes connected to a header pipe and which are used in place of the blackened heat absorbing plate.
- These glass tubes are cylindrical in shape.
- Therefore, the angle of the sunlight is always perpendicular to the heat absorbing tubes which enables these collectors to perform well even when sunlight is low such as when it is early in the morning or late in the afternoon, or when shaded by clouds.
- Evacuated tube collectors are particularly useful in areas with cold, cloudy wintry weathers.
- Fig. 2.7.2 shows schematic of **Evacuated tube collector.**

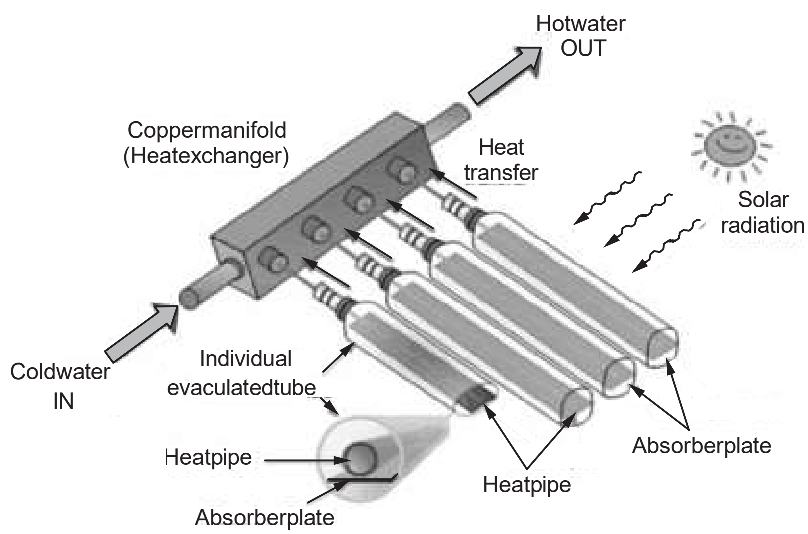


Fig. 2.7.2 Evacuated tube collector

- Inside the each glass tube, a flat or curved aluminum or copper fin is attached to a metal heat pipe running through the inner tube.
- The fin is covered with a selective coating that transfers heat to the fluid that is circulating through the pipe.
- This sealed copper heat pipe transfers the solar heat via convection of its internal heat transfer fluid to a "hot bulb" that indirectly heats a copper manifold within the header tank.

- These copper pipes are all connected to a common manifold whichisthen connected to a storage tank, thus heating the hot water during the day.
- The hot water can then be used at night or the next day due to the insulating properties of the tank.

Advantages of Evacuated Tube Collectors :

1. Achieves a high efficiency with large temperatures differences between absorber and surroundings
2. Supports space heating
3. Achieves higher temperatures
4. Low weight system

Disadvantages of Evacuated Tube Collectors :

1. More expensive system
2. More susceptible to breaking in domestic use
3. Cannot be mounted horizontally, must have a slope of 25 °C

2.7.3 Solar Air Heater

- Solar air heater is a device in which the solar energy is converted to thermal energy to heat the air.
- However, the main challenge in this device is the poor heat transfer rate and low efficiency due to various losses.
- Fig. 2.7.3 show the schematic of solar heater.

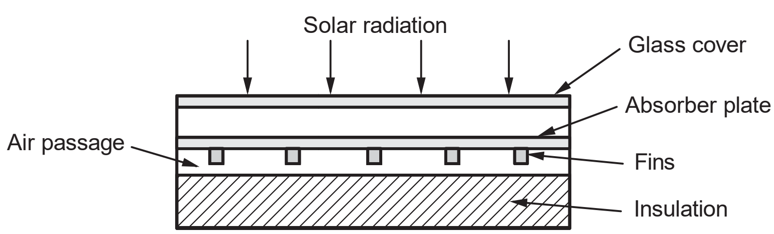


Fig.2.7.3Schematic of solar heater

- The main components of a solar air heater are an absorber plate, one or more channels for the flow of air, insulation for the bottom and lateral sides of the solar collector and one or more transparent covers.
- The use of a blower is optional for the air supply.
- Air stream is heated by the back side of the collector plate in flat plate collector.

- Fins attached to the plate increase the contact surface.
- The back side of the collector is heavily insulated with mineral wool or some other material.
- If the size of collector is large, a blower is used to draw air into the collector and transmit the hot air to dryer.
- The most favorable orientation of a collector for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus 150.
- The use of air as the heat transport fluid eliminates both freezing and corrosion problems and small air leaks are of less concern than water leaks.

Advantages of Solar Air Heater

1. The system is compact and less complicated.
2. Corrosion is a great problem in solar water heater. And this problem is not experienced in solar air heaters.
3. Leakage of air from the duct does not create any problem.
4. Freezing of working fluid virtually does not exist.
5. The pressure inside the collector does not become very high.
6. Thus air heater can be designed using cheaper as well as lesser amount of material and it is simpler to use than the solar water heaters.

Disadvantages of Solar Air Heater

1. Air heaters have certain disadvantages also the first and foremost are the poor heat transfer properties of air. Special care is required to improve the heat transfer.
2. Another disadvantage is the need for handling large volume of air due to its low density.
3. Air cannot be used as a storage fluid because of its low thermal capacity.
4. In the absence of proper design the cost of solar air heaters can be very high.

Applications of Solar air heaters

1. Heating buildings.
2. Drying agricultural produce and lumber.
3. Heating green houses.
4. Air conditioning buildings utilizing desiccant beds or a absorption refrigeration process.
5. Heat sources for a heat engine such as a Brayton or Stirling cycle.

2.8 Concentric Collectors

- Concentrating collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface.
- Such collectors use optical system in the form of reflectors or refractors.
- These collectors are used for medium (100-300 °C) and high-temperature (above 300 °C) applications such as steam production for the generation of electricity.
- The high temperature is achieved at absorber because of reflecting arrangement provided for concentrating the radiation at required location using mirrors and lenses.
- These collectors are best suited to places having more number of clear days in a year.
- The area of the absorber is kept less than the aperture through which the radiation passes, to concentrate the solar flux.
- These collectors require tracking to follow the sun because of optical system.
- The tracking rate depends on the degree of concentration ratio and needs frequent adjustment for system having high concentration ratio.
- The efficiency of these collectors lies between 50-70 %.
- The collectors need more maintenance than FPC because of its optical system.

Types of concentrating collectors

- The concentrating collectors are classified on the basis of reflector used; concentration ratio and tracking method adopted.

2.8.1 Types of Concentric Collectors

- The different types of focusing/concentrating type collectors are :

i. Parabolic trough collector.

ii. Mirror strip collector.

iii. Fresnel lens collector.

iv. Flat-plate collector with adjustable mirrors.

v. Compound Parabolic Concentrator (CPC).

vi. Parabolic dish collector.

2.8.1.1 Parabolic Trough Collector

- Fig. 2.8.1 shows the principle of the parabolic trough collector which is often used in focusing collectors.
- Solar radiation coming from the particular direction is collected over the area of reflecting surface and is concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic cross-section; the solar radiation is focused along a line.
- Mostly cylindrical parabolic concentrators are used in which absorber is placed along focus axis [Fig. 2.8.2].

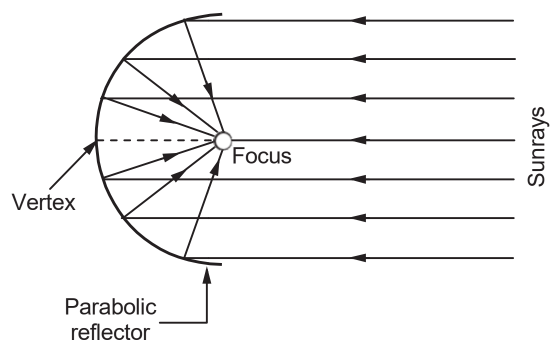


Fig. 2.8.1 Parabolic trough collector

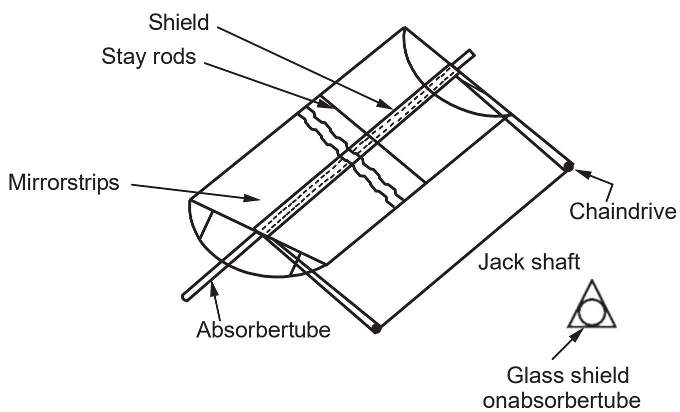


Fig. 2.8.2 Cylindrical parabolic system

2.8.1.2 Mirror Strip Collector

- Refer to Fig. 2.8.3. A mirror strip collector has a number of planes or slightly curved or concave mirror strips which are mounted on a base.
- These individual mirrors are placed at such angles that the reflected solar radiations fall on the same focal line where the pipe is placed.
- In this system, collector pipe is rotated so that the reflected rays on the absorber remain focused with respect to changes in sun's elevation.

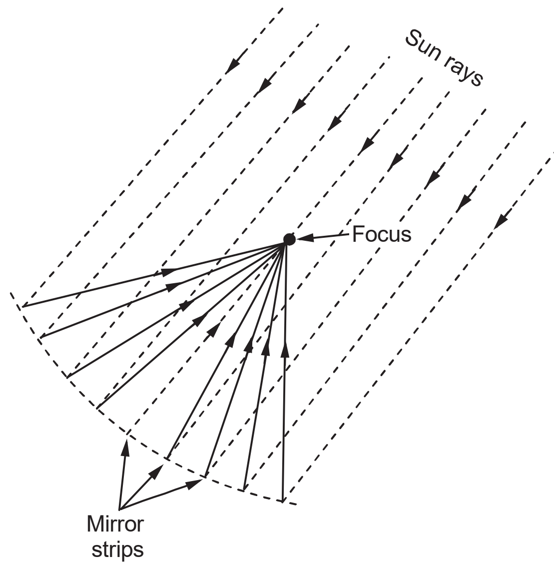


Fig. 2.8.3 Mirror strip collector

2.8.1.3 Fresnel Lens Collector

- Inthiscollector a Fresnel lens is used in which linear grooves are present on one side and flat surface on the other.
- The solar radiations which fall normal to the lens are refracted by the lens and are focused on the absorber (tube) as shown in Fig. 2.8.4.

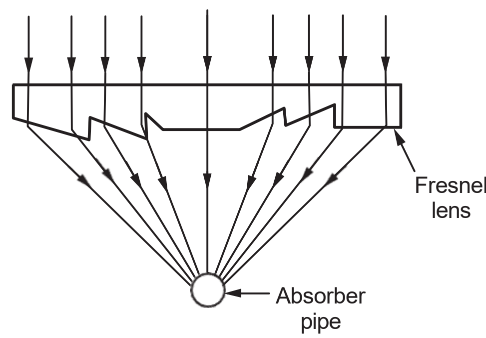


Fig. 2.8.4 Fresnellenscollector

- Both glass and plastic can be used as refracting materials for Fresnel lenses.

2.8.1.4 Flat-Plate Collector with Adjustable Mirrors

- Fig. 2.8.5 shows a flat-plate collector with adjustable mirrors.
- It consists of a flat- plate collector facing south, with mirrors attached to its north and south edges.
- If the mirrors are set at the proper angle, they reflect solar radiation on to the absorber plate.

- Thus,the latter receives reflected radiation in addition to that normally falling on it.
- In order to make the mirrors effective, the angles should be adjusted continuously as the sun's altitude changes.
- Since the mirrors can provide only a relatively small increase in the solar radiation falling on the absorber, flat-plate collectors with mirrors are not widely used.

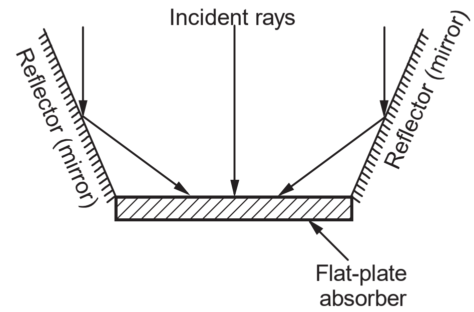


Fig. 2.8.5 Flat-Plate collector with adjustable mirrors

2.8.1.5 Compound Parabolic Concentrator (CPC)

- Fig. 2.8.6 shows the compound parabolic concentrator.
- It was designed by Winston (and Baranov).
- It consists of two parabolic segments, oriented such that focus of one is located at the bottom end point of the other and vice versa.
- The receiver is a flat surface parallel to the aperture joining of two foci of the reflecting surfaces.

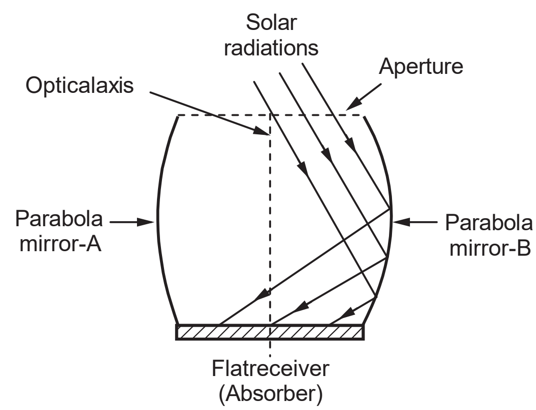


Fig. 2.8.6 Compound Parabolic Concentrator (CPC)

- For thermal and economic reasons the fin and the tubular type of absorbers are preferable.
- It is claimed that Winston collectors are capable of competitive performance at high temperatures of about 300 °C required for power generation, if they are used with selectively coated, vacuum enclosed receivers.
- The maximum concentration ratio available with paraboloidal system is of the order of 10,000.

Advantages of Compound Parabolic Concentrator (CPC):

1. High concentration ratio.
2. No need of tracking.
3. Efficiency for accepting diffuse radiation is much larger than conventional concentrators.

2.8.1.6 Paraboloidal Dish Collector

- Refer to Fig. 2.8.7. In this type of collector all the radiations from the sun are focussed at a point.
- This collector can generate temperature up to 300 °C and contraction ratio from 10 to few thousands.
- Its diameter is of the range between 6 to 7 m and can be commercially manufactured.

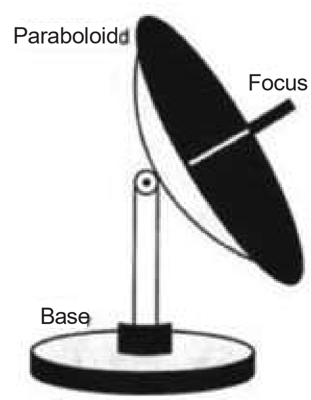


Fig. 2.8.7 Paraboloidal dish collector

2.8.1.7 Advantages of Concentrating Collectors

1. High concentration ratio.
2. High fluid temperature can be achieved.
3. Less thermal heat losses.
4. System's efficiency increases at high temperatures.
5. Inexpensive process.

2.8.1.8 Disadvantages of Concentrating Collectors

1. Non-uniform flux on absorber.
2. Collect only beam radiation components because diffuse radiation components cannot be reflected, hence these are lost.
3. Need costly tracking device.
4. High initial cost.
5. Need maintenance to retain the quality of reflecting surface against dirt and oxidation.

2.8.2 Difference between Flat Plate Collectors and Concentrating Type Collectors

Sr.No.	Flat plate collector	Concentric collector
1	It is less efficient solar collector	Highly efficient
2	Power Produced is less	Power produced is more.
3	Maximum temperature of fluid upto 300 °C.	Maximum Temperature of fluid up to around 5000 °C can be achieved.
4	It can be used in water heating.	It can be used in solar furnaces and solar power plants.

2.9 Solar Thermal Applications

- Solar energy has wide applications. These are discussed below :

A. Direct Solar Energy Applications

- It includes the applications like -

1. Solar water heating
2. Solar heating and cooling
3. Solar drier
4. Solar still
5. Solar cooker
6. Solar pond
7. Solar water pumping

B. Solar Electrical Applications

1. Solar cells
2. Ocean thermal energy conversion
3. Thermoelectric conversion

C. Biomass Energy Applications

2.10 Solar Heating and Cooling of Buildings

2.10.1 Space Heating

- Heating and cooling of buildings offer great opportunities for energy conservation as well as utilization of solar energy.
- A first step in designing an energy-efficient building should be an assessment of the various options for conservation.

- These should include energy-efficient lighting, double - or triple-glazed windows, shading, increased insulation, and elimination of unnecessary air leakage to maintain interior comfort.
- These measures are usually the domain of the architect, but recently specialized energy conservation engineering for buildings has become a part of the architectural design.
- Solar heating system can be divided into the following two categories.
  1. Active systems
  2. Passive systems

2.10.1.1 Active System

- Active system consists of the following components as shown in Fig. 2.10.1

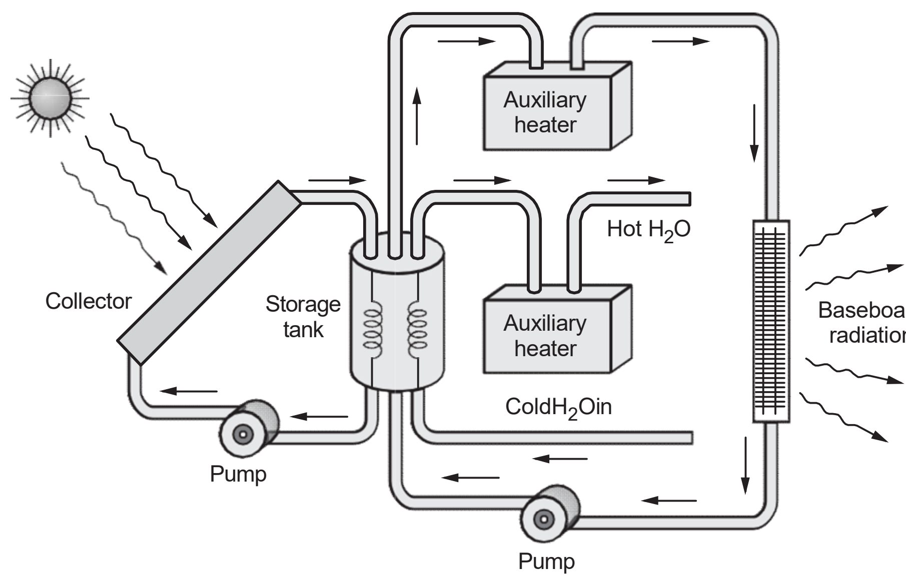


Fig. 2.10.1 Solar active space heating

- Storage tank is used to store the water heated by the solar collectors.
- As the sun rays are incident on the solar collectors it is then transfered to the storage tank, with the use of the heat energy the water from the tank gets heated.
- The heated water is then supplied to the auxiliary heaters where it gets heated and the temperature of the water increases.
- The heated water is then supplied to the buildings.

2.10.1.2 Passive System

- In this type of the system no mechanism is required for the system.
- Heat flows directly into the building without any mechanical components like pumps or blowers.
- Solar radiations are collected by means of the structure elements (Concrete, stone etc.)
- Sunlight is kept out during summer using roof overhangs.

2.10.2 Space Cooling (Solar Cooling of Building)

- Solar energy can be used in the air conditioning and refrigeration.
- The advanced absorption technology may be the futures air conditioning using solar power.
- Absorption cooling is essentially an air conditioning system driven not by electricity but by a heat source, in this case the sun.
- Evacuated-tube solar collectors and solar panels absorb the sun's heat which is then used to heat up a 1200 gallon insulated hot water storage tank until the water reaches 180 degrees Fahrenheit.
- The hot water is then pumped into a generator then into a chiller.
- The chiller contains an absorbent, usually lithium bromide salt.
- This absorbent yields the refrigerant, which condenses and produces chilled water. The air from inside the building is pushed, by a fan, over the the coil units containing the chilled water.
- The, now cool, air is circulated back into the building.
- There are single-effect and double-effect absorption systems.
- Double-effect systems use the heat twice in the series and are twice as efficient but require nearly twice as much heat.
- No moving parts.
- Quiet operation
- More compact system.

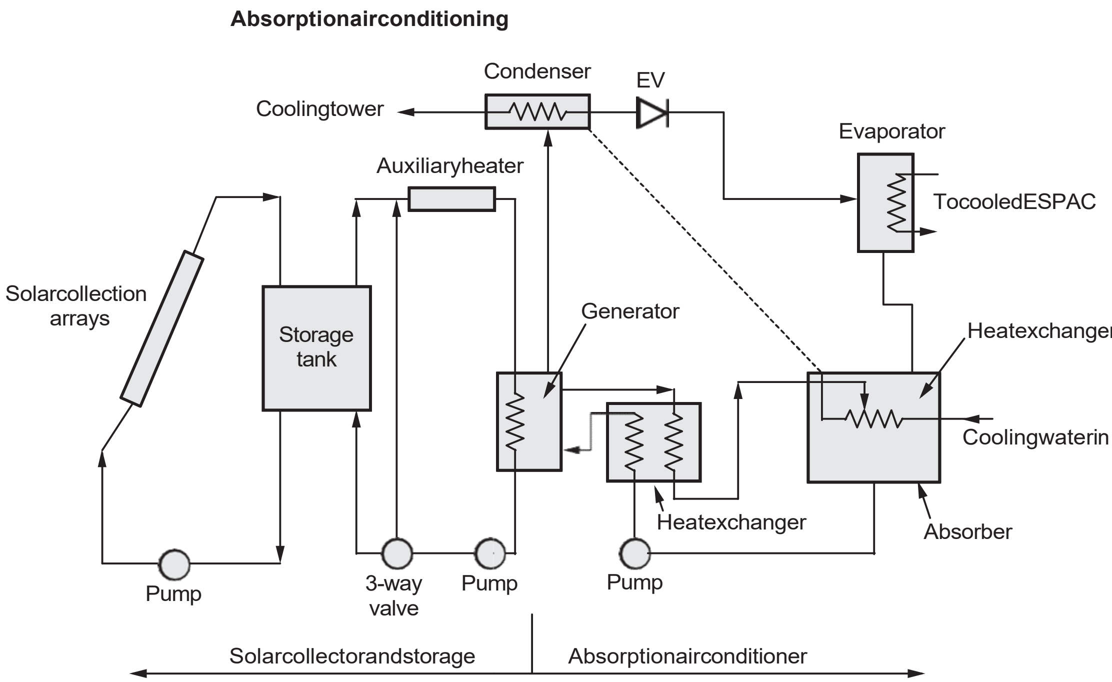


Fig. 2.10.2 Space cooling

2.11 Solar Cooker

- A solar cooker is a device which uses the energy of direct sunlight to heat, cook or pasteurise drink.
- Many solar cookers currently in use are relatively inexpensive, low-tech devices, although some are as powerful or as expensive as traditional stoves and advanced, large-scale solar cookers can cook for hundreds of people.
- Because they use no fuel and cost nothing to operate, many non-profit organizations are promoting their use worldwide in order to help reduce fuel costs and air pollution, and to slow down the deforestation and desertification caused by gathering firewood for cooking.
- Solar cooking is a form of outdoor cooking and is often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high, and the health and environmental consequences of alternatives are severe.

2.11.1 Box Type Solar Cooker

2.11.1.1 Construction and Working

- Solid and efficient, the box cooker is composed of an insulated wooden box containing a smaller box with a black base and internal walls covered in aluminium.
- A double-glazed glass top covers the assembly and produces a greenhouse effect.
- It can be made using local materials (wood, sheep's wool, etc.) and can easily reach a temperature of 120 to 150 °C.
- Easy to make, the box cooker is the one most frequently used.

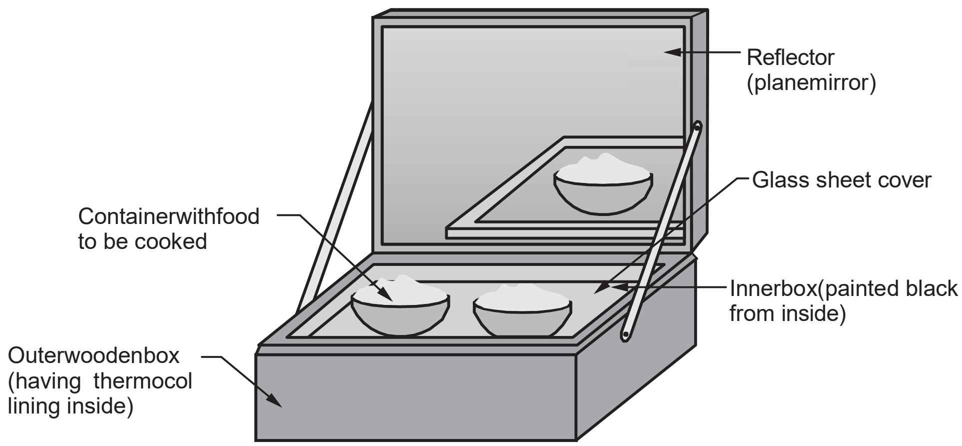


Fig.2.11.1:Box type solar cooker

2.11.1.2 Advantages and Disadvantages

1. The solar cooker saves time, money and energy.
2. No risk for the environment.
3. Solar cooking is slower than traditional cooking methods and consequently, enables the production of healthier dishes, preserving both taste and nutrients and making meat more tender.
4. Vegetables, fruits and meat cook perfectly without water, thereby accelerating the cooking process, while cereals and starchy foods need less than a third of the amount of water required for traditional cooking.
5. It can be used to cook all types of food (vegetables, fruits, meat, cereals, bread, etc.).

2.11.2 Dish Type Solar Cooker

- It is a concentrating type parabolic dish solar cooker with aperture diameter of 1.4 meter and focal length 0.28 meter.
- The reflecting material used for fabrication of this cooker is anodized aluminium sheet which has a reflectivity of over 75 %.
- The tracking of the cooker is manual and thus has to be adjusted in 15 to 20 minutes during cooking time.
- It has a delivering power of about 0.6 kW which can boil 2 to 3 liters of water in half an hour.
- The temperature achieved at the bottom of the vessel could be around 350 ° to 400 °C which is sufficient for roasting, frying and boiling.
- The cooker having a thermal efficiency of around 40 % can meet the needs of 10 to 15 people and can be used from one hour after sunrise to one hour before sunset on clear days.
- Dish solar cooker is being fabricated and promoted in the country by a few manufacturers/ suppliers.
- The cooker can be easily dismantled and assembled by anybody and thus may be nicely packed and transported anywhere in the country.
- The cooker is user friendly as the place of vessel to be kept for cooking is at a level which is convenient for the people to use.
- The cooker could be useful for individuals in rural as well as urban areas and also for small establishments like dhabas, tea shops, etc. on road sides.
- The cost of the cooker is Rs. 6000 - 7000/- and it can save up to 10 LPG cylinders/year on full use at small establishments.

2.11.3 Community Solar Cooker

2.11.3.1 Construction

- The unique feature of this cooker is that it is possible to cook using solar energy within the kitchen itself.
- The 7 m^2 large reflector standing outside the kitchen reflects the solar rays into the kitchen through an opening in its north wall while a secondary reflector further concentrates the rays on to the bottom of the pot / frying pan painted black.
- The temperature attained is so high (400 °C) that the food could be cooked in a shorter time unlike box solar cooker.

- It therefore acts like a conventional cooking device with the difference that instead of conventional cooking fuel like gas, electricity or firewood, the food is cooked with the help of solar energy.

Fig. 2.11.2 : Community solar cooker (cooker installed in a hostel at Gujarat)

2.11.3.2 Advantages

A. Community cooking

- Cooking for about 40 to 50 persons is possible with 7 m^2,. size dish cooker.
- Same is not possible with other types of solar cookers.
- One dish may take around 1 to 2 hours depending on the type of dish and solar insolation available.
- The cooker, however, works nicely in areas where solar insolation is good during most part of the year.
- It is possible to cook two meals with the cooker in those areas.

B. Indoor cooking :

- Since the solar rays are directed into the kitchen, it enables cooking indoors.
- The cook, therefore, does not have to go outside in the sun to load and unload the cooking pots as being done in box solar cooker.

C. Fast cooking :

- Due to high temperature and power at focal point, the cooking rate is significantly higher compared to other solar cookers.

D. Cooking of traditional food :

- Due to high temperature it is possible to cook almost all traditional dishes including making chapatis, purees, dhosa etc. as well as doing `Vaghar'/`Tadka' before adding the vegetables, dal etc.

E. Automatic tracking :

- There is a mechanical clockwork arrangement which rotates the outside primary reflector to track the sun automatically.

- The cook has to set this reflector in focus only once a day in the morning and thereafter for rest of the time the clockwork keeps on rotating the reflector automatically.

F. Multiple use :

- During the period when cooker is not in use for cooking, it can be used for hot water production.

2.11.3.3 Applications

- The cooker could be useful to residential schools, institutional kitchens such as industrial and administrative canteens, religious ashrams, hotels, hospitals, police and armed forces kitchens, etc.
- One cooker can serve for 50 people.
- For larger number of people, more cookers could be installed.
- It can save around 35 to 40 LPG cylinders / year on full use in community kitchens.

2.12 Solar Distillation or Solar Still

- *"The device which converts saline water into the pure drinking water is known as the solar still".*
- Drinking of the pure water is one of the primary need of the human beings.
- Solar still or solar distiller is the device used for the distillation of the water.

2.12.1 Construction and Working

- It consists of the glass cover through which the solar radiations enter in to the solar still.
- The glass cover is provided with the slope so as to provide maximum entrance to the solar radiations.
- The saline water is placed in the solar still.
- Solar radiations passed through the glass cover and is absorbed which are converted into the heat due to the black surface of the glass cover.
- The saline water gets heated due to the heat, vapours condenses over the cool interior surface of the transparent cover. Which are then collected into the purified water tank.
- Solar still provides near about 15 to 50 litres of the water per day.

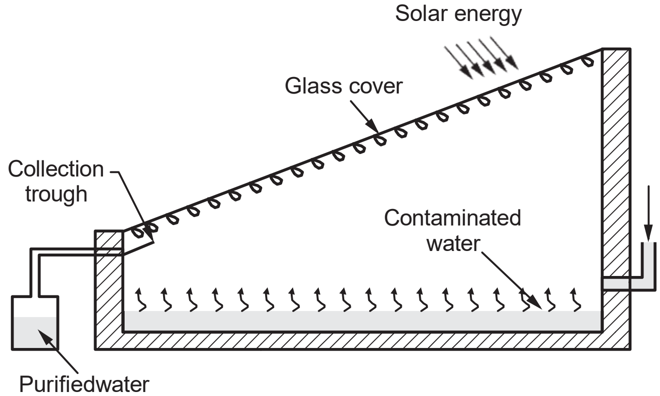


Fig. 2.12.1 : Solar still

2.12.2 Advantages

- Low energy consumption
- Simple mechanism
- Less maintenance

2.13 Solar Dryer

2.13.1 Construction and Details

- Solar thermal energy can be useful for drying wood for construction and wood fuels such as wood chips for combustion.

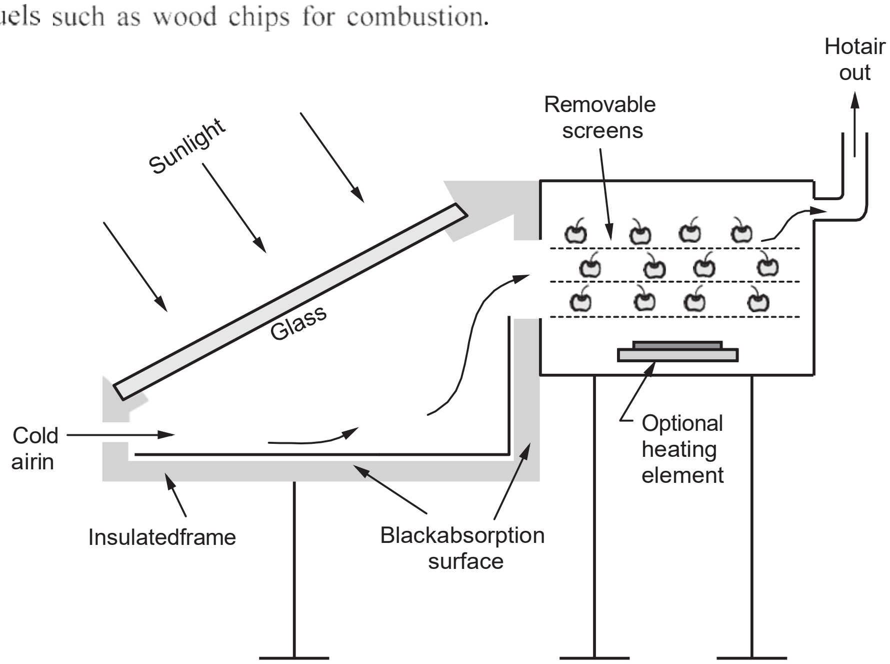


Fig.2.13.1 : Solar dryer

- Solar is also used for food productssuch as fruits,grains,and fish.
- Crop drying by solar means is environmentally friendly as well as cost effective while improving the quality.
- The less money it takes to make a product, the less it can be sold for, pleasing both the buyers and the sellers.
- Technologies in solar drying include ultra-low cost pumped transpired plate air collectors based on black fabrics.
- Solar thermal energy is helpful in the process of drying products such as wood chips and other forms of biomass by raising the temperature while allowing air to pass through and get rid of the moisture.

2.13.2 Advantages

- Dried products are healthy.
- Improves the bargaining position of the farmers.

2.13.3 Disadvantages

- Compromising in the quality of the product.
- Product is often unhygienic.

2.14 Solar Pumping

- In many remote and rural areas, hand pumps or diesel driven pumps are used for water supply.
- Diesel pumps consume fossil fuel, affect the environment, need more maintenance, and are less reliable.
- Photovoltaic (PV)-powered water pumps have received considerable attention because of major developments in the field of solar-cell materials and power electronic systems technology.
- Two types of pumps are commonly used for water-pumping applications :
- Positive displacement and centrifugal.
- Both centrifugal and positive displacement pumps can be further classified into those with motors that are surface mounted, and those that are submerged into the water ("submersible").
- Displacement pumps have water output directly proportional to the speed of the pump, but almost independent of head.

- These pumps are used for solar water pumping from deep wells or bores.
- They may be piston-type pumps or use a diaphragm driven by a cam or rotary screw, or use a progressive cavity system.
- The pumping rate of these pumps is directly related to the speed, and hence constant torque is desired.
- The typical PV stand-alone system consists of a solar array and a battery connected as shown in Fig. 2.14.1.

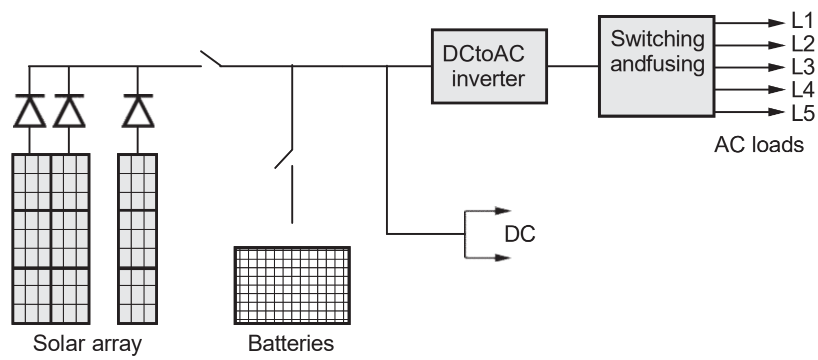


Fig. 2.14.1 : Solar pumping

- The PV array supplies power to the load and charges the battery when there is sunlight. The battery powers the load otherwise.
- An inverter converts the DC power of the array and the battery into 60 or 50 Hz power. Inverters are available in a wide range of power ratings with efficiencies ranging from 85 to 95 %.
- The array is segmented with isolation diodes for improving reliability.
- In such a design, if one string of the solar array fails, it does not load or short the remaining strings.
- Multiple inverters are preferred for reliability.
- For example, three inverters, each with a 35 % rating, are preferred to one with a 105 % rating.
- If one such inverter fails, the remaining two can continue supplying most loads until the failed one is repaired or replaced.
- The same design approach also extends to using multiple batteries.

- Moststand-alone PV systems are installed in developingcountries to provide basic necessitiessuch as lighting and pumping water.
- Photovoltaic (PV) power systems have made a successful transition from small standalone sites to large grid-connected systems.
- The utility interconnection brings a new dimension to the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid that generates base-load power using conventional fuels.
- This improves the overall economy and load availability of the renewable plant site the two important factors of any power system.
- The grid supplies power to the site loads when needed or absorbs the excess power from the site when available.
- A kilowatt-hour meter is used to measure the power delivered to the grid, and another is used to measure the power drawn from the grid.
- The two meters are generally priced differently on a daily basis or on a yearly basis that allows energy swapping and billing the net annual difference.
- The above figure is a typical circuit diagram of the grid-connected PV power system. It interfaces with the local utility lines at the output side of the inverter as shown.
- A battery is often added to meet short-term load peaks. In the U.S., the Environmental Protection Agency sponsors grid-connected PV programs in urban areas where wind towers would be impractical.
- In recent years, large building-integrated PV installations have made significant advances by adding grid connections to the system design.
- The project was part of the EPA PV DSP program. The system produces 18 kW power and is connected to the grid. In addition, it collects
- Sufficient research data using numerous instruments and computer data loggers.
- The vital data are sampled every 10 seconds, and are averaged and stored every 10 minutes.
- The incoming data includes information about air temperature and wind speed.
- The performance parameters include direct current (DC) voltage and current generated by the PV roof and the alternating current (AC) power at the inverter output side.

2.15 Solar Furnace

- *"Solar Furnace is a device for obtaining high temperature by concentrating solar radiations on the specimen".*

2.15.1 Construction and Working

- Solar furnace consist of the components like concentrator, Heliostat and Sun tracking system.
- Concentrator is used in the solar furnace for collecting the solar radiations on the. specific point.

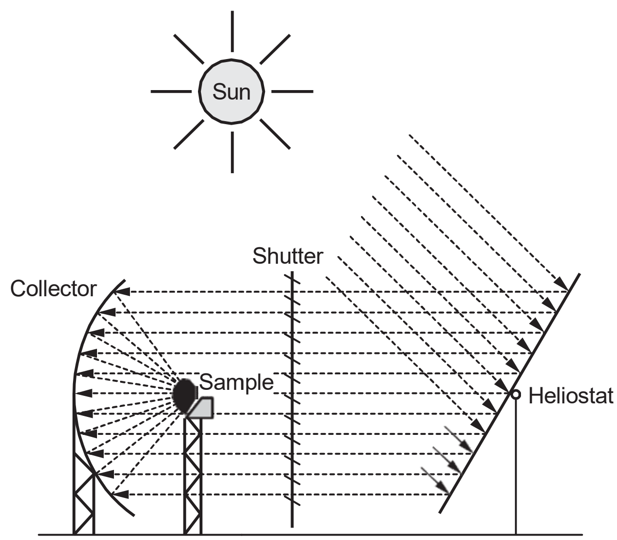


Fig. 2.15.1 : Solar furnace

- Concentrator may be either parabolic type or the reflection type can be used in the solar furnace.
- The function of the Heliostat is to orient solar radiation parallel to the optical axis of the concentrator.
- The dimensions of the heliostat must be 1.4 D × 1.4 D where, D-Aperture size.
- Sun tracking system is to provide the optimum output.
- The sunrays are falling on the heliostat which are mounted in a slope shape in order to get maximum sunrays.
- The heliostats act as the mirror which reflects the solar radiations on the solar concentrator.
- The resultant rays of the high temperatures upto the 1500 °C can be obtained using the solar furnace.

2.15.2 Advantages and Applications

2.15.2.1 Advantages

- Simple construction
- High temperature can be obtained.
- Temperature can be easily controllable.

2.15.2.2 Applications

- For phase change study.
- Used for the vaporisation process.

2.16 Solar Thermal Power Generation

- The solar thermal power generation involves the collection of solar heat which is utilised to increase the temperature of a fluid in a turbine operating on a cycle such as Rankine or Brayton.
- In another method, hot fluid is allowed to pass through a heat exchanger to evaporate a working fluid that operates a turbine coupled with a generator.
- Solar thermal power generation uses thermodynamic cycles which are broadly classified as follows :

1. Low Temperature Cycle
2. Medium Temperature Cycle
3. High Temperature Cycle

2.16.1 Low Temperature Power Plant

- Fig. 2.16.1 shows a schematic diagram of a low temperature solar power plant.
- In this system an array of flat-plate collectors is used to heat water to about 70 °C and then this heat is used to boil butane in a heat exchanger.
- The high pressure butane vapour thus obtained runs a butane turbine which in turn operates a hydraulic pump.
- The pump the water from a well which is used for irrigation purposes.
- The exhaust butane vapour (from butane turbine) is condensed with the help of water which is pumped by the pump and the condensate is returned to the heat exchanger (or boiler).

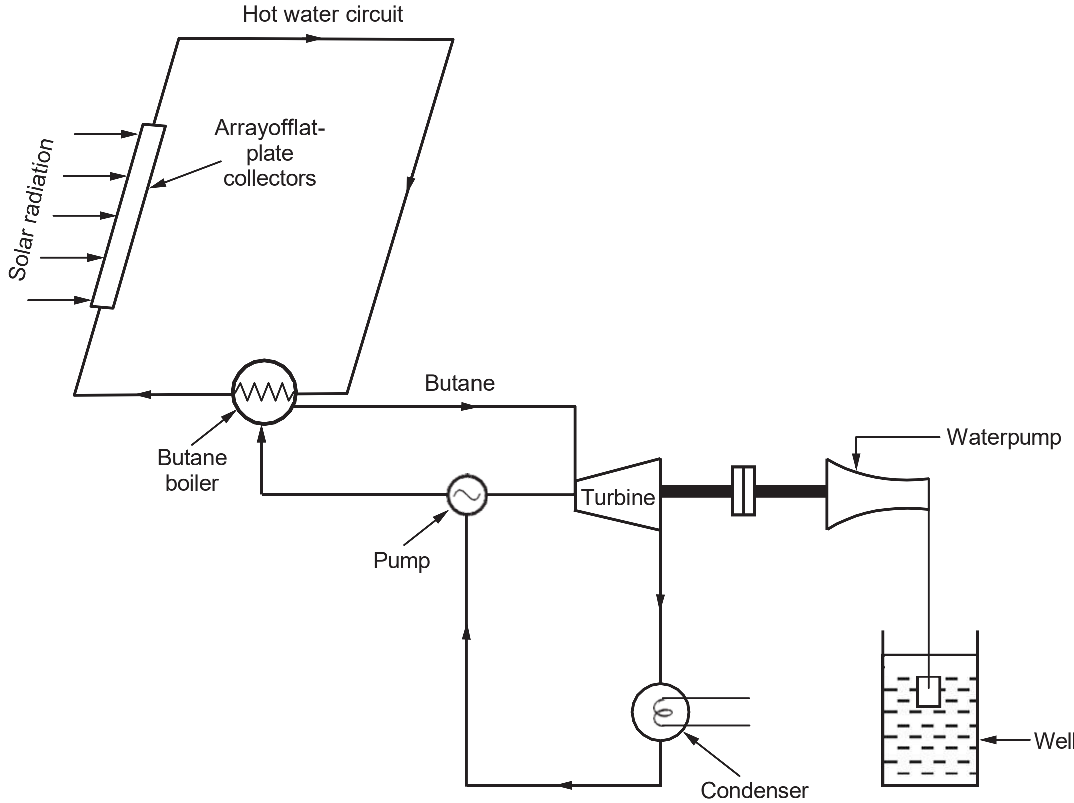


Fig. 2.16.1 Low temperature solar power plant

2.16.2 Medium Temperature Systems using Focusing Collectors

- A circular or rectangular parabolic mirror can collect the radiation and focus it on to a small area, a mechanism for moving the collector to follow the sun being necessary.
- Such devices are used for metallurgical research where high purity and high temperatures are essential, an example being a 55 m diameter collector giving about 1 MW (th) at Mont Louis in Pyrenees.
- Smaller units having 20 m diameter reflector can give temperatures of about 300 °C over an area of about 50m^2
- The collector efficiency is about 50 %.
- On a small scale, units about 1 m diameter giving temperatures of about 300 °C have been used for cooking purposes.

- Fig. 2.16.2 shows a concave solar energy collector focusing sun's rays on boiler at a focal point.
- Generation of steam at 250 °C could give turbine efficiencies up to 20-25 per cent.

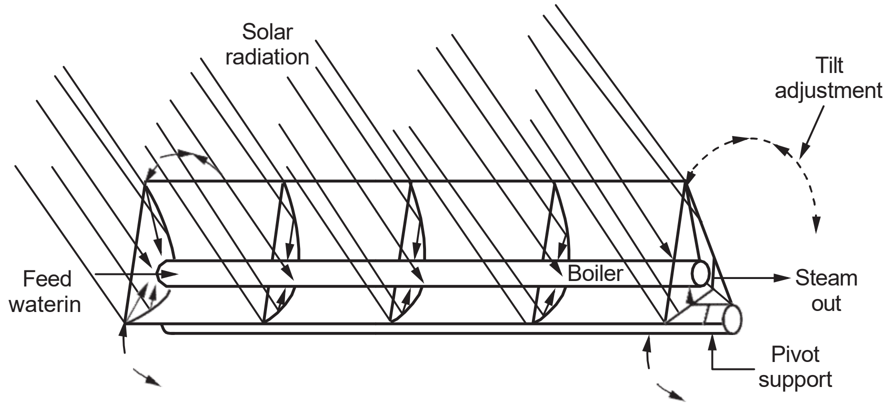


Fig. 2.16.2 Concave solar energy collector focuses sun's rays on boiler at focalpoint

2.16.3 High Temperature Thermal Power Generation using Central Receiver System

- For a large scale production of process-heat the following two concepts are available :

1. Solar Farm **2. Solar Power Plant**

1. The Solar Farm :

- It consists of a whole field covered with parabolic trough concentrators.

2. The Solar Tower :

- It consists of a central receiver on a tower and a whole field of tracking.
- In case of a 'solar farm' temperature at the point of focus can reach several hundred degrees Celsius.
- Fig. 2.16.3 shows a solar tower system.

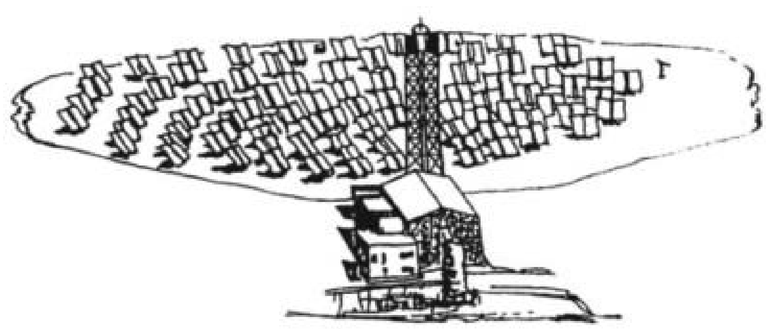


Fig. 2.16.3 Solar tower system

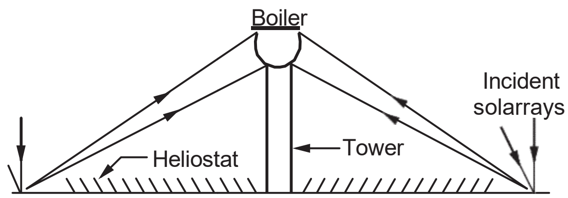


Fig. 2.16.4 Solar tower

- In case of central receiver **"solar tower"** concentrators, temperature can reach thousands of degrees Celsius, since a field of reflectors (heliostats) are arranged separately on sun - tracking frames to reflect the sun on to a boiler mounted on a central tower (Fig. 2.16.3, 2.16.4).
- With both systems ('solar farm' and 'solar tower'), a heat transfer fluid or gas is passed through the point or line of insolation concentration to collect the heat and transfer it to the point of use.
- Such heat can be used either directly in industrial or commercial processes or indirectly in electricity production via steam and a turbine.
- The solar technologies such as the above two systems that produce very hot water or steam are currently still under development and, in general, these technologies are not cost competitive with conventional power sources such as oil or gas.

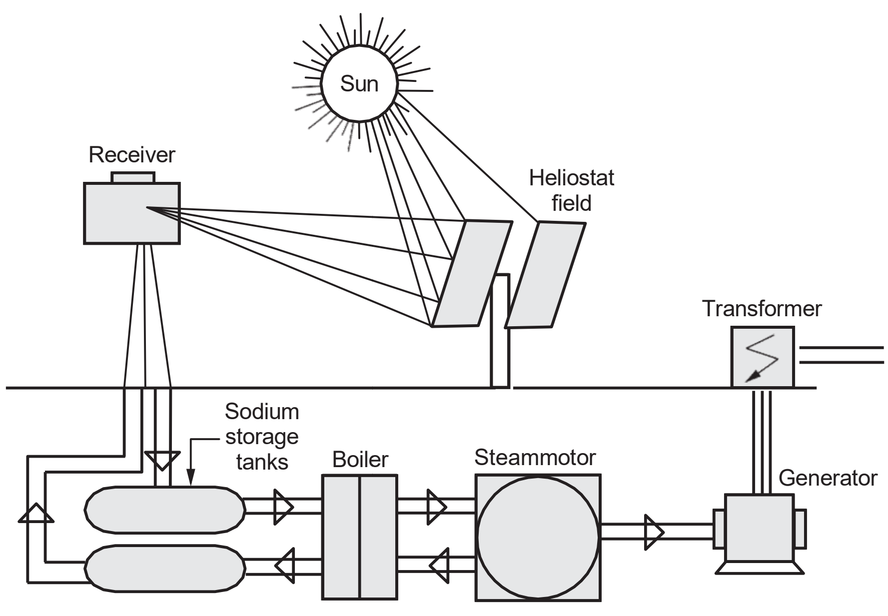


Fig. 2.16.5 Solar tower power plant

2.17 Fundamental of Solar Photo Voltaic Conversion

- Solar Photovoltaic (PV) is a technology that converts sunlight (solar radiation) into direct current electricity by using semiconductors.
- When the sun hits the semiconductor within the PV cell, electrons are freed and form an electric current.
- Solar PV technology is generally employed on a panel (hence solar panels).
- PV cells are typically found connected to each other and mounted on a frame called a module.
- Multiple modules can be wired together to form an array, which can be scaled up or down to produce the amount of power needed.

2.17.1 Basics of Semiconductor Material

- PV cells can be made from various semi-conductor materials.
- The most commonly used material today is silicon but other materials, such the ones listed below, are being tested and used to increase the efficiency of converting sunlight to electricity.

i. Monocrystalline Silicon

ii. Polycrystalline Silicon

iii. Amorphous Silicon

iv. Cadmium Telluride (CdTe)

v. Copper Indium Gallium Selenide (CIGS)

- Almost 90 % of the world's PV technologies, today, are based on some variation of silicon.
- In 2011, about 95 % of all shipments by U.S. manufacturers to the residential sector were crystalline silicon solar panels.
- The major difference between the technologies is the material used to generate electricity out of sunlight.
- Each type of material has different attributes, resulting in different applications and efficiencies. In general the efficiency of solar PV technologies varies, ranging between 6 - 18 % at the moment.

2.17.2 Photovoltaic Effect

- Photovoltaic (PV) effect is the conversion of sunlight energy into electricity.
- In a PV system, the PV cells exercise this effect.

- Semi-conducting materialsinthePVcellaredopedtoformP-Nstructureasan internal electric field.
- The p-type (positive) silicon has the tendency to give up electrons and acquire holes while the n-type (negative) silicon accepts electrons.
- When sunlight hit the cell, the photons in light excite some of the electrons in the semiconductors to become electron-hole (negative-positive) pairs.
- Since there is an internal electric field, these pairs are induced to separate.
- As a consequence, the electrons move to the negative electrode while the holes move to the positive electrode.
- A conducting wire connects the negative electrode, the load, and the positive electrode in series to form a circuit.
- As a result, an electric current is generated to supply the external load.
- This is how PV effect works in a solar cell.

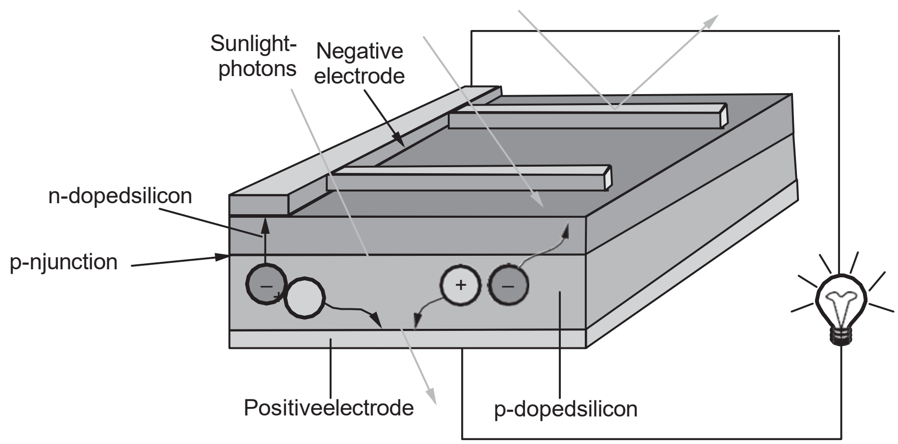


Fig. 2.17.1

2.18 Solar Cell

- Solar cells can convert the energy of sunlight directly into electricity.
- Consumer appliances used to provide services such as lighting, water pumping, refrigeration, telecommunications, and television can be run from photovoltaic electricity.
- As referring to the figure it is clear that sun rays are falling on the photoelectric material.
- Electrical circuit is provided between the p-n junction using the photovoltaic effect principle solar energy can be effectively converted into the useful electrical energy.

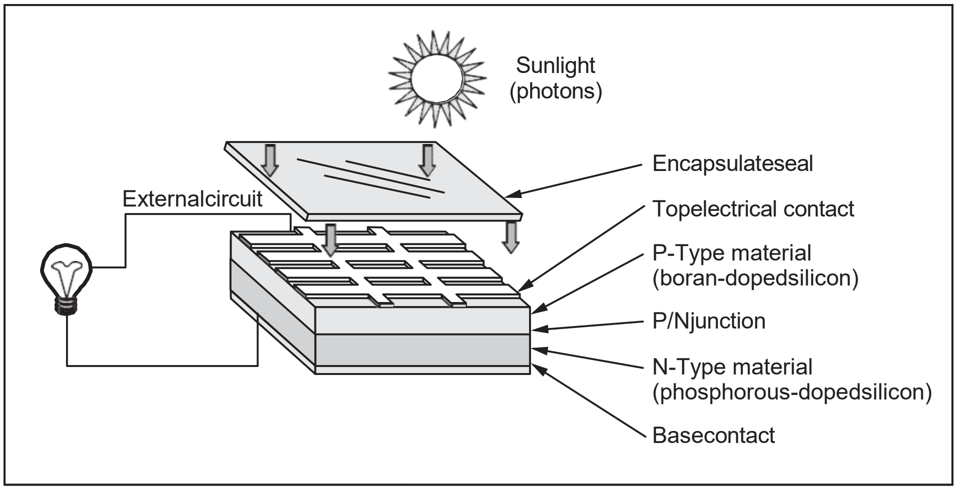


Fig. 2.18.1 Solar cell (Photovoltaic cell)

2.18.1 Modules and Arrays

- The major factors influencing the electrical design of the solar array are as follows :
  - The sun intensity
  - The sun angle
  - The load matching for maximum power
  - The operating temperature
- These factors are discussed in the following subsections :

a. Sun Intensity :

- The magnitude of the photocurrent is maximum under a full bright sun.
- On a partially sunny day, the photocurrent diminishes in direct proportion to the sun intensity.
- At a lower sun intensity, the I-V characteristic shifts downward as shown above.
- On a cloudy day, therefore, the short-circuit current decreases significantly.
- The reduction in the open-circuit voltage, however, is small.
- The photo conversion efficiency of the cell is insensitive to the solar radiation in the practical working range.
- This means that the conversion efficiency is the same on a bright sunny day as on a cloudy day.
- We get a lower power output on a cloudy day only because of the lower solar energy impinging on the cell.

b.Sun Angle:

- The cell output current is given by $I = I_o \cos\theta$, where I_o is the current with normal sun (reference), and θ is the angle of the sun line measured from the normal.
- This cosine law holds well for sun angles ranging from 0 to about 50°.
- Beyond 50°, the electrical output deviates significantly from the cosine law and the cell generates no power beyond 85°, although the mathematical cosine law predicts 7.5 % power generation.

c. Shadow Effect :

- The array may consist of many parallel strings of series-connected cells.
- A large array may get partially shadowed due to a structure interfering with the sun line.
- If a cell in a long series string gets completely shadowed, it loses the photo-voltage but still must carry the string current by virtue of its being in series with all other cells operating in full sunlight.
- Without internally generated voltage, the shadowed cell cannot produce power. Instead, it acts as a load, producing local I2R loss and heat.
- The remaining cells in the string must work at higher voltage to make up the loss of the shadowed cell voltage.

d. Temperature Effects :

- With increasing temperature, the short-circuit current of the cell increases, whereas the open-circuit voltage decreases.
- The effect of temperature on PV power is quantitatively evaluated by examining the effects on the current and the voltage separately.

e. Effect of Climate :

- On a partly cloudy day, the PV module can produce up to 80 % of its full sun power.
- It can produce about 30 % power even with heavy clouds on an extremely overcast day.
- Snow does not usually collect on the module, because it is angled to catch the sun.
- If snow does collect, it quickly melts.
- Mechanically, the module is designed to withstand golf-ball-size hail.

f. Sun Tracking:

- More energy is collected by the end of the day if the PV module is installed on a tracker with an actuator that follows the sun.
- There are two types of sun trackers :
  - One-axis tracker, which follows the sun from east to west during the day.
  - Two-axis tracker, which follows the sun from east to west during the day, and from north to south during the seasons of the year.

2.18.2 Solar Cell Types

- Classification of the solar cell is based on the following categories :

I) According to the cell size

a. Small size solar cell

- The size of the solar cell has the following four categories -

  a. Round single crystalline having 100 mm diameter.

  b. Square single crystalline having area of 100 cm^2

  c. 1000 mm × 1000 mm square multicrystalline

  d. 125 × 125 mm square muticrystalline solar cells

b. Large size solar cell

- These are used widely in the terrestrial applications due to their brittleness property.

II) According to the thickness of the active material

- These types of solar cells can be divided into the following two categories -

a. Bulk material cell

- These cells are most suitable for the terrestrial applications.

b. Thin film cell

- These cells are not suitable for the commercial applications.

III) According to the type of the junction system

- These are further divided in to the following categories

  a. p-n homogeneous cell

  b. p-n heterogeneous cell

  c. p-n multi junction cell

  d. Metal semiconductor Scotky junction

IV)Accordingtothetypeofthe activematerial

- These are further divided in to the following categories
  a. Single crystal silicon cell
  b. Multicrystal silicon cell
  c. Amorphous silicon cell
  d. Cooper indium diselenide cell
  e. Cadmium telluride cell
  f. Organic P-V cell

2.18.3 Material

- Conventional solar cells are made of Si single crystal and have an efficiency of around 22 - 24 %, while polycrystalline Si cells have an efficiency of 18 %.
- The efficiency of the solar cell depends on the band gap of the material Polycrystalline.
- Solar cells are cheaper to manufacture but have a lower efficiency since the microstructure introduces defects in the material that can trap carriers.
- Amorphous solar cells have an even lower efficiency but can be grown directly on glass substrates by techniques like sputtering so that the overall cost of manufacturing is lowered.
- There are also design improvements in the solar cell that can enhance the efficiency. PERL (Passivated Emitter rear locally diffused) cells, s, have an efficiency of 24 % due to the inverted pyramid structure etched on the surface that enhances absorption.
- Typical solar cells are made of the same material so that the pn junction is a homo junction.
- A comprehensive state of current research in different solar cell technologies
- Heterojunction solar cells are also possible and they have the advantage of minimizing absorption in regions other than the depletion region, but overall cost increases because of the use of different materials and the tight processing conditions needed to produce defect free interfaces.
- A number of semiconductor materials are suitable for the manufacture of solar cells.
- The most common types using silicon semiconductor material (Si) are :
  - Monocrystalline Si cells
  - Polycrystalline Si cells
  - Amorphous Si cells

2.18.4 Advantages and Disadvantages

- Solar cells are compact in size.
- Easy to manufacture.

2.18.5 Applications

- Used for production of electricity.
- Now-a-days solar power banks are available in the market for smartphone charging.

2.19 Solar Photovoltaic Power Generation

- Photovoltaic conversion is the direct conversion of sunlight into electricity without any heat engine to interfere.
- Photovoltaic devices are rugged and simple in design requiring very little maintenance and their biggest advantage being their construction as stand-alone systems to give outputs from microwatts to megawatts.
- Hence they are used for power source, water pumping, remote buildings, solar home systems, communications, satellites and space vehicles, reverse osmosis plants, and for even megawatt scale power plants.
- Fig. 2.19.1 shows a basic photovoltaic system integrated with the utility grid.
- It consists of the following elements

1. Solar array
2. Blocking diode
3. Battery storage
4. Inverter/Converter
5. Switches and Circuit breakers

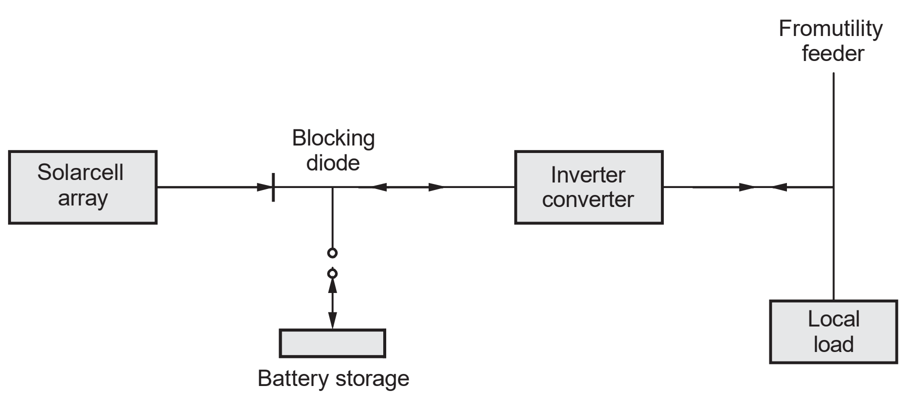


Fig. 2.19.1 Basic Photovoltaic system integrated with power grid

1.SolarArray

- It is a large or small element which converts the isolation into useful DC electrical power.

2. Blocking diode

- It lets the array generated power flow only towards the battery or grid.
- Without a blocking diode, the battery would discharge back through the solar array at the time of no isolation.

3. Battery storage

- It is used to store the solar energy.

4. Inverter/Converter

- It converts the battery bus-voltage to AC of frequency and phase to match to integrate with the utility grid.
- It contains a suitable output step up transformer and power correction circuits.

5. Switches and circuit breakers

- It permits isolating parts of the system as the battery.

2.19.1 Solar PV System Configurations

- SPV system configurations can be of three types for different applications as described below :

1) Stand-alone SPV systems without storage battery and storage battery
2) Grid interactive SPV system.
3) Hybrid systems

2.19.1.1 Stand- Alone SPV Systems

- A simple stand-alone PV system harnesses the solar energy and stores it in battery banks that could be used even at night times when there is no sunlight.
- A stand-alone small-scale PV system employs rechargeable batteries.
- Roof top systems are best suited example for these systems.
- The roof top system consists of solar modules which produces electricity is connected to the battery via charge controller.
- Further it is connected to the stand-alone inverter to convert Direct Current (DC) to Alternating Current (AC), making it available to connect to AC loads.

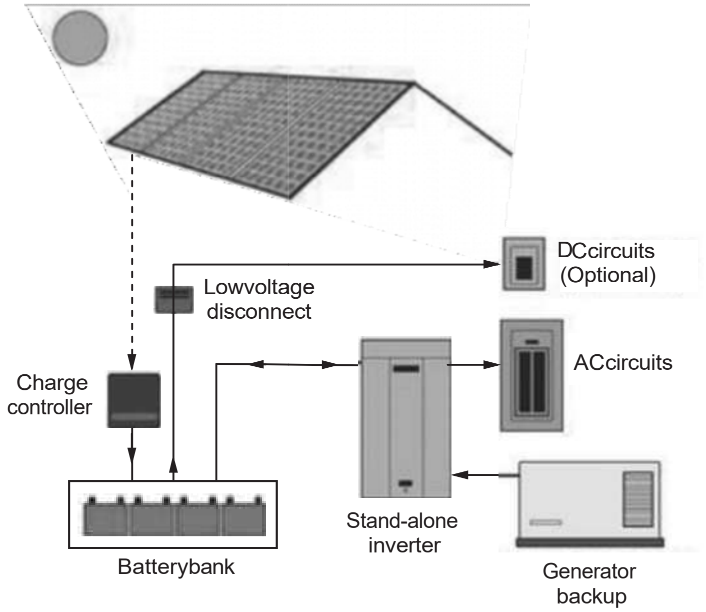


Fig. 2.19.2 Stand-alone roof top system with battery storage

- Deep cycle lead acid batteries are generally used to store the solar power generated by the PV panels, and then discharge the power when energy is required.
- Deep cycle batteries are not only rechargeable, but they are designed to be repeatedly discharged almost all the way down to a very low charge.

2.19.1.2 Grid Interactive SPV System

- A grid-connected photovoltaic power system, is an electricity generating system that is connected to the utility grid.
- A grid-connected PV system consists of solar panels, one or more inverters, a Power Conditioning Unit (PCU) and grid connection equipment.
- When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.
- A grid connected system is connected to a large public electrical grid (owned by utility company) and feeds power into the grid.
- Grid connected systems vary in size from residential (2 - 10 kW) to solar power stations (1 - 10 MW).
- In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is met by the PV system.
- Only the excess is fed into the grid when there is an excess.

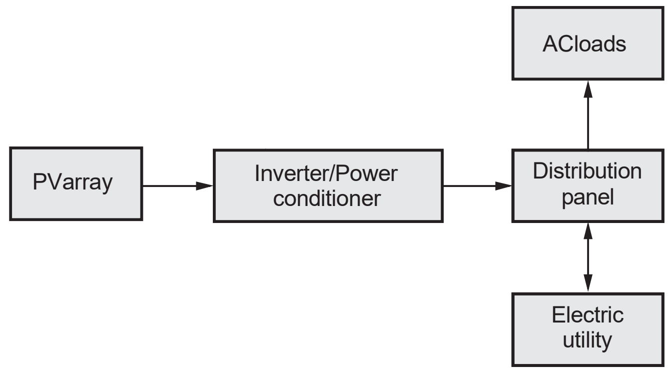


Fig. 2.19.3 Grid-connected photovoltaic system

2.19.1.3 Hybrid System

- Solar hybrid systems are power systems that combine solar power from a photovoltaic system with another energy source.
- One of the most common hybrid systems being PV diesel hybrid system, coupling PV and diesel generators, also known as diesel gensets.
- The diesel generators are used to steadily fill in the gap between the load and the power generated by the PV system.
- Battery storages can be used to enhance the overall system performance to ensure that the amount of energy meets the demand.
- An energy management system can also be included to optimize the system as the diesel gensets capacity is limited and the solar energy production is inconsistent.

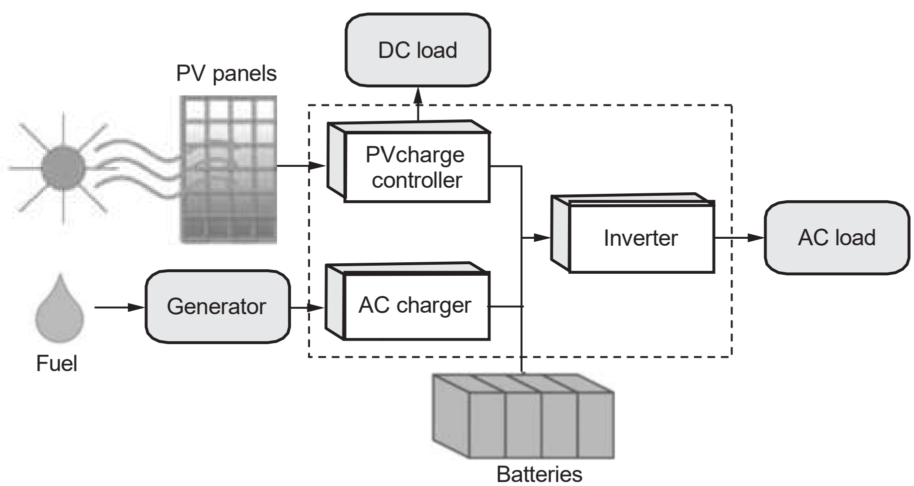


Fig. 2.19.4 Schematic drawing of a PV-diesel hybrid system

2.19.2 Advantages of Photovoltaic Systems

1. Systems are durable.
2. No operational cost.
3. Low maintenance.
4. More flexibility available.
5. Systems are eco-friendly.
6. Highly reliable.
7. Long effective life.
8. Absence of moving parts.
9. Can function unattended for long periods.
10. High power to weight ratio.

2.19.3 Limitations of Photovoltaic Systems

1. Weather dependent.
2. Low efficiency
3. High installation cost.

2.20 Applications of Solar PV System

- Photovoltaic cells could be associated with small or large power plants, because it is small and works well and can be applied to local energy generation on the roof top of a building.
- The cost of the energy storage and power conditioning equipment might however, make generation in large stations the most economical method.
- Solar cells have also been used to operate irrigation pumps, navigational signals high way emergency call system, rail road crossing warnings, automatic meteorological stations, etc.
- Some of the typical applications include the following :

1. Solar street lighting system.
2. Home lighting systems.
3. Water pumping systems (for micro irrigation and drinking water supply).

4.Solar vehicles.

5. Radio beacons for ship navigation at ports.

6. Community radio and television sets.

7. Cathodic protection of oil pipelines.

8. Railway signalling equipment.

9. Weather monitoring.

10. Battery charging

2.20.1 Solar PV Water Pumping

- In many remote and rural areas, hand pumps or diesel driven pumps are used for water supply.
- Diesel pumps consume fossil fuel, affect the environment, need more maintenance, and are less reliable.
- Photovoltaic (PV) - powered water pumps have received considerable attention because of major developments in the field of solar-cell materials and power electronic systems technology.
- Two types of pumps are commonly used for water-pumping applications : Positive displacement and centrifugal.
- Both centrifugal and positive displacement pumps can be further classified into those with motors that are surface mounted, and those that are submerged into the water ("submersible").
- Solar water pumping is based on PV technology that converts sunlight into electricity to pump water.

Solar Pump Block Diagram

- The solar pump block diagram mainly includes a solar panel, water pump, electric motor, and controller.
- This pump is basically an electrical pump, and this pump uses the electricity which is received from the solar panels to work.
- These panels store the energy from the solar.
- The electric motor manages the alternating current or direct current.
- The controller used in this system adjusts the output power as well as speed.

- Fig.2.20.1shows block diagram of solar pump

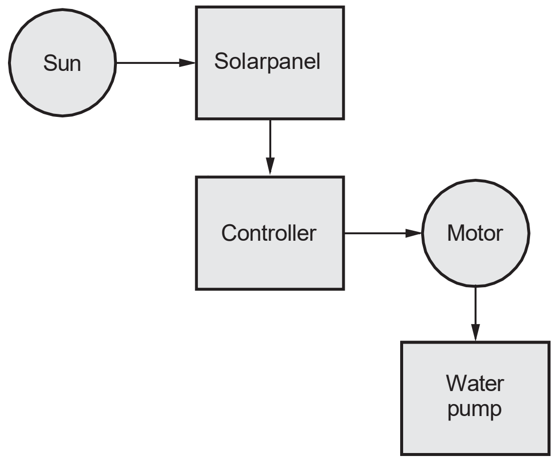


Fig. 2.20.1 Block diagram of solar pump

Working

- When the solar energy drops sun rays on the PV panels then the solar panel converts the rays into electrical energy.
- Then the solar energy supplies to the electrical motor to operate the pumping system using cables.
- By the revolution of the shaft which is fixed to the pump, then the pump begins to pick up the soil water and supplies to the fields.
- Fig. 2.20.2 (See Fig. 2.20.2 on next page) shows schematic of solar water pumping system.

Advantages of a solar water pumping system

1. No fuel cost - as it uses available free sun light
2. No electricity required
3. Long operating life
4. Highly reliable and durable
5. Easy to operate and maintain
6. Eco-friendly

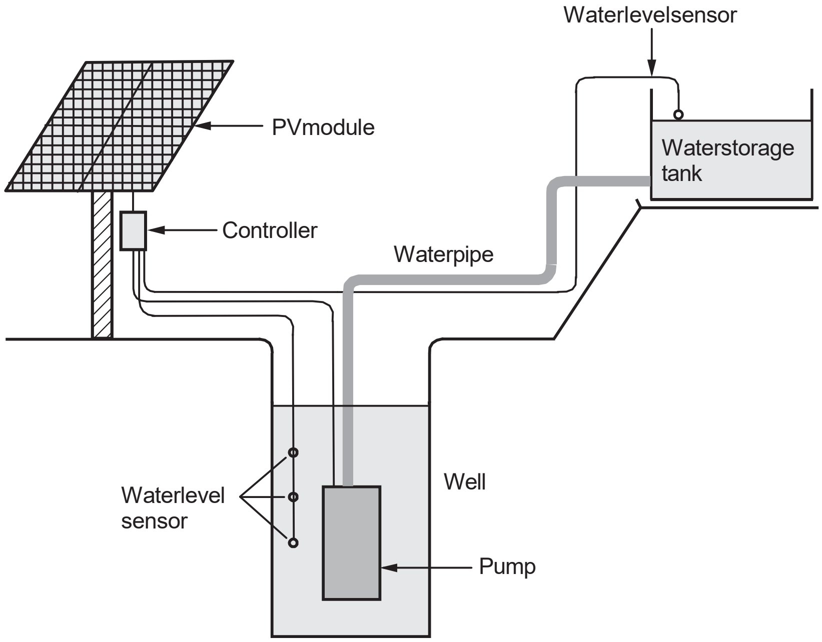


Fig. 2.20.2 Solar water pumping system

Disadvantages of a solar water pumping system

1. It is expensive.
2. The output of the panel will depend on the weather.
3. It requires a water storage tank as well as a battery.

Applications of a solar water pumping system

1. Minor irrigation
2. Drinking water for unelectrified villages and remote locations
3. Horticulture, poultry farming, silviculture and pisciculture
4. Farm house
5. Wild life sanctuary
6. Tourist resort

2.20.2 Solar PV Lighting System

- In a solar photovoltaic (PV) lighting system, solar radiation replaces the burning of fossil fuels such as coal or natural gas or the harnessing of water power to generate the electricity necessary to power the lighting.

- A solar PV lighting system consists of a PV panel, battery,electronic circuits,light source (lamp), and luminaire (optics).
- Figure 2.20.2 shows the components in a typical solar PV lighting system.
- PV panels transform solar energy into electrical energy.
- A PV panel is made up of many PV cells, which are created by semiconductor positive-negative **(pn) junctions.**
- The electrical energy created by the PV cells can energize light sources (lamps) directly or be stored in a battery for later use.
- The dc current generated by the PV cell or the battery can be regulated and stabilized using an electronic circuit to energize dc light sources like incandescent, Light-Emitting Diodes (LED), or fluorescent lamps operated on dc ballasts; or they can be converted into 120 volts, 60 hertz ac to energize ac light sources such as fluorescent lamps operated on ac ballasts.
- Ac ballasts are more commonly available.

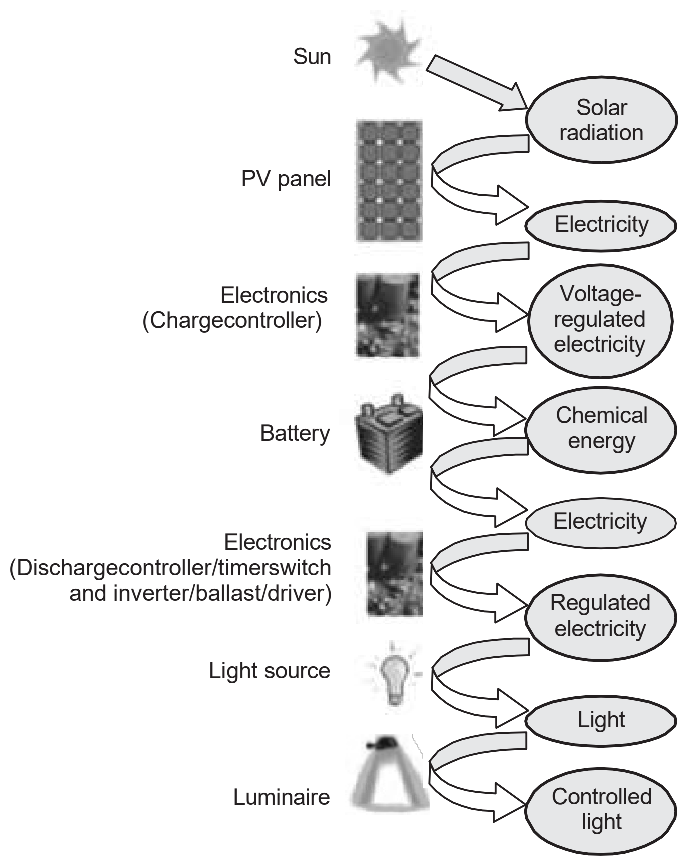


Fig. 2.20.3 Solar PV lighting system components and energy flow diagram

- Electronic components, including charge controllers, timer switches, and ballasts for fluorescent lighting (or drivers for LEDs or inverters for ac lamps) provide regulation and control to the electric energy.
- The light source provides the light, and the luminaire that houses these components provides protection for the elements and optics to direct the light.
- The light output of a PV lighting system depends on the amount of solar energy received and the efficiency or efficiency of its components, including the PV panel, battery, electronics, light source, and luminaire.

Advantages of Solar PV lighting system

1. Solar power generation is economically competitive where grid connection or fuel transport is difficult, costly or impossible. For example : satellites, hilly areas, remote locations and when power is not available.
2. The DC power id generated from the panels will be supplied to batteries to get charged.
3. Also the inverters can help us in conversion of DC to AC.
4. Through this pumps can also be operated for lifting of water.(moderate height)
5. Operational cost is almost negligible.

Disadvantages of Solar PV lighting system

1. Solar energy systems do not work in night.
2. Solar cells are currently costly and require a large initial capital investment.
3. For larger applications, big size batteries are required.
4. Maintenance of batteries is always the critical issues.
5. Solar cells are very delicate (need to be handled carefully)
6. Need high precision machinery for the assembly of panels.
7. The dust from the silicon cells is dangerous to health.(while assembling the panels)

2.20.3 Solar PV Medical Refrigeration System

- Solar PV power is ideally suited for telecommunication applications such as local telephone exchange, radio and TV broadcasting, microwave and other forms of electronic communication links.
- In most telecommunication application, storage batteries are already in use and the electrical system is basically DC.

- In hilly and mountainous terrain, radio and TV signalsmaynot reachastheyget blocked or reflected back due to undulating terrain.
- At these locations, low power transmitters are installed to receive and retransmit the signal for local population.

2.20.4 Solar PV Stand Alone System

- Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads.
- Worldwide, stand alone solar installations are very popular while in India almost all captive power plants are of the grid-tie.
- It is often a good idea to start with small and very simple stand alone solar PV system first and then progress from there.

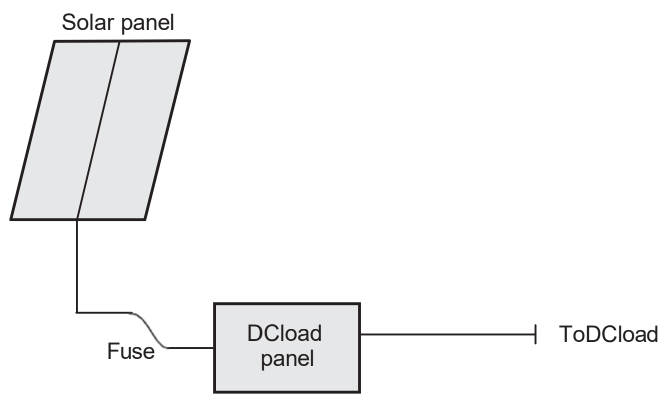


Fig. 2.20.4

Working :

- The simplest type of stand-alone PV system is a **"Direct-coupled system"**, where the DC output of a PV module or array is directly connected to a DC load.
- Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps.
- Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system.
- For certain loads such as positive-displacement water pumps; a type of electronic DC-DC converter, called a Maximum Power Point Tracker (MPPT) is used between the array and load to help better utilize the available array maximum power output.

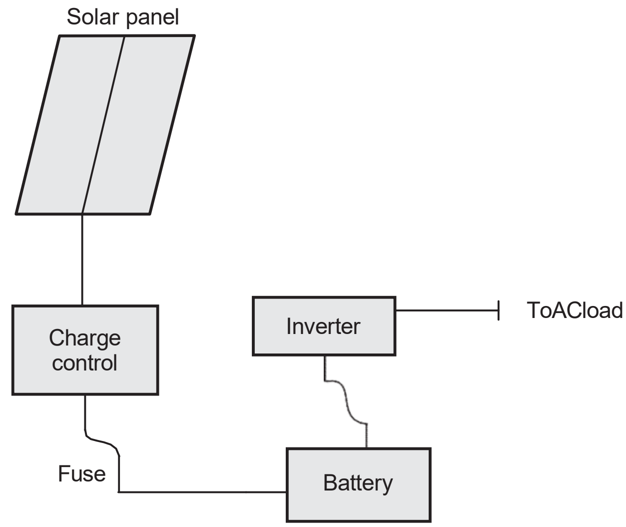


Fig. 2.20.5

- DC loads can also be connected directly to the battery bank.
- A more common type of the standalone system is where the PV system with a battery bank powers the AC loads.
- The **"Small stand-alone"** system is an excellent system for providing electricity economically.
- These systems are used primarily for RV power, lighting, cabins, backup and portable power systems.
- The size of the photovoltaic array (number of solar panels) and battery will depend upon individual power requirements.
- The solar panels charge the battery during daylight hours and the battery supplies power to the inverter as needed.
- The inverter changes the 12 volt batteries DC power into 230 V volt AC power, which is the most useful type of current for most applications.
- The charge controller terminates the charging when the battery reaches full charge, to keep the batteries from "gassing-out", which prolongs battery longevity.

Chapter 2
Wind Energy

1 Distinguish clearly between (a) Constant speed constant frequencies WTG unit. (b) Variable speed constant frequency WTG system. (c) Nearly constant speed constant frequency system.

2 Why a tall tower is essential for mounting a horizontal axis wind turbine?

3 With a neat diagram, explain how wind energy can be converted into electrical energy.

4 Explain the principle and application of wind electric system. State the basic Components and their working in wind electric system.

5 Explain with a neat diagram the working of various types of wind generators.

6 Explain briefly about the horizontal wind mills with neat sketch?

7 Explain briefly about the vertical wind mills with neat sketch?

8 Explain the terms

i.Yaw control ii. Pitch control iii. Teethering control

9 Write short notes on (a) Application of wind energy (b) Savonius rotor (c) Darrieus rotor (d) Wind energy storage.

10 What are the most favorable sites for installing of wind turbines?

UNIT - III

3 Wind Energy

Syllabus

Wind Data and Energy Estimation - Types of Wind Energy Systems - Performance - Site Selection - Details of Wind Turbine Generator - Safety and Environmental Aspects.

Contents

3.1 Wind Energy Resources

- Wind energy is an indirect form of solar energy created by a combination of factors, including the uneven heating of Earth's atmosphere by solar radiation, variations in topography, and the rotation of Earth.
- People have been putting wind energy to use throughout history to propel sail boats, mill flour from grain, and pump water.
- Today the wind-induced mechanical power of huge multi-blade rotors-sweeping circles in the air as much as 100 meters in diameter is routed to generators that produce electricity.
- In 2019, wind power provided about 42 % of all the energy consumed from renewable sources.
- That contribution is expected to grow and the potential is large.
- Expansion of wind power depends on a variety of factors, including fossil-fuel prices, federal tax credits, state renewable energy programs, technology improvements, access to transmission grids, and public opinion.
- If those factors remain relatively constant, wind power generation capacity is expected to grow about one-third by 2040.
- Wind energy, like sunlight, is a "free" source.
- The cost arises in converting it to electricity and integrating that electricity into the nation's power grid. It is not, however, universally welcomed.
- Many oppose its use on aesthetic and environmental grounds.

3.1.1 Origin of Wind

- Wind is simply air in motion.
- Wind is almost entirely caused by the effects of the sun which, each hour, delivers 175 million watts of energy to the earth.
- This energy heats the planet's surface, most intensively at the equator, which causes air to rise.
- This rising air creates an area of low pressure at the surface into which cooler air is sucked, and it is this flow of air that we know as "wind".
- In reality atmospheric circulation is much more complicated and, after rising at the equator air travels polewards.

- As it travels the air cools and eventually descends to the earth's surface at about 30° latitude (north and south), from where it returns once again to the equator (a closed loop known as a Hadley Cell).
- Similar cells exist between 30° and 60° latitude (the Ferrel Cells) and between 60° latitude and each of the poles (the Polar Cells).
- Within these cells, the flow of air is further impacted by the rotation of the earth or the "Coriolis Effect".
- This effect creates a sideways force which causes air to circulate anticlockwise around areas of low pressure in the northern hemisphere and clockwise in the southern hemisphere.
- While these mechanisms are responsible for the creation of winds at a global level, those at the level of an individual wind farm are in practice also impacted by more local effects.
- The largest part of the energy stored in the wind can be found at high altitudes where continuous wind speeds over 160 km/h (100 mph) occur.
- The wind energy is converted through friction into diffuse heat during the Earth's surface and atmosphere.

3.1.2 Characteristics of Wind Energy

1. Wind energy is a renewable source of energy.
2. Wind energy is a pollution-free, infinitely sustainable form of energy
3. Wind energy does not require fuel.
4. Wind energy doesn't create greenhouse gases
5. Wind energy doesn't produce toxic or radioactive waste

3.1.3 Wind Speed

- Wind speed, or wind flow speed, is a fundamental atmospheric quantity caused by air moving from high to low pressure, usually due to changes in temperature.
- The wind speed is extremely important for the amount of energy a wind turbine can convert to electricity.
- The energy content of the wind varies with the cube (the third power) of the average wind speed.
- Wind speed describes how fast the air is moving past a certain point.

- This may be an averaged over a given unit of time, such as miles per hour, or an instantaneous speed, which is reported as a peak wind speed, wind gust or squall.
- Wind direction describes the direction on a compass from which the wind emanates, for instance, from the North or from the West.
- Wind speed and direction are important for monitoring and predicting weather patterns and global climate.
- Wind speed and direction have numerous impacts on surface water.
- These parameters affect rates of evaporation, mixing of surface waters, and the development of seiches and storm surges.
- Wind speed is typically reported in miles per hour, knots, or meters per second. One mile per hour is equal to 0.45 meters per second, and 0.87 knots.
- Wind direction is typically reported in degrees, and describes the direction from which the wind emanates.
- A direction of 0 degrees is due North on a compass and 180 degrees is due south.
- A direction of 270 degrees would indicate a wind blowing in from the west.
- The measurement of wind speed is usually done using a cup or propeller anemometer, which is an instrument with three cups or propellers on a vertical axis.
- The force of the wind causes the cups or propellers to spin.
- The spinning rate is proportional to the wind speed.
- Wind direction is measured by a wind vane that aligns itself with the direction of the wind.

3.1.4 Vertical Wind Speed Gradient

- The wind speed varies with the height above the ground. It is called wind shear.
- The wind speed at the surface due to the friction between air and surface of the ground is zero.
- The wind speed increases most rapidly near the ground with height and it increases less rapidly with greater height.
- The change in wind speed becomes nearly zero at a height of about 1 km above the ground.
- The vertical variation of the wind speed and the wind-speed profile can be expressed by many functions.

- The two more common functions that have been developed todescribethechange in mean wind speed with height are based on experiments.

i) Power exponent function :

- The power exponent function is given by

$$V(z) = V_r \left(\frac{z}{z_r} \right)^{\alpha}$$

Where z = Height above the ground level,

V_r–Wind speed at the reference heightz_r above the ground level.

A typical value of α is 0.1.

ii) Logarithmic function

- Logarithmic function can be expressed as

$$\frac{V(z)}{V_r} = \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_r}{z_0}\right)}$$

where, V_r=Wind speed at the reference heightz_r above the ground level.

z_0–Roughness length

z = height above the ground level

The parameter α and z_0 varies with different types of terrain. A typical value of α is from 0.01 to 0.28 and the values of z_0 is from 0.001 to 0.3.

3.2 Basics of Wind Energy Electricity Generation

- The typical components of a wind turbine consist of gearbox, rotor shaft and brake assembly all this being lifted into position.
- In a wind farm, individual turbines are interconnected with a medium voltage (often 34.5 kV), power collection system and communications network.
- At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.
- A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade.

- Whenwindflowsacrosstheblade,theairpressureononesideoftheblade decreases.
- The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin.
- The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator.
- This translation of aerodynamic force to rotation of a generator creates electricity.

3.2.1 Grid Management

- Induction excitation generators are usually used for wind power generation and require reactive power.
- Therefore, the substation used in the wind power generation collection system includes a large number of capacitor banks for power factor correction.
- Different types of wind turbine generators behave differently during transmission grid disturbances.
- So extensive modeling of the dynamic electromechanical characteristics of a new wind farm is required by transmission system operators to ensure predictable stable behaviour during system faults.
- In particular, induction generators cannot support the system voltage during faults, unlike steam or hydro turbine-driven synchronous generators.
- Doubly fed machines usually have more ideal grid interconnection characteristics.
- Transmission systems operators will provide a wind farm developer with a grid code to specify the requirements for interconnection to the transmission grid.
- This will include power factor, constancy of frequency and dynamic behaviour of the wind fan turbines during a system fault.

3.2.2 Capacity Factor

- Because wind speeds are not constant, the annual energy output of a wind farm is not the sum of the generator's nameplate ratings multiplied by the total hours in a year.
- The ratio of actual productivity in a year to this theoretical maximum is called the capacity factor.
- Typical capacity factors are 15 - 50 %.

- The upper end of the range is achievedatanadvantageouslocationandisdueto improved wind turbine design.
- Online data is available for some locations, and the capacity factor can be calculated from the yearly output.

Capacity factor = Actual productivity in a year / Theoretical maximum productivity in a year

- The capacity factor is influenced by several parameters, including the variability of the wind at the site, but also the generator size having a smaller generator would be cheaper and achieve higher capacity factor, but would make less electricity (and money) in high winds.
- Conversely a larger generator would cost more and produce little extra power and, depending on the type, may stall out at low wind speed.
- Thus an optimum capacity factor can be used, which is usually around 20 - 35 percent.

3.2.3 Penetration

- Wind energy 'penetration' refers to the fraction of energy produced by wind compared with the total available generation capacity.
- There is no generally accepted 'maximum' level of wind penetration.
- The limit for a particular grid will depend on the existing generating plants, pricing mechanisms, capacity for storage or demand management, and other factors.
- An interconnected electricity grid will already include reserve generating and transmission capacity to allow for equipment failures; this reserve capacity can also serve to regulate for the varying power generation by wind plants.
- Studies have indicated that 20 % of the total electrical energy consumption may be incorporated with minimal difficulty.
- These studies have been for locations with geographically dispersed wind farms, some degree of dispatchable energy or hydropower with storage capacity, demand management, and interconnection to a large grid area export of electricity when needed.
- Beyond this level, there are few technical limits, but the economic implications become more significant.
- Electrical utilities continue to study the effects of large (20 % or more) scale penetration of wind generation on system stability and economics.

3.2.4 Variability and Intermittency

- Electric power generated from wind power can be highly variable at several different timescales: hourly, daily, or seasonally.
- Wind power forecasting methods are used, but predictability of any particular wind farm is low for short-term operation.
- Intermittency and the non-dispatchable nature of wind energy production can raise costs for regulation, incremental operating reserve.
- Fluctuations in load and allowance for failure of large fossil-fuel generating units requires operating reserve capacity, which can be increased to compensate for variability of wind generation.
- Hybrid wind power can be used during low wind period.
- Wind power can be replaced by other power stations during low wind period.
- Pumped-storage hydroelectricity or other forms of grid energy storage can store energy developed by high-wind periods and release it when needed.
- Stored energy increases the economic value of wind energy since it can be shifted to displace higher cost generation during peak demand periods.
- The potential revenue from this arbitrage can offset the cost and losses of storage; the cost of storage may add 25 per cent to the cost of any wind energy stored, but it is not envisaged that this would apply to a large proportion of wind energy generated.

3.3 Wind Energy Economics

3.3.1 Cost Trends

- Although Wind power has a low operating cost, it carries high capital cost.
- The estimated average cost per unit includes the cost of construction of the turbine and transmission facilities, borrowed funds, return to investors (including cost of risk), estimated annual production and other components.
- Wind energy calculations are performed on the basis of the assumptions that lead to excessive costs and may deviate from the actual costs.

3.3.2 Incentives

- Wind energy in many countries receives financials or other support to encourage its development.

- Wind energy project are benefitted from subsidies to increase itsattractivenessand compensate for subsidies received by other forms of production.
- Sometimes, incentives are provided for businesses for use wind-generated power.

3.3.3 Wind Economics Determining Factors

- The following factors determining the economics of the wind power :

1. Financing and ownership structure
2. Taxes and policy incentives by the government.
3. Wind resource
4. Turbine size, model and tower height
5. Green field or site expansion
6. Land, transmission and ancillary services.

3.4 Advantages, Disadvantages and Application of Wind Power

3.4.1 Advantages of Wind Power

1. The wind is free and with modern technology it can be captured efficiently.
2. Environmental friendly.
3. Reliable source of energy.
4. Many people find wind farms an interesting feature of the landscape.
5. Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.
6. Wind turbines have a role to play in both the developed and third world.
7. Wind turbines are available in a range of sizes which means a vast range of people and businesses can use them.
8. Single households to small towns and villages can make good use of range of wind turbines available today.

3.4.2 Disadvantages of Wind Power

1. The strength of the wind is not constant and it varies from zero to storm force.
2. This means that wind turbines do not produce the same amount of electricity all the time.
3. Many people feel that the countryside should be left untouched, without these large structures being built.

4. The landscape should left in its natural form for everyone to enjoy.
5. Wind turbines are noisy. Each one can generate the same level of noise as a family car travelling at 70 mph.
6. Many people see large wind turbines as unsightly structures and not pleasant or interesting to look at. They disfigure the countryside and are generally ugly.
7. When wind turbines are being manufactured some pollution is produced.

3.4.3 Application of Wind Power

1. Mechanical application : Mainly (water pumping) Multi-blade wind mill used for water pumping.
2. Electricity generation : Wind turbines vary in size and type.
3. They are commercially available for electricity generation. Size of wind turbines (400 Watt - 5 MW).

3.5 Wind Data

- The wind is calculated on the basis of various factors such as the time availability, budget allocated for the measurement and accuracy needed for the estimation.
- If time and money are available, the highest accuracy can be achieved.
- At the same time, the cost compromise should be followed to balance the power output and money spent.
- It is better to use metrological data or civil aviation data.
- Basically, the measurements are wind speed and wind direction.
- The standardized wind data should be used similar to a metrological department.
- The metrological department collects data constantly about wind from many airports and data from anemometers located at 10 m height in order to follow the world standard.
- Sometimes, anemometers provide inaccurate data due to the friction in bearings rotating slowly.
- The most important factor to size the wind speed data is really unanswerable.
- It is typically oversized as a substitute of undersized.

3.5.1 Wind Measurement

- A wind measurement provides data to improve wind resource assessment and to increase confidence in site evaluation.
- Thus in order to find out the feasibility of site for taking up wind related projects the information about meteorological data especially wind data along with other environmental data and it analysis is important.
- They are the following parameters :

i. Parameters which define measurement

ii. Type and Quality of equipment

iii. Measurement levels of sensors

iv. Accuracy of measurement, it's duration and data recovery

v. Sampling of data and intervals in which it is recorded

vi. Storage format for data

vii. Processing procedures applied to data

viii. Reports on data

- Fig. 3.5.1 shows a schematic diagram of the wind data analysis procedure.

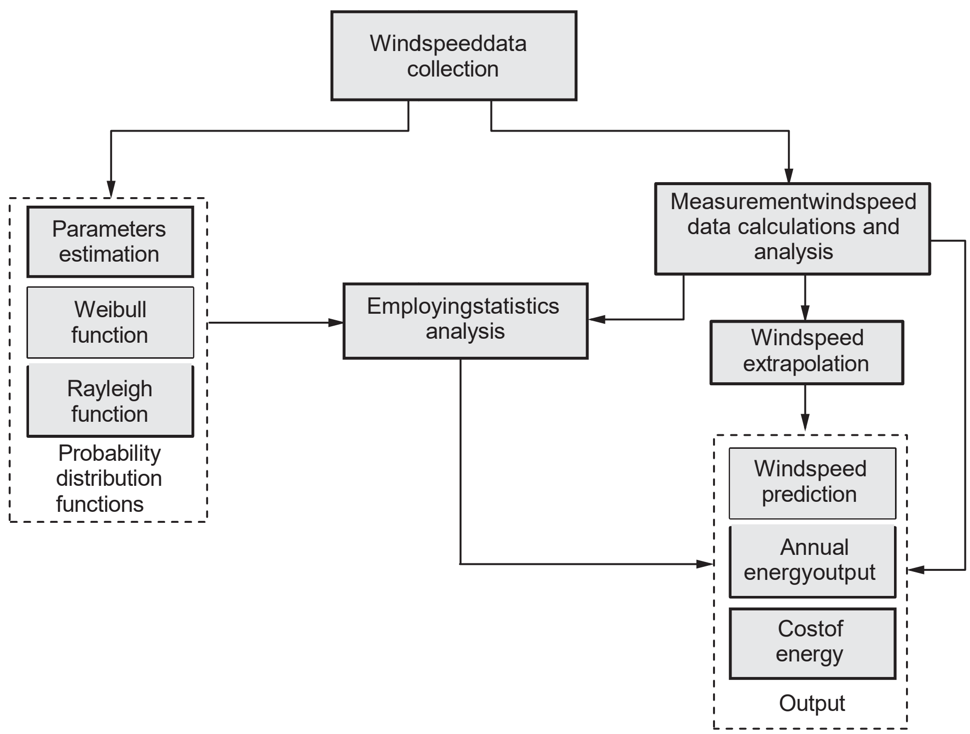


Fig. 3.5.1 Schematic diagram for wind data analysis procedure

3.6 Wind Energy Estimation

3.6.1 Wind Power and Wind Power Density

- The power in the wind is proportional to the wind speed cubed
- The kinetic energy in air of mass m moving with speed V is given by the following in joules :

$$\text{Kinetic energy} = \frac{1}{2}mV^2 \quad \ldots(3.6.1)$$

- The power in moving air is the flow rate of kinetic energy per second in watts :

$$\text{Power} = \frac{1}{2}(\text{Mass flow per second})V^2 \quad \ldots(3.6.2)$$

If

- P = Mechanical power in the moving air (watts),
- ρ = Air density (kg/m^3),
- A = Area swept by the rotor blades (m^2), and
- V = Velocity of the air (m/sec),
- Then the volumetric flow rate is AV, the mass flow rate of the air in kilograms per second is ρAV, and the mechanical power coming in the upstream wind is given by the following in watts :

$$P = \frac{1}{2}\rho(AV)V^2 = \frac{1}{2}\rho AV^3 \quad \ldots(3.6.3)$$

- Two potential wind sites are compared in terms of the specific wind power expressed in watts per square meter of area swept by the rotating blades.
- It is also referred to as the power density of the site, and is given by the following expression in watts per square meter of the rotor-swept area :

$$\text{Specific power of the site} = \frac{1}{2}\rho V^3 \quad \ldots(3.6.4)$$

- Equation (3.6.4) gives the maximum value of the wind available.
- This is the power in the upstream wind.
- From the equation (3.6.4) we can say that kinetic energy of the wind is directly proportional to the cube of the velocity.

- It varies linearly with thedensity of theair sweeping the bladesand with thecube of the wind speed.
- The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed.
- For Aero turbine with large swept area,

$$A = \frac{\pi}{4} \times D^2 \quad \ldots(3.6.5)$$

- Where, D is the Diameter of the rotor.

$$P = \frac{1}{2} \times \rho \times A \times V^3$$

$$= \frac{1}{2} \times \rho \times \frac{\pi}{4} \times D^2 \times V^3$$

$$P_a = \frac{1}{8} \times \rho \times D^2 \times V^3 \times \pi \quad \ldots(3.6.6)$$

- Equation (3.6.6) shows that power available at the wind rotor is directly proportional to the Diameter square.
- Thus, if we vary the diameter of the rotor the power available at the wind increases four times.

3.6.2 Maximum Wind Power and Maximum Wind Efficiency

- Wind energy is obtained by the converting kinetic energy of the wind into the electrical energy.
- To obtain the mathematical relation between the maximum power let's assume following assumptions -
  i. Flow of wind is incompressible
  ii. Wind has constant mass flow rate.

Let,

p_a– Atmospheric wind pressure.

p_u=Pressure on upstream of wind turbine

p_d=Pressure on downstream of wind turbine V_a= Atmospheric wind velocity

V_u=Velocity of upstream of wind turbine

V_d–Velocity of downstream of wind turbine V_b= Velocity of wind at blades.

A_b–Area of blades

m = Mass blow rate of wind

ρ = Density of air

The kinetic energy of wind stream passing through the turbine rotor is given by -

$$K.E. = \frac{1}{2} m V_b^2 \qquad ...(3.6.7)$$

and $$m = \rho A_b V_b \qquad ...(3.6.8)$$

Equation (3.6.7) can be written as,

$$\therefore \quad K.E. = \frac{1}{2}\rho A_b V_b \times V_b^2$$

$$= \frac{1}{2}\rho A_b V_b^3$$

Now,

Force on the rotor disc can be given as

$$F = (P_u - P_d) A_b \qquad ...(3.6.9)$$

Also, $$F = m[V_u - V_d] \qquad ...(3.6.10)$$

Applying Bernoulli's equation to upstream and downstream sides, we get

$$P_a + \frac{1}{2}\rho V_u^2 - P_u + \frac{1}{2}\rho V_b^2 \qquad ...(3.6.11)$$

and $$P_d + \frac{1}{2}\rho V_b^2 - P_a + \frac{1}{2}\rho V_d^2 \qquad ...(3.6.12)$$

Solving equations (3.6.11) and (3.6.12) we can obtain

$$P_u - P_d - \frac{1}{2}\rho\left[V_u^2 - V_d^2\right] \qquad ...(3.6.13)$$

Equating equations, (3.6.9) and (3.6.10) we get

$$(P_u - P_d)A_b = m[V_u - V_d] \qquad ...(3.6.14)$$

Solving equations (3.6.13) and (3.6.14) we get

$$\frac{1}{2}\rho\left(V_u^2 - V_d^2 A\right)_b - m(V_u - V_d)$$

$$\frac{1}{2}\rho A_b(V_u + V_d)(V_u - V_d) = \rho A_b V_b \quad (V_u V_d) \quad \because m = \rho A_b V_b$$

$$\therefore \qquad V_b = \left(\frac{V_u +}{V_d}\right) \qquad \ldots(3.6.15)$$

Ina wind turbinesystem"speed flow work"W'is nothing but difference between the downstream and upstream

$$\therefore \qquad W = (K.E)_u - (K.E)_d$$

$$= \frac{1}{2} m \left[V_u^2 - V_d^2\right]$$

$$W = \frac{1}{2}\left(V_u^2 - V_d^2\right) \qquad \ldots(3.6.16)$$

$$m = 1 \text{ bar unit mass}$$

The power output 'P' of wind turbine (rate of work done) is given by

$$P = \frac{1}{2} m \left[V_u^2 - V_d^2\right]$$

$$P = m\left[\frac{V_u^2 - V_d^2}{2}\right]$$

$$= \rho A_b V_b \left[\frac{V_u^2 - V_d^2}{2}\right] \quad \because m = \rho A_b V_b \text{equation (3.6.8)}$$

$$-\rho A_b\left(\frac{V_u + V_d\, 2}{}\right)\left(\frac{V_u^2 - V_d^2}{2}\right)$$

$$V_b = \frac{V_u + V_d}{2} \qquad \text{equation (3.6.15)}$$

$$P = \frac{\rho A_b}{4}(V_u + V_d)\left(V_u^2 - V_d^2\right) \qquad \ldots(3.6.17)$$

To get maximum power we will differenciate equation (3.6.17) w.r.t. dV_d and equate to zero.

$$\therefore \qquad \frac{dP}{d(V_d)} = 3(V_d)^2 + 2V_uV_d - V_u^2 = 0$$

This quatratic equation has two solution

$$V_d = \frac{1}{3}V_u \text{ and } V_d = -V_u \text{ (not possible practically) } \therefore V_d = \frac{1}{3}V_u$$

∴ We will replace $V_d = \frac{1}{3}V_u$ in equation (3.6.17) ...(3.6.18)

$$P_{max} = \frac{1}{4}\rho A_b V_u \left[\; + \frac{1}{3}V_u\right]\left[(V_u)^2 - \left(\frac{1}{3}V_u\right)^2\right]$$

$$= \frac{1}{4}\rho A_b \left[\frac{4}{3}V_u\right]\left[\frac{8}{9}V_u^2\right]$$

$$P_{max} = \frac{8}{27}\rho A_b V_u^3 \qquad \text{...(3.6.19)}$$

Equation (3.6.19) can be modified as

$$P_{max} = \frac{8}{27} \times \frac{2}{2} \times \rho A_b V_u^3 \quad \therefore \frac{2}{2} \text{ Multiplying R.H.S}$$

$$P_{max} = \frac{16}{27}\left[\frac{1}{2}\rho A_b V_u^3\right]$$

$$P_{max} = 0.593 \underbrace{\left[\frac{1}{2}\rho A_b V_u^3\right]}_{P_{Total}} \qquad \text{...(3.6.20)}$$

but in equation (3.6.20) $\frac{1}{2}\rho A_b V_u^3 = P_{Total}$ power of wind stream

$$\boxed{P_{max} = 0.593\, P_{Total}} \qquad \text{...(3.6.21)}$$

Ratio of $\frac{'P_{max}'}{P}$ = coefficient of power or power coefficient

It is indicated by 'C_P'

$$\therefore \qquad \mathbf{C_P = 0.593}$$

3.6.3 Forces on Blades and Axial Thrust on Turbine

- There are two types of forces operating on the blades of a propeller-type wind turbine.

i) Circumferential forces in the direction of wheel rotation that provide the torque and

ii) Axial forces in the direction of the wind stream that provide an axial thrust that must be counteracted by proper mechanical design.

- The circumferential force, or torque, T is obtained from

$$T = \frac{P}{\omega} = \frac{P\pi}{DN} \qquad ...(3.6.1)$$

where T = Torque, N or lb,

ω = Angular velocity of turbine wheel, m/s

D = Diameter of turbine wheel = $\sqrt{4A/\pi}$, m

N = Wheel revolutions per unit time, s^{-1}

For a turbine operating at power P, the torque is given by

$$T = \eta \frac{1}{8g_c} \frac{\rho D V_1^3}{N} \qquad ...(3.6.2)$$

For a turbine operating at maximum efficiency η_{max} = 16/27, the torque is given by T_{max},

$$T_{max} = \frac{2}{27g_c} \frac{PDV_1^3}{N}$$

The axial force or axial thrust, is

$$F_a = \frac{1}{2g_c} \rho A (V_1^2 - V_2^2)$$

$$= \frac{\pi}{8g_c} \rho D^2 (V_1^2 - V_2^2)$$

The axial force on a turbine wheel operating at maximum efficiency where $V_o = 1/3 V_i$ is given by

$$F_{a,max} = \frac{4}{9g_c} \rho A V_1^2 = \frac{\pi}{9g_c} \rho D^2 V_1^2$$

- The axial forces are proportional to the square of the diameter of the turbine wheel which makes them difficult to cope with in extremely large-diameter machines.
- There is thus an upper limit of diameter that must be determined by design and economical considerations.
- The performance of a wind mill rotor stated as coefficient of performance is expressed as :

$$C_p – A/P_{max} – A/(12\rho V^3)$$

where ρ = Density of air

A = Swept area

V = Velocity of the wind

3.7 Wind Energy Conversion

3.7.1 Principles of Wind Energy Conversion

- A wind turbine is a machine that converts kinetic energy of the moving air into mechanical energy which in turns is converted into electrical energy by a generator.
- Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle.
- It extracts the energy from the wind by transferring the thrusting force of the air passing through the turbine rotor into the rotor blades.
- All the wind turbines work on two (or three) physical principles by which energy is extracted from the wind.

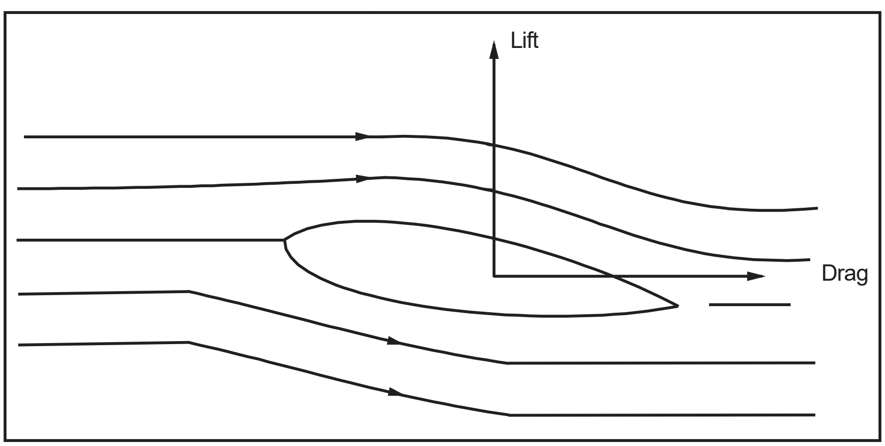


Fig. 3.7.1 Aerofoil

- These principles are either (i) Drag force or (ii) Lift force or (iii) Combination of the two forces
- The basic features that characterize lift and drag are :

1. Drag is in the direction of airflow.
2. Lift is perpendicular to the direction of airflow.
3. Generation of lift always causes a certain amount of drag to be developed.
4. With a good aerofoil (Fig. 3.7.1), the lift produced can be more than thirty times greater than the drag.
5. Lift devices are generally more efficient than drag devices.

3.7.2 Aerodynamics of Wind Turbine

- As a fluid moves around a solid object, two forces are created : drag and lift.
- "Drag" and "lift" forces act perpendicularly to each other.
- They depend upon the shape of the solid, the direction of the movement, the density of the solid and fluid, and the velocities of each.
- In the case of wind turbines, the solid object is the blade, and the fluid is air, which moves around the blade as it turns.

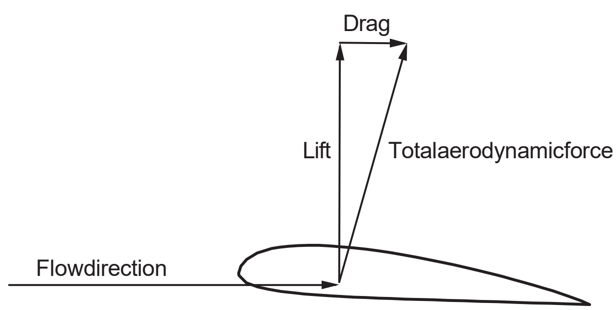


Fig. 3.7.2 Forces acting on a turbine blade

Drag force :

- This force is the resistance of the object's movement in the fluid and pushes against the direction of the object's movement (See Fig. 3.7.2)
- In order for an object to have less drag force, it needs to allow the fluid to flow around it more easily.
- For example, if you you're your hand flat out of a car window, you'll feel much less drag than if you hold your hand sideways.
- Turbine blades need to be designed to reduce the drag force as much as possible so that the turbine can turn with very little resistance.

Liftforce:

- This force propels an object upward, at a right angle to the direction of the object's movement.
- Lift is the force responsible for airplanes and helicopters being able to fly.
- When enough air flows over the wings or blades, the lift force becomes more powerful than gravity and the aircraft takes off.

3.8 Details of Wind Turbine Generator

- A wind energy conversion system is simple in construction which is operated and maintained by the local population.
- Following are the parts of the wind turbine :

1. Blades
2. The rotor
3. Nacelle
4. A gearbox and coupling (transmission system)
5. Aeroturbine
6. Controller
7. Electrical generator
8. Supporting structure.

- Fig. 3.8.1 shows the various parts of wind energy conversion system.

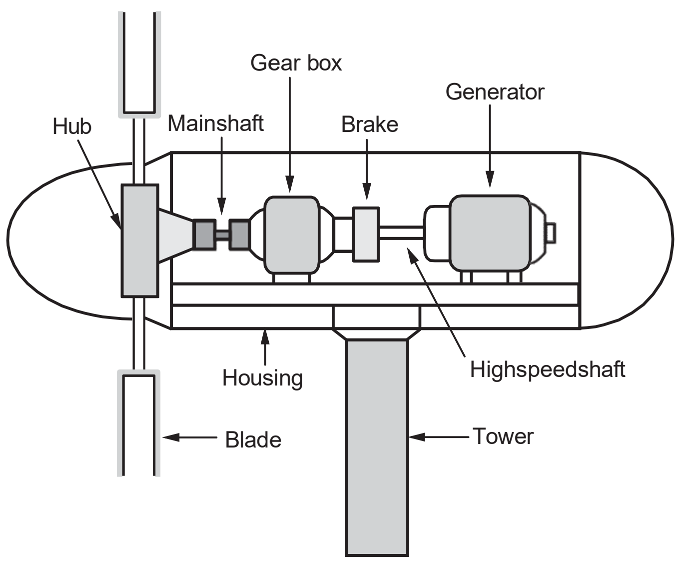


Fig. 3.8.1 Components of wind turbine

1.Blades

- Lifting style wind turbine blades.
- These are designed most efficiently, to capture the energy of strong and fast winds.
- Some European companies manufacture single blade turbines.

2. The Rotor

- The rotor is aerodynamically designed to occupy the maximum surface area of the wind to spin the most ergonomically.
- The blades are lightweight, durable and corrosion-resistant material.
- The best materials are composites of fibreglass and reinforced plastic.

3. Nacelle

- A housing which contains all the components which are essential to operate the turbine efficiently is called a nacelle.
- It is mounted on top of a tower and includes gearboxes, low and high-speed shafts, generators, controllers and brakes.
- Wind vane and wind speed anemometer are mounted on the nacelle.
- Nacelle provides housing for :

1. Low-speed shaft
2. Brake
3. Gearbox
4. High-speed shaft
5. Generator
6. Anemometer
7. Wind vane.

4. A Gearbox and Coupling (Transmission System)

- A gearbox magnifies or amplifies the energy output of the rotor.
- The gearbox is located between the rotor and the generator.
- A rotor rotates the generator as guided by the tail pane.

5. Aeroturbine

- Aeroturbine converts wind energy into rotary mechanical energy.

6.Controller

- The controller senses wind direction, wind speed power output of the generator rotor and other performance quantities of the system.
- And initiates proper control signals to take suitable corrective action.

7. Electrical Generator

- This unit produces electricity from the rotation of the rotor.
- The generator comes in various sizes with respect to the output.
- This generator converts mechanical energy into electrical power.
- The output of the generator coupled to the load or system grid.

8. Supporting Structure

- This is the heavy structure set up with a proper foundation and carries all the components of the windmill.
- It should be properly designed with a proper factor of safety to withstand a dead load of all components and wind force.

3.9 Types of Wind Turbine

- Wind mills are classified as per the following categories -

A. According to axis position

- Vertical Axis Wind Mill (VAWM)
- Horizontal Axis Wind Mill (HAWM)

B. According to size

- Smaller turbines (lower than 100 kilowatts)
- Medium turbines (up to 100 kilowatts)
- Large turbines. (Greater than 100 kilowatts)

C. Depending on output power

- A.C. Power
- D.C. Power wind mills

D. Depending on utilization of output

- Battery Storage
- Direct Connection to electromagnetic converter.

E. Depending on the rotational speed of the aero turbines

- Constant Speed with variable pitch blades
- Constant speed with fixed pitch blades

3.9.1 Vertical Axis Wind Turbine

- Vertical wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically as shown in Fig 3.9.1.
- The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind.
- This is an advantage on site where the wind direction is highly variable or has turbulent winds.
- With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier.
- The main drawback of a VAWT generally creates drag when rotating into the wind.
- It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop.
- The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine.
- Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life.
- However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and these can double the wind speed at the turbine.
- If the height of the rooftop mounted turbine tower is approximately 50 % of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

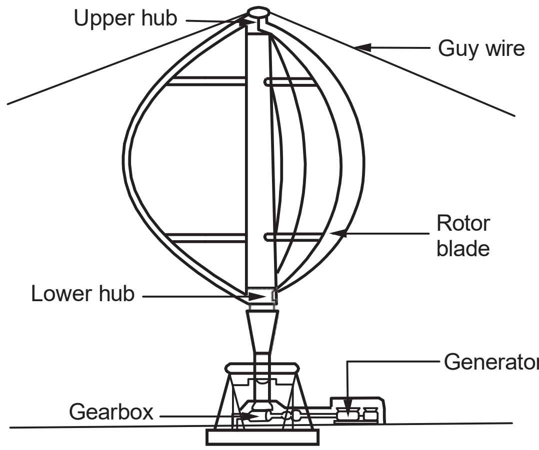


Fig. 3.9.1 Vertical axial wind turbine

3.9.1.1 Types of VAWT

- VAWTs are further classified as

(i) Darrieus turbine

(ii) Giromill turbine

(iii) Savonius Turbine

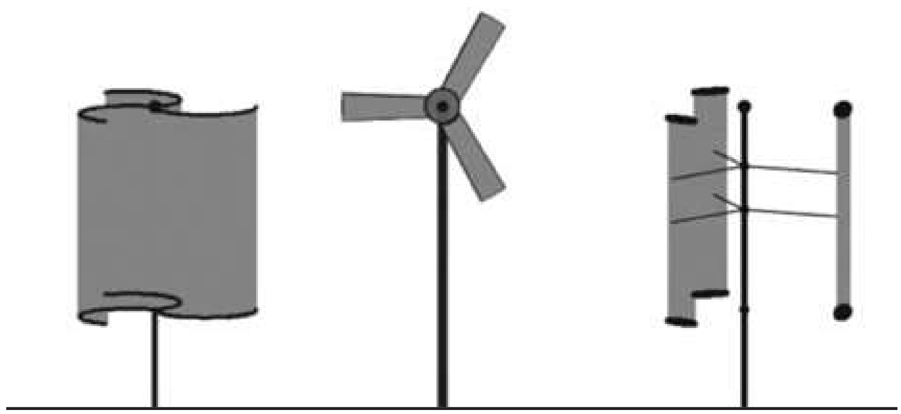


Fig. 3.9.2 Types of VAWT

i) Darrieus Turbine

- Darrieus turbine is type of HAWT. It was first discovered and patented in 1931 by French aeronautical engineer, Georges Jean Marie Darrieus.

- Itisalsoknownaseggbeaterturbinebecauseofitseggbeatershapedrotor blades.
- It consists of vertically oriented blades which are mounted on a vertical rotor.
- It is not a self-starting turbine and hence a small powered motor is required to start its rotation.
- First the Darrieus turbine is rotated by using a small powered motor.
- Once it attains sufficient speed, the wind flowing across its blades generates lift forces and this lift forces provides the necessary torque for the rotation.
- As the rotor rotates, it also rotates the generator and electricity is produced.

ii) Giromill Turbine :

- It is similar to the Darrieus turbine but the difference is that, it has H-shaped rotor.
- It works on the same principle of Darrieus turbine.
- This turbine has H - shaped rotor.
- Here Darrieus design which has egg beater shaped rotor blades are replaced by straight vertical blades attached with central tower with horizontal supports.
- It may consists of 2-3 rotor blades.
- Giromill turbine is cheap and easy to build as compared with Darrieus turbine.
- It is less efficient turbine and requires strong wind to start.
- Same as darrieus types of wind turbines, it is also not self- starting and requires small powered motor to start.
- It is capable of working in turbulent wind conditions.

iii) Savonius Turbine

- It was first discovered in 1922 by a Finnish Engineer Sigurd Johannes Savonius.
- It is one of the simplest turbine among all known turbines.
- It is a drag-type device and consists of two or three scoops.
- If we look it from above than it looks 'S' shape in cross section.
- The scoops of these turbines have curvature shape and because of that, it experiences less drag when it moves against the wind instead of moving with the wind.
- Since it is a drag-type machine, it is capable of extracting very less amount of wind power as compared with other similar sized lift-type turbines.

3.9.1.2 Advantages of Vertical Axis Wind Turbine

1. It is simple in design and easy to construct and transport.
2. It can be easily installed to desired location.
3. It requires less ground area for its installation.
4. Initial installation cost is very less as compared with the HAWT.

5.It can work in turbulent wind condition.

6. It is omni-directional and hence do not need to track winds.
7. They are smaller in size and hence can be used for domestic or private purpose easily.
8. They have low maintenance cost as compared with the HAWT.

3.9.1.3 Disadvantages of Vertical Axis Wind Turbine

1. It is less efficient. The efficiency of this turbine is about 30 - 35 %.
2. They are not self-starting. A small powered motor is needed to start it.
3. Guy wires may required to support this turbine.

3.9.2 Horizontal Axis Wind Turbine

- Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of a wind turbine.
- A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis as shown in Fig. 3.9.3.
- Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind.
- Small turbine are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind.
- Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.
- Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower.
- Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds.
- Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

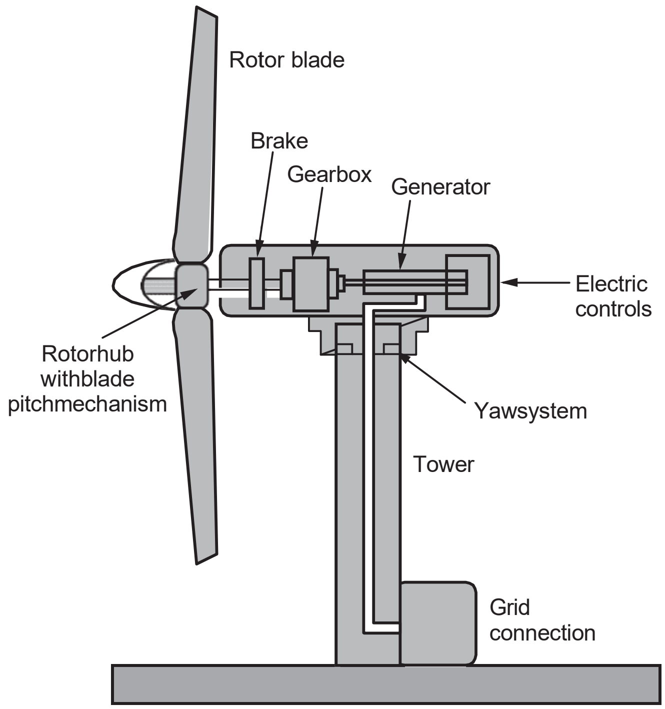


Fig. 3.9.3 Schematic structure of horizontal axis wind turbine

- Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind.
- Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance.
- Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

Advantages of Horizontal Axis Wind Turbine

1. It has self-starting ability. It does not require any external power source to start.
2. It has high efficiency as compared with the VAWT.
3. Capable of working in high wind speed condition.
4. In the case of slow wind condition, its angle of attack can be varied to get maximum possible efficiency.
5. Since all blades of this turbine work simultaneously, so it is capable of extracting maximum energy form the wind.

Disadvantages of Horizontal Axis Wind Turbine

1. Its initial installation cost is high.
2. It requires large ground area for its installation.
3. Because of its giant size of blades and towers, it becomes difficult to transport it to the sites.
4. High maintenance cost.
5. Creates noise problem.
6. It cannot be installed near human population.
7. It is not good for the bird's population. They are killed by its blades rotation.

3.10 Difference between Horizontal Axis Wind Turbine and Vertical Axis Wind Turbine

Sr.no.	Horizontal axis wind turbine	Vertical axis wind turbine
1.	In HAWTs, the axis of rotation of the rotor is Horizontal to the ground.	In VAWTs the axis of rotation of the rotor is perpendicular to the ground.
2.	Yaw mechanism is present.	Absence of Yaw mechanism.
3.	It has high initial installation cost.	It has low initial installation cost.
4.	They are big in size.	They are small in size.
5.	Its efficiency is high.	It has low efficiency.
6.	It requires large ground area for installation.	It requires less ground area for installation.
7.	High maintenance cost.	Low maintenance cost as compared with HAWT.
8.	They are self-starting.	They are not self-starting.
9.	They are unable to work in low wind speed condition.	They are capable of working in low wind speed condition.
10.	Difficult in transportation.	Easy in transportation.
11.	They are mostly used commercially.	They are mostly used for private purpose only.
12.	It cannot be installed near human population.	It can be installed near human population.
13.	It is not good for the bird's population.	It is good for the bird's population.

3.11 Performance of Wind Turbine Rotors

- To understand and analyze the characteristics of a wind turbine, several technical parameters are discussed below :

1. Solidity :

- Solidity is usually defined as the percentage of the circumference of the rotor which contains material rather than air.
- High-solidity machines carry a lot of material and have coarse blade angles.
- Solidity determines the quantity of blade material required to intercept a certain wind.
- Mathematically, solidity, $\sigma = \dfrac{N \times A}{\pi R^2}$ ...(3.11.1)

Where, N is blade number, A is blade area(m^2) , R is wind turbine radius (m).

- "Solidity" represents the fraction of the swept area of the rotor which is covered with metal.

2. Tip Speed Ratio

- Tip-speed ratio is the ratio of the speed of the rotating blade tip to the speed of the free stream wind.
- There is an optimum angle of attack which creates the highest lift to drag ratio.
- Because angle of attack is dependant on wind speed, there is an optimum tip-speed ratio.
- Power coefficient varies with tip speed ratio
- Characterized by C_p vs tip speed ratio curve

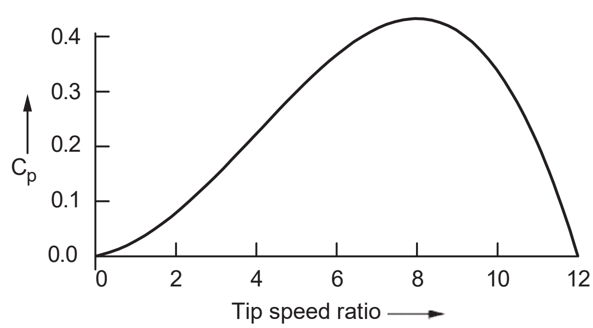


Fig. 3.11.1

- Wind energy conversion system decreases with increasing tip speed ratio.
- As high torque requires high solidity so WECS are best at low tip speed ratio.

3. Torque and Power Coefficient

i)Coefficient of Power(C_p)

- PowerCoefficient(C_p)isa measure of wind turbine efficiency often used by the wind power industry.
- $C_p$is the ratioof actual electric power produced by a wind turbine divided by the total wind power flowing into the turbine blades at specific wind speed.
- When defined in this way, the power coefficient represents the combined efficiency of the various wind power system components which include the turbine blades, the shaft bearings and gear train, the generator and power electronics.
- The$C_p$for a particular turbine is measured or calculated by the manufacturer, and usually provided at various wind speeds.
- If you know the$C_p$at a given wind speed for aspecific turbine you can use it to estimate the electrical power output.

$$C_p = \frac{\text{Electricityproducedbywindturbine}}{\text{Total Energy available in the wind}}$$

ii) Torque coefficient

- Torque Coefficient is the ratio of the torque produced by the wind turbine shaft the maximum torque.

$$C_T = \frac{T}{T_{max}}$$

where T=Shaft torque andT_{max} = Torque at maximum efficiency.

The maximum conceivable torque T on a turbine rotor occurs if the maximum thrust could be applied at the blade tip farthest from the axis.

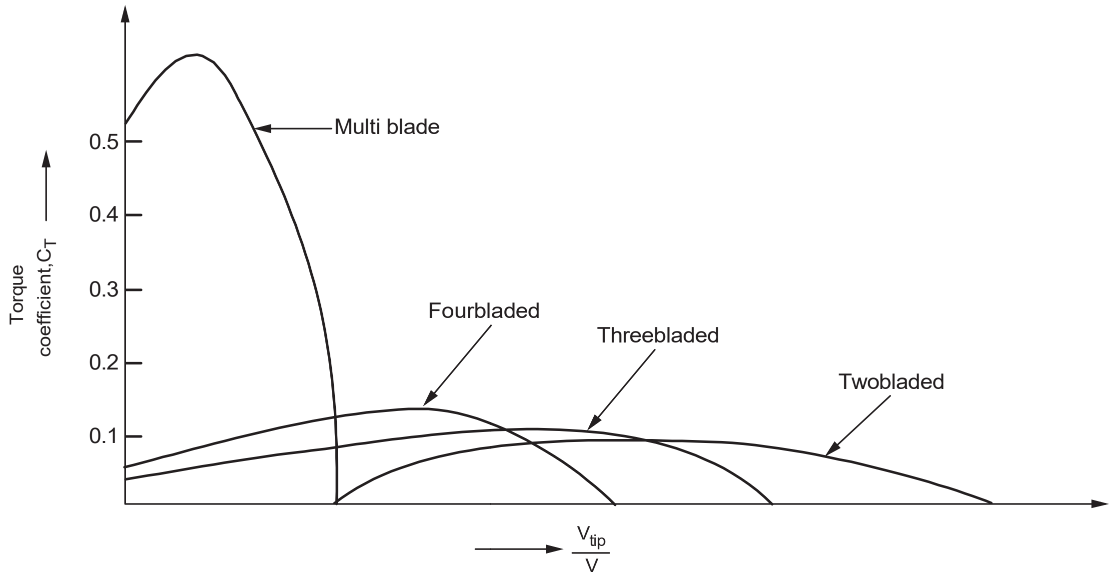


Fig. 3.11.2

4. Rotor Power Control

- However, there is s range of wind speeds before the cut-out speed where turbines employ various active and passive control strategies to deal with high wind speeds that would otherwise pose a threat to the turbines.
- These control strategies can broadly be classified as

i) Stall regulation

ii) Pitch regulation

i) Stall-regulated wind turbine

- Stall-regulated wind turbine, on the other hand, have their blades designed so that when wind speeds are high, the rotational speed or the aerodynamic torque, and thus the power production, decreases with increasing wind speed above a certain value (usually not the same as the rated wind speed).
- This behavior is illustrated in below Fig. 3.11.3, where a typical stall-regulated turbine is represented by the curve.
- The decrease in power with increasing wind speeds is due to aerodynamic effects on the turbine blades (regions of the blade are stalled, propagating from the hub and outwards with increasing wind speeds).

- The blades are designed so that they will perform worse(in terms of energy extraction) in high wind speeds toprotect the wind turbinewithout the need for active controls.
- The benefit of stall-regulation over pitch-regulation is limited the capital cost of the turbine, as well as lower maintenance associated with more moving parts.
- Like the pitch-regulated wind turbine, stall-regulated wind turbine also have brakes to bring the turbine to a halt in extreme wind speeds.

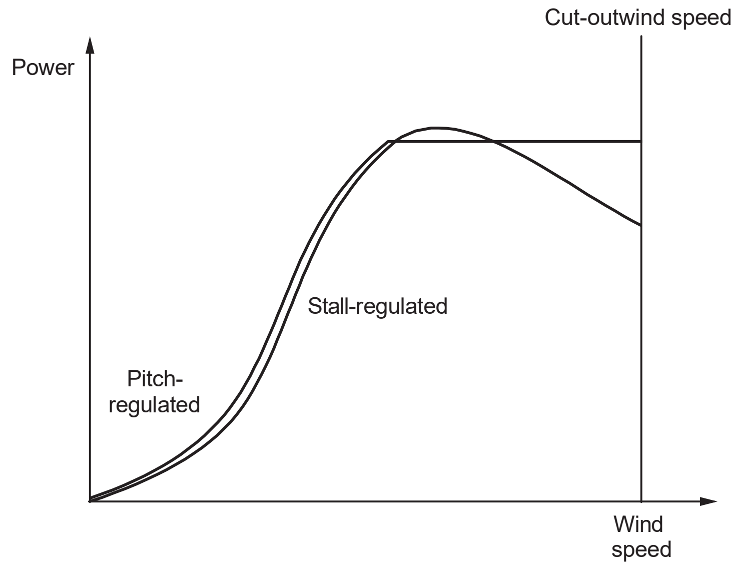


Fig. 3.11.3 Pitch-regulated and Stall-regulated Wind Turbine

ii) Pitch-regulated wind turbine

- Pitch-regulated wind turbine have an active control system that can vary the pitch angle (turn the blade around its own axis) of the turbine blades to decrease the torque produced by the blades in a fixed-speed turbine and to decrease the rotational speed in variable-speed turbines.
- This type of control is usually employed for high wind speeds only (usually above the rated speed), when high rotational speeds and aerodynamic torques can damage the equipment.
- When wind speeds get very high (above rated power), the blades will pitch so that there is less lift and more drag due to increasing flow separation along the blade length (the blades are pitched into stall).
- This will slow down the turbine's rotational speed or the torque transferred to the shaft so that the rotational speed or the torque is kept constant below a set threshold.

- Pitch regulated turbines see increasing power up until the rated wind speed, beyond which it sees constant power up until a cut-out speed when the pitch control is no longer able to limit the rotational speed/aerodynamic torque or where other forces like structural vibrations, turbulence or gusts pose a threat to a rotating turbine.
- Fig. 3.11.2 shows the pitch-regulated turbine is represented by the curve.

3.12 Control of Wind Turbine

- The main function of the wind turbine is to extract the maximum amount of energy at a wind speeds around 12 - 15 meters per second under allowable weather conditions and provide protection to the rotor and power electronic equipments at high wind speeds in case of storms or an emergency.
- At high wind speed, the rotor speed can no longer be controlled by increasing the generated power because this would overload the generator and power electronic equipments.
- In case of stronger winds it is necessary to waste a part of the excess energy of the wind in order to avoid damaging the wind turbines.
- This is achieved by proper design of blade and control systems.
- There are three main techniques for regulating the power of a wind turbine as discussed below.

3.12.1 Yaw Orientation Control

- This approach is used in small wind turbines.
- In this arrangement yawing or tilting the plane of rotation in the direction of wind pressure limits power extraction.
- This offers the reduction in the effective flow cross-section of the rotor and the flow incident on each blade is considerably modified.
- Figure 3.12.1 shows the drastic drop in performance co-efficient when wind turbine is turning out of the wind. In a horizontal-axis wind turbine a yaw system turns the rotor in such a way that the wind direction is perpendicular to the swept rotor area.

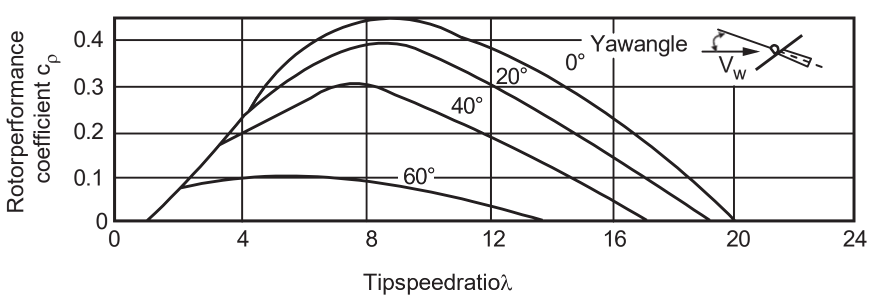


Fig. 3.12.1 Rotor performance co-efficient under skewed air flow

- In case of very high wind speed, more thanthecut-outspeed,therotoraxisis turned perpendicular to the wind direction.
- This action is carried out by an active yaw-control system.

3.12.2 Stall Regulated Turbines

- In this arrangement, rotor blades are bolted onto the hub at a fixed angle.
- The geometry of the blade profile however has been aerodynamically designed to ensure that the moment the wind speed becomes too high; it creates turbulence on the side of the rotor blades which is not facing the wind.
- This stall the aerodynamic design of the rotor blade regulates the power of a wind turbine and it does not require any moving parts.
- The blade is rigidly fixed to hub at a fixed angle and the pitch angle distribution along the blade is constant for all wind speeds.
- The wind turbine produces the maximum power within a certain wind speed limit.
- When the wind speed exceeds certain level, the design of rotor aerodynamics causes the rotor to stall.
- It is simple, robust and most economical but suffers from difficulties of over speeding of wind turbine in case of lose of grid connection and high mechanical stress caused by wind gusts.
- A normal stall controlled wind turbine will usually have a drop in the electrical power output for higher wind speeds, as the rotor blades gives more stall.

3.12.3 Pitch Regulated Turbines

- In this arrangement the blades are physically rotated about their radial axis in case of change of wind velocity to reduce the angle of attack so that it operates at a maximum C_p and obtain maximum power output and hydraulics or stepper motors are usually used to provide pitch mechanism.
- It is therefore possible to have an almost optimum pitch angle at all wind speeds and a relatively low cut-in wind speed.
- The speed of the rotor is continuously adjusted such that the tip speed ratio remains constant at a value to give the maximum C_p and efficiency of the turbine.
- Positive pitching increases the pitch angle so as to decrease the angle of incidence whereas negative pitching increases the angle of incidence.

- In case of storm or an emergency, the pitch angle increases to a large value thus increasing the angle of attack and forces the turbine to stall to prevent it from damage.
- The drawback with this method is that it involves the extra complexity due to the pitch mechanism and its controller.
- Variable speed pitch regulated wind turbines operate at fixed pitch with a variable rotor speed to maintain an optimum tip speed ratio.
- When the rated power is reached, the generator torque is used to control the electrical power output while the pitch control is used to maintain the rotor speed within acceptable limits.
- A conventional control system for a pitch-controlled turbine is shown in Fig. 3.12.2.

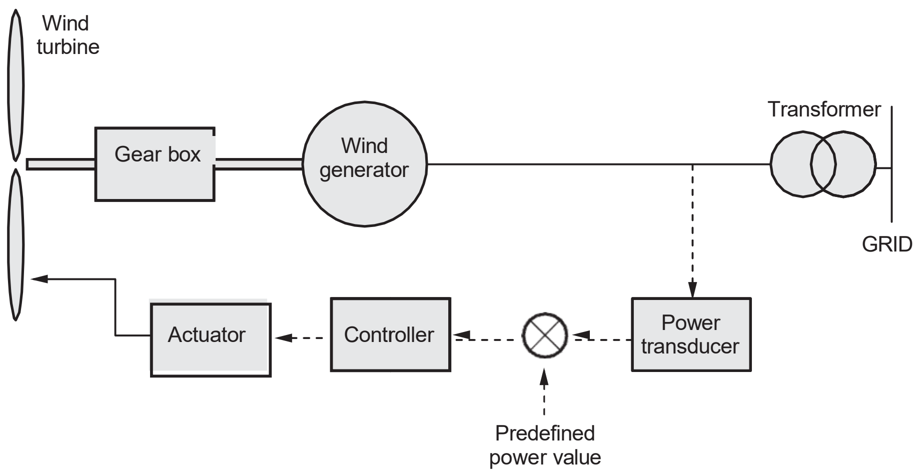


Fig. 3.12.2 pitch-controlled turbine

- First the power generated by the wind turbine is measured and is compared with the predefined power value.
- The error signal then is passed to the controller which finally controls the actuator to rotate the blades.

3.13 Performance of Wind Mill

- For any location with a known wind resource, there are several factors that can be used to predict electrical generation from a wind turbine.
- The most important include the power curve, the cut-in wind speed, the rated wind speed and power output, and the cut-out wind speed.

- These factors along with turbine availability all contribute to the capacity factor of a turbine.
- All of these terms are explained in more details as follows.

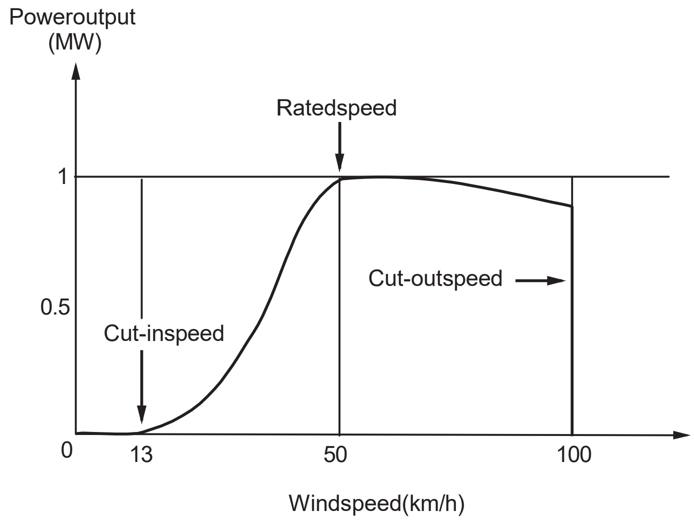


Fig. 3.13.1

1. Cut in wind speed :

- The lowest wind speed at which the turbine will generate power is called the cut-in wind speed.
- Although at face value this parameter should be clear, there are several nuances.
- Because of the mass of the rotor, a spinning turbine will produce power at a lower wind speed than a turbine starting from a standstill.
- If the power curve is calculated based on the properties of the turbine, the cut-in wind speed tends to be lower, as it does not account for the rotational mass of the rotor.
- A low cut-in wind speed is generally desired, since this translates to more time when the turbine is producing at least some power.

2. Design wind speed :

- It is the speed at when the windmill reaches its maximum efficiency.

3. The rated wind speed :

- It is the speed at when the machine reaches its maximum output power.
- The output of most machines level off above the rated speed.
- However, typically rated speed about 15 m/s (54 Km / hr, 34 mph) which is about double the expected average speed of the wind.

4.Cut-outwindspeed:

- When the wind speed becomes very high, the energy contained in the airflow and the structural loads on the turbine becomes too high and the turbine is taken out of service (between 17 and 30 m/s).
- It is the maximum wind speed at which the turbine is allowed to deliver power and is normally limited by loads and safety constraints.
- In addition to mechanical or electrical brakes, the turbines may be slowed down by stalling or furling.

i) Stalling :

- Wind turbine stalling works by increasing the angle at which the relative wind strikes the blades (angle of attack), and it reduces the induced drag (drag associated with lift).
- Stalling is simple because it can be made to happen passively (it increases automatically when the winds speed up), but it increases the cross-section of the blade face-on to the wind, and thus the ordinary drag.
- A fully stalled turbine blade, when stopped, has the flat side of the blade facing directly into the wind.

ii) Furling

- Furling is the process of forcing, either manually or automatically, the blades of a wind turbine out of the direction of the wind in order to stop the blades from turning.
- Furling works by decreasing the angle of attack, which reduces the induced drag from the lift of the rotor, as well as the cross-section.
- One major problem in designing wind turbines is getting the blades to stall or furl quickly enough should a gust of wind cause sudden acceleration.
- A fully furled turbine blade, when stopped, has the edge of the blade facing into the wind.

iii) Survival Or Maximum Wind Speed

- The survival wind speed is the maximum wind speed that the wind turbine is designed to withstand safely.
- Most wind turbines have a specified survival wind speed of 50 m/s - 65 m/s (112 mph - 145 mph), and in many cases this value is regulated by national standards.

- Wind turbines can also be specified to havehighersurvivalwindspeedsfor installations in unusual or special environments.
- The survival wind speed is really more of insurance or a safety consideration, as wind turbines typically do not suffer any damage from winds higher than the stated survival speeds.

3.14 Types of Wind Energy Systems / Power Plants

1. Remote Wind Power Plants

- Areas which are remote but are blessed with good wind speeds and frequency need a wind turbine which is maintenance free or low-maintenance for long periods of time.
- This means that they should have the capability of standing against all odds of climate even if they are relatively smaller in size than their conventional counterparts.
- These types of turbines are known as remote wind power turbines and are specifically designed with these objectives in view.

2. Small scale or Stand-alone wind turbines plants :

- It is more suitable for small scale wind power such as domestic systems.
- The control of output is very important for efficient cost effective systems.
- Fig. 3.14.1 shows the components and its arrangement for small scale domestic wind power system.
- Stand alone; generating systems are needed to supply electrical power to remote locations where connection to the grid is either not possible or inconvenient or to provide a power back up in case of unreliable supplies from the power utility.
- Simpler, dedicated power units are needed for applications such as pumping water, electric fences, traffic signals, navigational aids, Cathodic Protection (CP) to prevent corrosion in oil, gas and chemical installations, remote monitoring and portable systems for recreational and emergency vehicles.
- Many of these very small systems are designed to run on DC rather than alternating current and do not require expensive inverters and control systems.

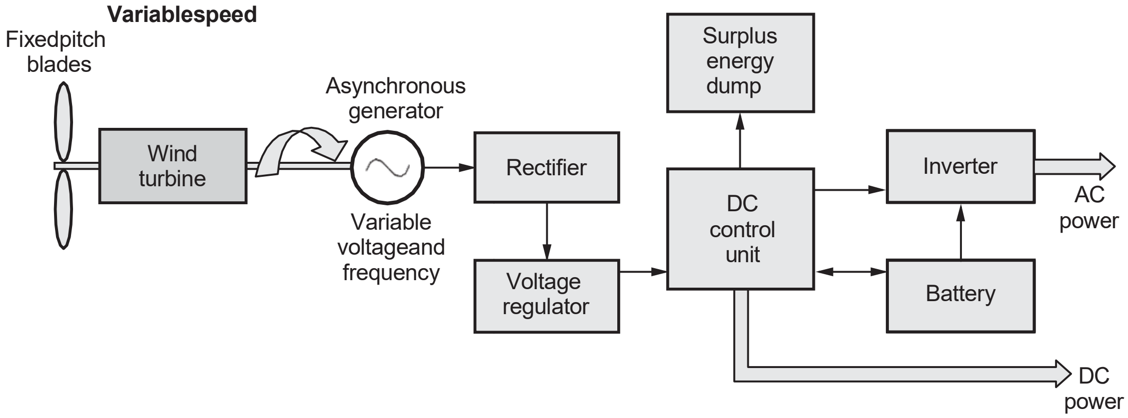


Fig.3.14.1Small scale wind power (Domestic systems)

3. Medium scale wind turbines plants :

- Medium scale wind power plants are used in multiplicity of places like community center, health clinic or school.
- The basic aspire of the wind, turbine is to be diesel saver.
- The diesel generator provides power in windless periods.
- A reasonable amount of diesel fuel could to saved with a control strategy and system architecture which allows in shutting down the diesel generator when the wind is sufficient to carry the load.

4. Hybrid Wind Power Plants

- Wind is not fully reliable so we cannot depend on wind alone for generation of power.
- The best bet would be to combine a wind power plant with some other renewable source of energy, like solar energy.
- That would be certainly a better idea and you can imagine that when there is a lot of heat, the solar generators would do their job and when the sky is overcast and winds are blowing, the wind power plants would take over.
- Such an arrangement is known as hybrid arrangement and is useful in regions where there is a lot of heat and wind.

5. Grid Connected Wind Power Plants

- This concept is similar to a hybrid system.
- The wind power plant is used in conjunction with a main grid which supplies most of the power.

- The main purpose of the wind turbines is to supplement the energy supply forthe grid, whereas the main function in the hybrid system is to complement the energy supply, hence the minor difference in the set up

6. Wind Farms

- Unity is strength : a group of people could perform a much bigger task than an individual. This is the concept underlying the wind farms.
- As the name itself suggests, a wind farm is a collection of wind turbines which collectively power a given area or utility harnessing the wind force in a collective manner thereby amplifying the effect of a single unit.

3.15 Wind Pump

- Water pumping is one of the important applications of wind energy.
- A water-pumping windmill pumps water from wells, ponds, and bore wells for drinking, minor irrigation, salt farming, fish farming, etc.
- The most widely used type of wind pump is constructed of a steel, multi-bladed high solidity fan-like rotor that drives a reciprocating pump linkage usually via a reduction gearing that is directly connected with a piston pump located in a borehole directly under it.
- The design of wind turbines for water pumping is relatively simple compared to electricity-generating turbines.
- The mechanical power at the rotor shaft is used directly to drive a pumping device. Turbines with high starting torque are suitable for pumping and this requires high solidity rotors operating at a low tip ratio of 2 or less.
- The most prevalent wind turbines for water pumping are of the horizontal-axis type and typically have rotors blades usually made from curved sheet metal and need not be of a complex aerofoil section.
- The important components of a wind pump are as follows :

(i) Rotor : This can vary widely in both size and design. Diameters range from less than 2 m to 7 in. The number of blades can vary from 6 to 24. A rotor with more blades runs slower but is able to pump with more force.

(ii) Tail : This keeps the rotor pointing into the wind like a weather vane. The whole top assembly pivots on the top of the tower. It allows the rotor to face in any direction.

(iii) Transmission system : This turns the rotation of the rotor into reciprocating motion (up and down) in the pump rod. Normal types use a gearbox or are direct drive. In direct drive, the pump rod moves up and down once for each turn of the rotor.

(iv) Pump rod : This transmits the motion from the transmission at the top of the tower to the pump at the bottom of the well. The motion of the pump rod is reciprocating (up and down) and the distance it travels (called the stroke) is typically of about 30 cm, depending on the pump. It is usually made of steel.

(v) Pump : This is normally submerged below the water level on the downward stroke, the cylinder is filled with water and on the upward stroke, the water is lifted by the piston up the drop pipe. The pump hangs on the drop pipe.

(vi) Drop pipe : This is the pipe through which the water is pumped and also encloses the pump rod.

(vii) Well : The source of water pumped by the wind pump.

(viii) This is normally galvanized steel with three or four legs. Its height varies from 5 m to 20 m. The bases of the legs are fixed, often bolted, to a concrete foundation.

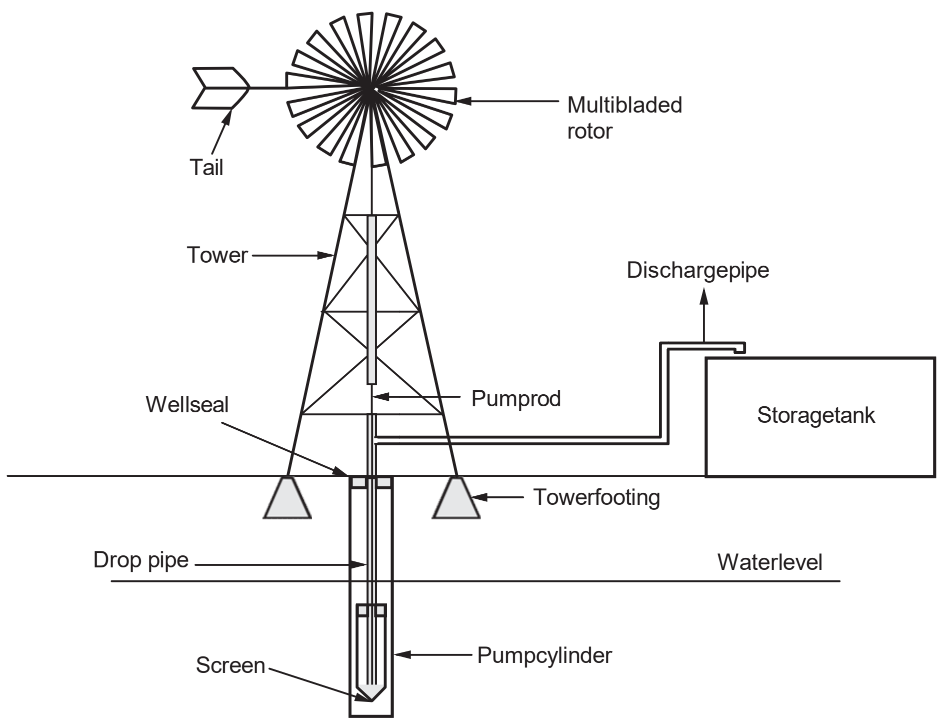


Fig. 3.15.1 Schematic of a wind pump and its components

3.16 Wind Energy Potential and Site Selection

- The selection of sites for wind farm development is not simply a matter of taking boxes on a list of desirable features.
- As with most things in life it is a matter of compromise and a cost benefit analysis of positive features against negative ones.
- The criteria include various parameters and exclusion factors such as : wind speed information, elevation, slope, highways and railways, built up area, forest zone and scenic area.
- On the other hand, offshore wind farms are different from onshore wind farms in many respects and so the usual ways of thinking about the electrical aspects may not be appropriate.
- Clearly costs will be higher than on land.
- However, reliability and availability are also much more important, because faults may be more frequent and could take much longer to locate and repair.
- Unlike onshore public transmission and distribution networks, the relatively low capacity factors are likely to make full redundancy uneconomic.
- The restricted space and high cost of support structures offshore conflict with the need for additional switchgear to isolate faulty equipment.
- Within the offshore wind farm, the regular array may produce electrical system configurations different from the radial system typical of onshore wind farms.
- The wind farm monitoring or SCADA system also needs to be reconsidered.
- The main characteristics offshore are :
- The site selected for wind farm development need to have many positive attributes including :

  a. Superior wind speed

  b. Good road access to sites

  c. Suitable terrain and geology for onsite access

  d. Low population density

  e. Minimum risk of agro-forestry operations

  f. Close to suitable electrical grid

  g. Supportive land holders

  h. Significant tourism infrastructure in place

i. Privately owned free hold land

j. Good industrial support for construction and ongoing operations

k. Land use is primarily for grazing and cropping

l. Significant potential for revalidation.

3.17 Site Selection Consideration

1. Visual impact

- Wind turbines are located in windy places, and most of the time, those places are highly visible.
- To many people, those big towers with 2 or 3 blades create visual pollution.
- To minimize the impacts of visual pollution, many investors implement the actions.

2. Wild life and endangered species

- Wind farms affect birds mainly through collision with turbines and associated power lines, disturbance leading to displacement including barriers to movement, and loss of habitat resulting from wind turbines.
- To minimise the risk of bird collision, site selection should be done precisely.

3. Electromagnetic interference

- Electromagnetic interference is an electromagnetic disturbance that interrupts, obstructs, or degrades the effective performance of electronics or electrical equipment.
- Wind turbines may reflect, scatter or diffract the electromagnetic waves which in turn interfere with the original signal arriving at the receiver.

4. Noise impact

- Noise can generally be classified according to its two main sources : aerodynamic and mechanical. Aerodynamic noise is produced when the turbine blades interact with eddies caused by atmospheric turbulence. Mechanical noise is generated by the rotor machinery such as the gearbox and generator. Noise could be reduced by better designed turbine blade geometry and by selection of proper operating conditions.

5. Social Considerations

- Social factors that affect the selection of a site include public acceptance, distance from residential area and alternative land use options of candidate wind farm site. Public may oppose projects because of possible environmental or social effects. Distance from residential area gain importance not to interfere with social life during wind farm construction or operation.

6. Regulatory boundaries

- There may be some national or international level regulation related with the construction and operation of wind farms. These regulations must be explored before evaluating the socio-political position of a wind farm project. Most of them probably change from region to region.

7. Public acceptance

- Public is the most vital component of a region and their opposition to issues can lead to abolish proposed projects.
- Support of public for wind energy generation is expected to be high in general but proposed wind farms have often been met with strong local opposition.

8. Land use

- Land use affects the decision of wind farm siting from two points of view.
- Firstly, there are some cases where no wind farms can be built although sufficient wind speed was detected.
- These cases are mainly related with land use or condition.
- Land related constraints include forest area, Wetlands, Land of high productivity, Archaeological sites, Aviation zones, Military zones etc.

9. Distance from the residential area

- Noise and vibration stemming from the wind turbines may cause residents to suffer from sleep disturbance, headaches, visual blurring.
- Those types of complaints can be avoided if the wind turbines are sited a considerable distance from the residential area.

3.18 WIND POWER Potential IN TAMIL NADU

- Power development is an important input for the States Industrial, Commercial and Socio economic growth.
- For this, the availability of affordable, reliable and quality power is necessary.
- Therefore, adequate provision has to be made for augmenting power supply to bridge the gap between demand and supply as well as to meet the increasing future demand.
- The 2018-19 year was a transformational one for India.
- Compared to the previous four years, thermal power installations dropped by 60 per cent to just eight GW of the net new capacity, while renewable energy installations more than doubled to a record 15.7 GW.
- Keeping this in view, Government is giving utmost importance to power sector in Tamil Nadu.
- The Government of Tamil Nadu is committed to mitigate the climate change effects by bringing out policies conducive to promote renewable energy generation in the State.
- The state is blessed with various forms of renewable energy sources viz., Wind, Solar, Biomass, Biogas, Small Hydro, etc.
- Municipal and Industrial wastes could also be useful sources of energy while ensuring safe disposal.

Renewable Energy Programme/ Systems	Cumulative Achievement (in MW)
Wind Power	8506.72
Bagasse Cogeneration	710.90
Biomass Power	265.59
Hydro	2321.90
Solar Power (SPV)	3973.98
Total	15799

Table 3.18.1 Renewable Energy Generation (Up To 31-01-2020)

Source: teda.in

- Table 3.18.1 explains that among the renewable energy sources, wind power leads with 7597.65 MW in installation in Tamil Nadu.

- The wind power gross and exploitable potential in Tamil Nadu is shown in Table 3.18.2.

Location	District	Gross Potential (MW)	Technical Potential (in MW)
Aralvaimozhi Pass-Muppandal Region	Kanya Kumari and Tirunelveli	2100	1600
Sengottah Pass-Kayathar Region	Tirunelveli and Thoothukudi	1300	700
Palghat Pass-Poolavadi Region	Coimbatore and Erode	1450	1300
Other areas		650	400
Total		**5500**	**4000**

Table 3.18.2 Wind power potential in Tamil Nadu

3.18.1 Factors Influencing Wind Power in Tamil Nadu

1. Geographical Location

- Tamil Nadu is one of the best windy sites in our country.
- It is situated at Southern most tip of India.
- It is surrounded by seas in two sides-Bay of Bengal in east and Indian Ocean in south and also Western ghats in the western border.
- The western ghats consists of small hills of low altitude but continuous.
- Thus, there is constant and high wind flow at Aralvaimozhi, Pazhavoor, Palghat and Sengottah passes.

2. South West Monsoon

- In the months of May, June and July, the sun travels to the line of Cancer.
- During summer when the sun is shining brightly over the northern hemisphere, the big land mass of Asia is intensely heated.
- The intense heating creates a low pressure area.
- The low pressure area ultimately becomes so intense that even the south-east trade wind of southern hemisphere is drawn across the equator by it.

- The rotation of earth about its own axis turned the wind assouth-west monsoon.
- The monsoon wind from the Indian Ocean and Arabian Sea causes high wind flow to Tamil Nadu.

3. North East Monsoon

- In August, September, October and November, the sun is in the line of Capricorn.
- Therefore, north-east trade wind crosses the equator and become north-east monsoon.
- During this monsoon also Tamil Nadu especially the three windy regions - Muppandal, Kayathar and Poolavadi- experiences bountiful wind flow since it is situated near the equator.

4. Nearness to Sea

- Among the three passes, Aralvaimozhi pass is just adjacent to the sea shore.
- During the day time the water gets heated quickly and becomes a low pressure area.
- The land mass does not get immediately heated.
- Therefore, the pressure is high. Wind flows from high pressure to low pressure area.
- Thus during day time, Muppandal region in this pass has a good wind flow.
- In the night, the water becomes cool quickly than the land mass.
- Thus, in the evening hours and night, wind flows from sea to this region.

5. Wind Passes in Tamil Nadu

- Nature has bestowed with three passes in Tamil Nadu namely, Aralvaimozhi pass, Sengottah pass and Palghat pass.
- These three regions serve as an entry points to good amount of wind and having a funnel effect of blowing the wind across the entire terrain.
- Kambam Pass in Dindigul District has been identified as wind potential area in the recent past.

Chapter 3
Solar Energy

1 Describe thermal energy storage system of solar energy.

2 Define solar irradiance, solar constant, extraterrestrial and terrestrial radiations. What is the standard value of solar constant?

3 Explain the depletion process of solar radiation as it passes through the atmosphere to reach at the surface of the earth.

4 Define the terms: altitude angle, incident angle, zenith angle, solar azimuth angle, latitude angle, declination angle, and hour angle.

5 Explain the construction and principle of operation of a sunshine recorder

6 Describe the working of solar thermal power plant.

7 Describe the working of central receiver or tower power plant.

8 Explain the principle of working of solar pond.

9 With the help of schematic diagram, explain the working of solar pond electric power plant

10 Write short notes on V-I characteristics on PV cell.

11 Explain the types of PV Cell.

12 Discuss the types of PV system.

UNIT - V

5 Other Renewable Energy Sources

Syllabus

Tidal energy - Wave Energy - Open and Closed OTEC Cycles - Small Hydro-Geothermal Energy - Hydrogen and Storage - Fuel Cell Systems - Hybrid Systems.

Contents

5.1 Tidal Energy

5.1.1 Introduction to Tidal Power

- **Tidal Energy** or **Tidal Power** as it is also called, is another form of hydro power that utilizes large amounts of energy within the oceans tides to generate electricity.
- A tide is created by the gravitational effect of the sun and the moon on earth, thereby causing cyclical movement of the seas, leading to the tides.
- Because the earth's tides are ultimately due to the gravitational forces between the sun, the moon and the earth, tidal energy is practically inexhaustible; thereby getting classified under renewable energy.
- Tidal power is the only technology that draws energy inherent in the orbital characteristics of the Earth-moon system, and to a lesser extent in the Earth-sun system.
- Tunnels allowing the tides to go in and out as the water flows through. Water flowing through can turn a turbine.
- It is a fairly new advancement in the area of renewable power generation, with the world's first large tidal power plant being set up in the year 1966, under the name Rance Tidal Power station in France.
- Though not widely used now, it has a good potential for future electricity generation.
- Historically, however, tidal mills have been used in Europe and America.
- Here, the water is captured in a pond or a catchment area and is allowed to strike a water wheel whose mechanical energy or power was used to mill grain.
- Tidal energy is produced from the surge and fall of the ocean tides.
- It is used in areas where the difference between the rise and fall of the tides is large.
- Tidal power generation is still in its infancy, as there are only a few commercial scale power plants in the whole world.
- In fact only 20 sites in the world have been identified for possible tidal power stations.
- The Sihwa lake tidal power plant is the largest installation in the world with a capacity of 254 MW.

5.1.2 Principle of Tide Generation

- The tides are caused by the combined attraction of sun and moon on the waters of the revolving globe.
- The effect of the moon is about 2.6 times more than that of the sun, influencing the tides of the oceans.
- Tide is a periodic rise and fall of the water level of the ocean, twice during a lunar day i.e. 24 hours 50 minutes in which the water in oceans and seas rises and falls.
- The excess of 50 minutes over the solar day results in the maximum water level, occurring at different times on different days.
- The amplitude of water level variations at different points on the earth depends on the latitude and the nature of the shore.
- The rotation of the earth causes two high tides and two low tides to occur daily at any place.
- The revolution of the moon around the earth increases the time interval between two successive high tides from 12 hours to about 12 hours and 25 minutes.
- As the moon revolution takes about 28 days, the three bodies, i.e. the sun, the moon and the earth are in alignment every two weeks at new and full moon.

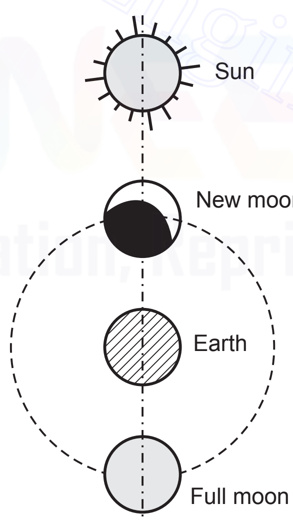


Fig. 5.1.1 Sun and moon combination act to create spring tides

- During these periods the sun and moon act in combination to produce tides of maximum range as shown.
- The solar pull comes inline with the lunar pull at 'Newton' and 'Full Moon', causing greater flow and ebb, known as spring tides.

- When the two pulls act at right angles to each other, as at waxing and waning' Half Moons', i.e.in first and third quarters, we get low tides called 'Neap Tides' as shown.

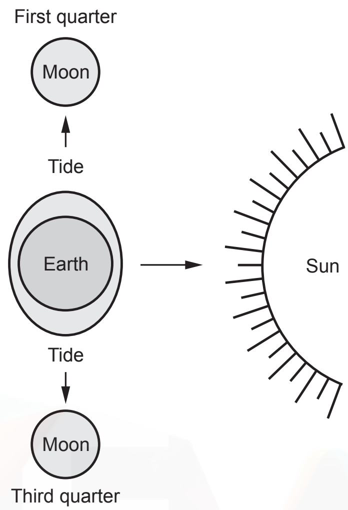


Fig. 5.1.2 Sun and moon combination act to create spring tides

- The spring tide is particularly great when the moon is 'New' and 'Full' at which time it is at the closest point of its orbit to the earth.
- The revolution of the earth and the moon together around the sun gives rise to further variation and due to this effect the highest spring tide occurs at the equinoxes in March and September.

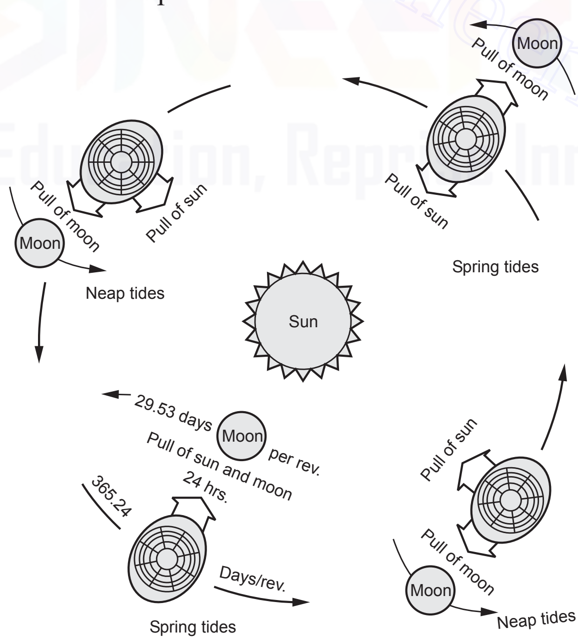


Fig. 5.1.3 Origin of tides

- A high tide is experienced at a point which is directly under the moon.
- At the same time, at a diametrically opposite point on the earth's surface, the real so occurs a high tide due to dynamic balancing of the ocean water over the globe.

  In the course of the earth's rotation the water bulges out.

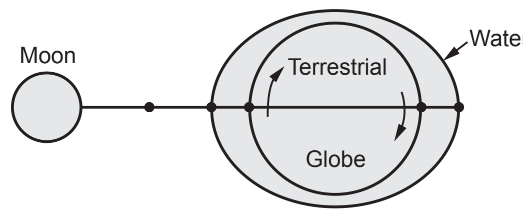


Fig. 5.1.4 Distribution of water over the earth's surface under the effect of the moon

- Tidal range is the difference in water levels between two consecutive high tides and low tides.
- The rise and fall of water level in the sea during tides can be represented by a sine curve.

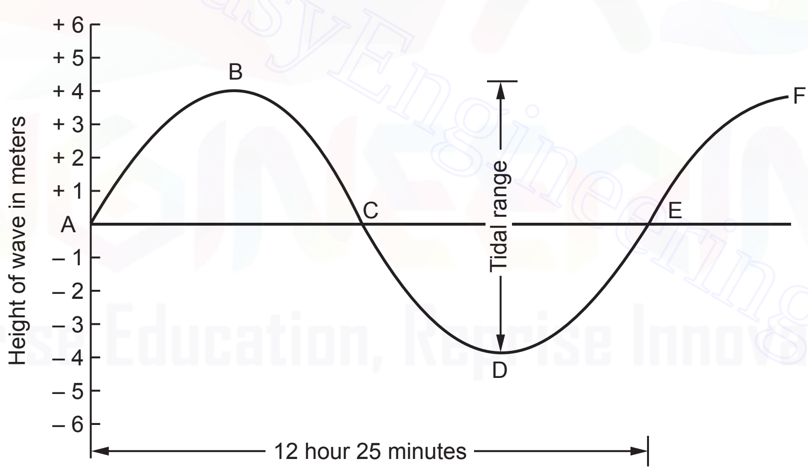


Fig. 5.1.5 Tidal range

- Point B, a position of high tide, while the point D represents a position of low tide.
- One tidal day is of 24 hours and 50 minutes and there are two tidal cycles in one tidal day.
- The normal tide is a semi-diurnal tide with a period of 12 hours and 25 minutes.
- Diurnal means daily, i.e. activities of tide pattern during 24 hours.

- Diurnal tides indicate two high and two low tides created by moon during one rotation of the earth on its axis.
- The daily tidal cycle follows a sinusoidal pattern.
- Amplitude of tidal range reduces steadily from spring tide to neap tide, and then increases with the same pattern to the next spring tides.
- This monthly cycle occurs due to one revolution of the moon around the earth. Both the tide cycles, namely the daily and the monthly cycles at a particular location repeat in a most orderly fashion and are predictable.
- The tides are caused by cosmic phenomena, and are not affected by weather conditions and yearly rains.

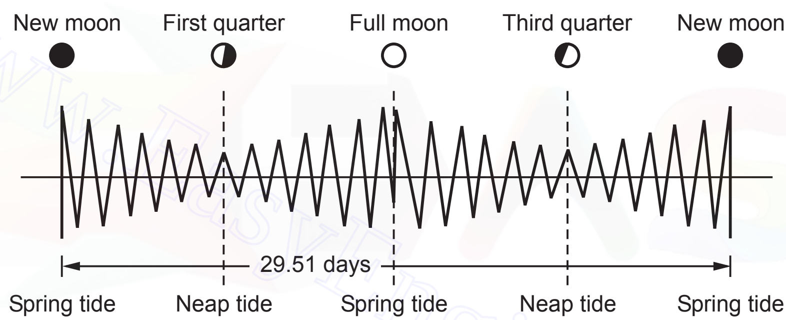


Fig. 5.1.6 Tidal variation in a lunar month

- Both the periodicity and predictability of tidal action are important characteristics which favour strongly the utilization of this phenomenon as an energy source.
- Tides at any location repeat themselves almost identically in a cycle of 19 years.
- Within any one year interval, the differences are small, and the available energy is practically the same from year to year.
- Precisely for the semi-diurnal tides, there is a relation between the tidal range and the hours of the high and low tides.
- Thus, at a particular location, the tidal range at a given time during the day shall always be within limits of the known maximum value.
- The tide range varies and depends upon the land situation against the sea.

5.1.3 Energy from Tides

- The energy of the tide wave contains two components, namely potential and kinetic.

- The potential energy is the work done in lifting the mass of water above the ocean surface.
- This energy can be calculated as :
- $E = g\rho A\int zdz = 0.5 g\rho Ah^2$

Where E - Energy,

g - Acceleration of gravity,

ρ - Seawater density, which equals its mass per unit volume,

A - Sea area under consideration,

z - Vertical coordinate of the ocean surface and

h - Tide amplitude.

- Taking an average $(g\rho) = 10.15\ Kn/m^3$ for seawater, tide cycle per square meter of ocean surface can be obtained as :

$$E = 1.4\ h^2,\ \text{W-hr}$$

Or

$$E = 5.04\ h^2,\ \text{KJ}$$

- The kinetic energy T of the water mass m is its capacity to do work by virtue of its velocity V.
- It is defined by $T = 0.5\ mV^2$.
- The total tide energy equals the sum of its potential and kinetic energy components.

5.1.4 Transformation of Tidal Energy into Electrical Energy

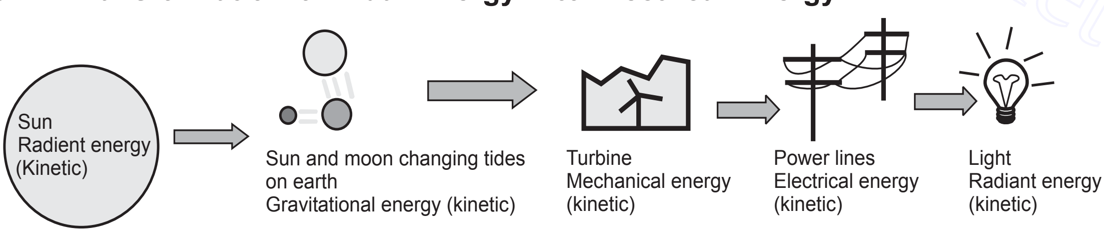


Fig. 5.1.7

- Fig. 5.1.7 shows an example of an energy transformation for tidal power.
- First, sun (radiant energy) and the moon control the tides by gravity (we didn't learn about gravitational energy but it is involved in this energy transformation).
- Because of the moon and sun, the water moves from low tide to high tide.

- When it moves, it turns a turbine (mechanical energy).
- The turbine powers a generator.
- Then we get electricity because the energy goes through power lines (electrical energy) to us so we can do things like turn on lights (radiant energy).

5.1.5 Types of Tidal Energy Technologies

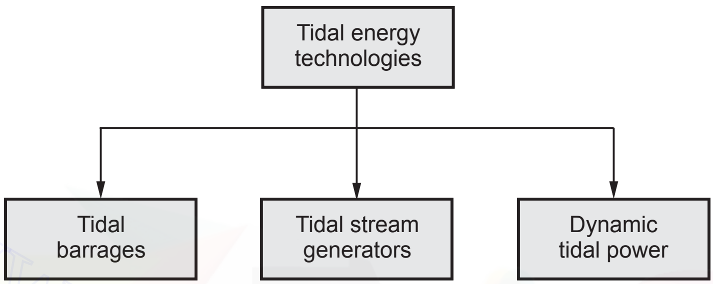


Fig. 5.1.8

1. Tidal barrage :

- Tidal barrages make use of potential energy : that is the difference in height between the high and the low of the tides.
- This energy can be seized with the placement of specialized dams on the course of flow.
- They are dam like structures that capture the energy of water moving in and out of a bay.
- They first allow the water to move in during high tide and release the water back during low tide.
- This is the key difference between a tidal barrage and a conventional dam.
- They are among the oldest methods of tidal power generation, with the Rance tidal power plant in France using the same method.

2. Tidal Stream Generator (TSG) :

- TSGs make use of the kinetic energy of the moving tides to rotate the turbines, in a similar way to wind turbines.
- Some tidal generators can be directly built into an existing bridge.
- They were first conceived in the 1970s during the oil crisis.

3. Dynamic tidal power :

- Dynamic tidal power is an untried but promising technology or method that uses both the potential as well as kinetic energy of the tides.

5.1.6 Components of Tidal Barrage Power Plants

- For utilization of tidal energy, water must be trapped at high tide behind a dam or barrage and then made to drive turbine coupled to an electric generator as it returns to sea during low tides.
- The available energy is proportional to the square of the amplitude.
- There are three main components of a tidal power plant.

1. Dam or barrage
2. Sluice-ways from the basins to the sea and vice versa.
3. Power house

- Fig 5.1.9 shows the Schematic Layout of Tidal Power House

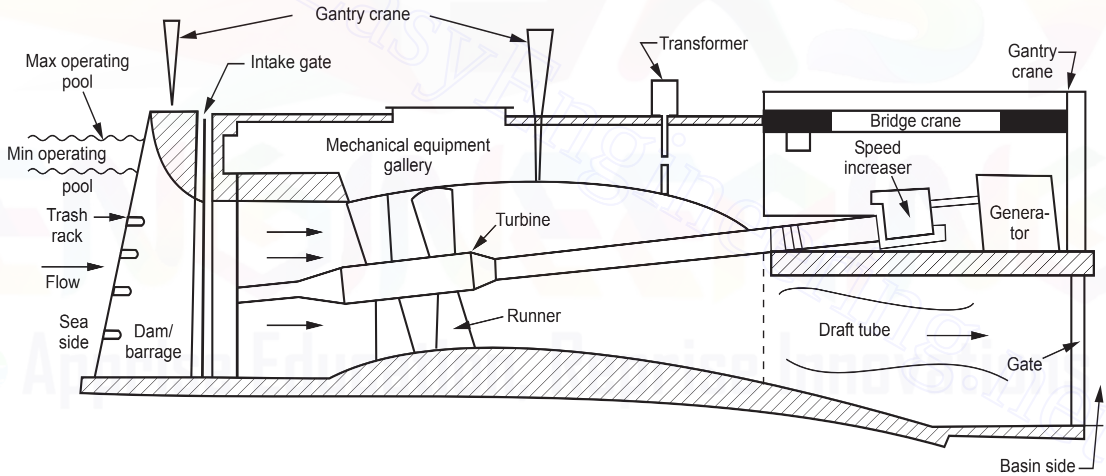


Fig 5.1.9 Schematic layout of tidal power house

1. Barrage

- Dam and barrage are synonymous terms.
- The function of dam is to form a barrier between the sea and the basin or between one basin and the other in case of multiple basins.
- Tidal power barrages have to resist waves whose shock can be severe and where pressure changes sides continuously.
- The barrage needs to provide channels for the turbines in reinforced concrete.

- The location of the barrage is important, because the energy available is related to the size of trapped basin and to the square of the tidal range.
- The nearer it is built to the mouth of bay, the larger the basin, but the smaller the tidal range.
- A balance must also be struck between increased output and increased material requirements and construction costs.
- Tidal barrages require sites where there is a sufficiently high tidal range to give a good head of water the minimum useful range are around three meters.

2. Gates and Locks

- The sluice ways are used either to fill the basin during the high tide or empty the basin during the low tide, as per operational requirement.
- Gate structures can be floated as modular units.
- Though, in existing plants, vertical lift gates have been used.
- The technology is about ready to substitute a series of flap gates.
- Flap gates are gates operated by water pressure that are positioned so as to allow water in to the holding basin and require no mechanical means of operation.
- The flap gates allow only in the direction of the sea to basin.
- Hence, the basin level rises well above to sea level as ebb flow area is far less than flood flow area.

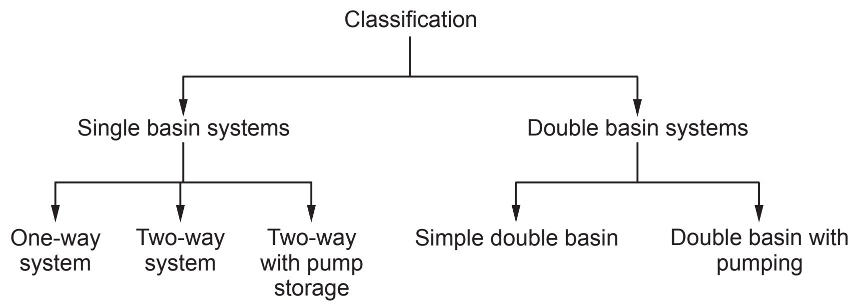
3. Power house

- The turbines, electric generators and other auxiliary equipment's are the main components of a power house.
- For small head, large size turbines are needed; hence, the power house is also a large structure.
- Both the French and Soviet operating plants use the bulb type of turbine of the propeller type, with revisable blades, bulbs have horizontal shafts coupled to a single generator.

5.1.7 Classification and Operation of Tidal Power Plant

- The tidal power plants are generally classified on the basis of the number of basins used for the power generation.
- They are further subdivided as one-way or two-way system as per the cycle of operation for power generation.

- The classification is represented with the help of a line diagram as given below.



A] Single Basin System

1. Single basin-one-way cycle

- This is the simplest form of tidal power plant.
- In this system a basin is allowed to get filled during flood tide and during the ebb tide, the water flows from the basin to the sea passing through the turbine and generates power.
- The power is available for a short duration ebb tide.

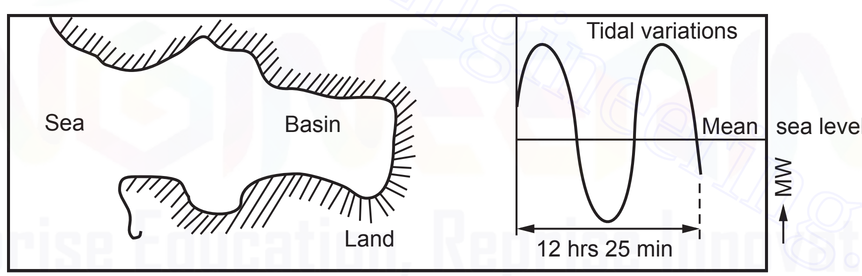


Fig. 5.1.10 (a) Tidal region before construction of the power plant and tidal variation

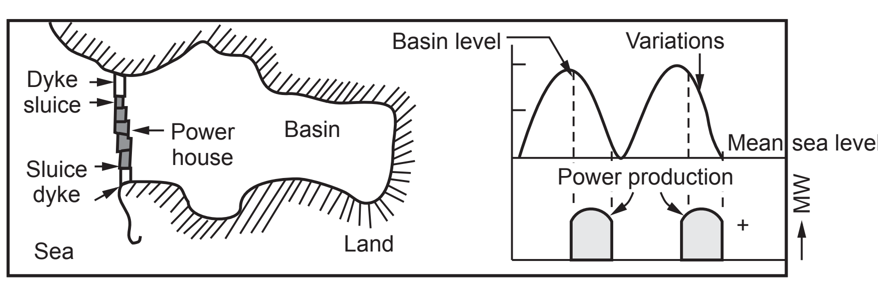


Fig. 5.1.10 (b) Single basin, one-way tidal power plant

- Fig. 5.1.10 (a) shows a single tide basin before the construction, of dam and Fig. 5.1.10 (b) shows the diagrammatic representation of a dam at the mouth of the basin and power generating during the falling tide.

2. Single-basin two-way cycle

- In this arrangement, power is generated both during flood tide as well as ebb tide also.
- The power generation is also intermittent but generation period is increased compared with one-way cycle.
- However, the peak obtained is less than the one-way cycle.
- The arrangement of the basin and the power cycle is shown in Fig. 5.1.11.

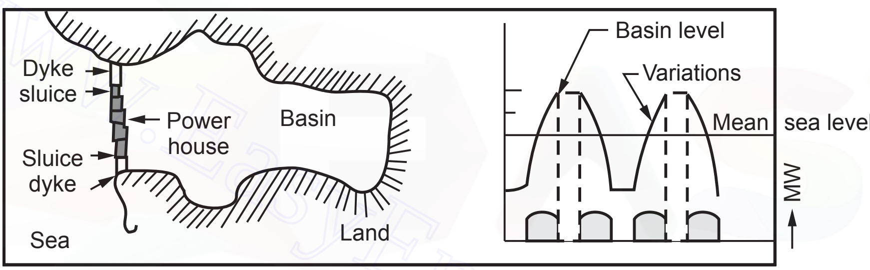


Fig. 5.1.11 Single-basin two-way tidal power plant

- The main difficulty with this arrangement, the same turbine must be used as prime mover as ebb and tide flows pass through the turbine in opposite directions.
- Variable pitch turbine and dual rotation generator are used of such scheme.

3. Single basin two-way cycle with pump storage

- In this system, power is generated both during flood and ebb tides.
- Complex machines capable of generating power and pumping the water in either directions are used.
- A part of the energy produced is used for introducing the difference in the water levels between the basin and sea at any time of the tide and this is done by pumping water into the basin up or down.
- The period of power production with this system is much longer than the other two described earlier.

- The cycle of operation is shown in Fig. 5.1.12.

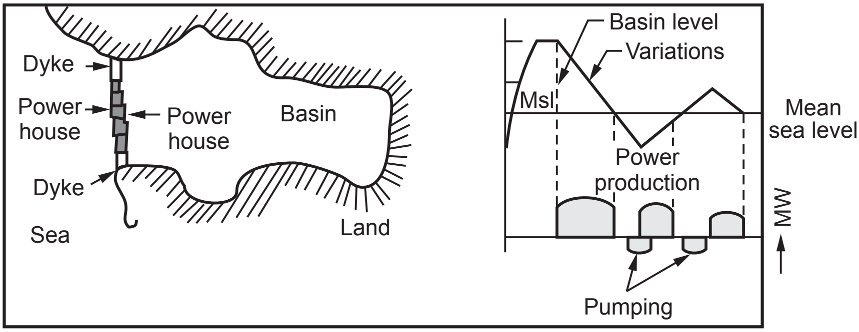


Fig. 5.1.12 Single-basin, two-way tidal plant coupled with pump storage system

B] Double Basin System

1. Simple double basin type

- In this arrangement, the turbine is set up between the basins as shown in Fig. 5.1.13.

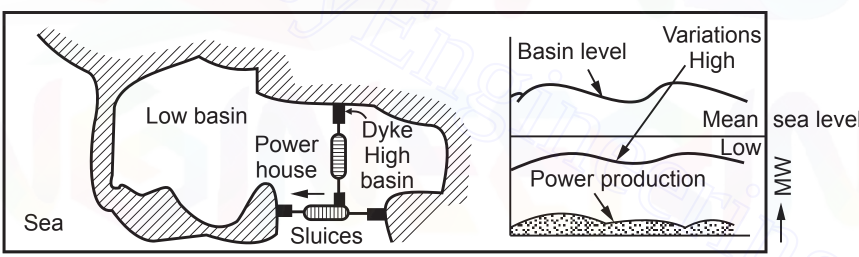


Fig. 5.1.13 Double basin, one-way tidal plant

- One basin is intermittently filled tide and other is intermittently drained by the ebb tide.
- Therefore, a small capacity but continuous power is made available with this system as shown in figure.
- The main disadvantages of this system are that 50 % of the potential energy is sacrificed in introducing the variation in the water levels of the two basins.

2. Double basin with pumping

- In this case, off peak power from the base load plant in an interconnected transmission system is used either to pump the water up the high basin.
- Net energy gain is possible with such a system if the pumping head is lower than the basin-to-basin turbine generating head.

5.1.8 Estimation of Tidal Power in Single Basis System

- Consider a basin of surface area A m^2 at the maximum basin level.
- Let R be the range of the tide and V the volume of water stored from the low level to high tide level as shown in Fig. 5.1.14.

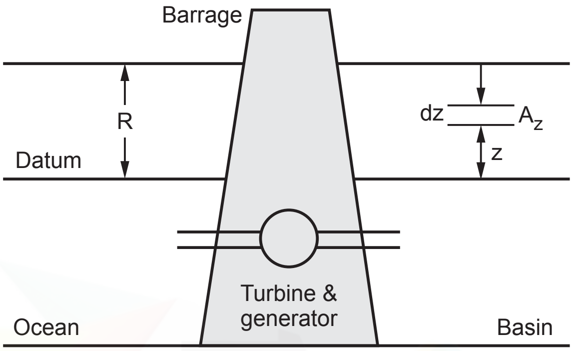


Fig. 5.1.14 Ocean with single basin tidal project

- The volume of water contained in an elemental strip of thickness dz; at surface area of A_z, at a depth z above the low tide in the basin $dV = A_z dz$.
- Assume that the basin is empty with its water level, at z = 0 and the ocean is at high tide level. i.e. z = R.
- By instantaneously filling the basin, the energy potential available is E_f. Then

$$E_f = \rho g \int_{z=0}^{z=R} z A_z dz$$

where

$$\rho = \text{Sea water density in } kg/m^3$$

$$= 1025\ kg/m^3$$

$$g = \text{Gravitational constant}$$

$$= 9.81\ m/s^2$$

For the particular case where A_z is constant and independent of z.

$$E_f = A_z \rho g \int_{z=0}^{z=R} z dz$$

$$= A\rho g \frac{R^2}{2} \qquad ...(5.11.1)$$

- The above equation provides energy conversion from a single basin type with single effect, i.e. either filling the basin or emptying the basin.
- The duration of time for single effect is 6 hours and 12.5 minutes which is equal to 22350 seconds.
- The average theoretical power P generated by the water is W in watts during a semi-diurnal tide of 6 hours and 12.5 minutes (22350 seconds)

$$\text{Average power, } P = \frac{W}{\text{Time in seconds}} = \frac{A\rho g R^2}{2 \times 22350}$$

or
$$\frac{P}{A} = \frac{1}{44700} \times 1025 \times 9.81\, R^2\ W/m^2$$

- Average power generated during one filling or emptying process = 225 AR^2 kW .... (5.11.2)

Where, A = Area of the basin in m^2

R = Range of the tide in m

- The average power is calculated based on average operating head of R/2 for a limited period in a single basin emptying operation.
- There are friction losses, conversion efficiencies of turbine and generator that reduce the power output.
- Hence, that the optimal annual energy production is only 30% of the average theoretical power calculated above.

Example 5.1.1 : *A tidal power plant of single basin type, has a basin area of $25 \times 10^6\ m^2$. The tide has a range of 10 m. The turbine however, stops operating when the head on it falls below 2 m. Calculate the energy generated in one filling process, in kWh if the turbine generator efficiency is 75 %. Take density of sea water is 1025 kg/m^2.*

Solution : Given data :

$$A = 25 \times 10^6\ m^2,\ R = 10\ m,\ r = 2\ m,\ W = ?,\ \eta = 75\%\ ,\ \rho = 1025\ kg/m^3$$

r is the head below turbine stops operating.

The average theoretical power P is

$$P_{avg} = \frac{w}{\text{Time in sec.}} = \frac{A\rho g\,(R^2 - r^2)}{2 \times 22350}$$

$$= \frac{25 \times 10^6 \times 1025 \times 9.81\,(10^2 - 2^2)}{22350}$$

$$= 539.88 \times 10^6 \text{ W}$$

$$= \frac{539.88}{1000} \times 3600 \times 10^6 \text{ kWh}$$

$$= 1943.568 \times 10^6 \text{ kWh}$$

When considering turbine generator efficiency, the energy generated.

$$= 1943.568 \times 10^6 \times 0.75$$

$\therefore$ $\boxed{W = 1457.676 \times 10^6 \text{ kWh}}$ **... Ans.**

Example 5.1.2 : *A typical tidal project has an installed capacity of 2000 MW in 50 units each of 40 MW rated output. The embankment is 6 km long and the head at rated output is 5.3 m. The turbine generator efficiency is 75 %. Assume density of sea water as 1025 kg/m³. If the generation is 4 hours twice a day, calculate i) the basin capacity and ii) the annual energy generation per year. Assuming power decreases linearly.*

Solution : Given data :

$$P_t = 2000 \text{ MW, No. of units} = 50\text{, power per unit } P = 40 \text{ MW}$$

$$L = 6 \text{ km, } h = 5.3 \text{ m, } \eta = 0.75,\ \rho = 1025\,\text{kg/m}^3,$$

$$t = 4 \times 2 = 8\text{h} = 8 \times 3600 \text{ seconds.}$$

i) The basin capacity, V :

Power per unit, $P = \eta \times P_{avg.} = \eta \times \frac{1}{2}\frac{\rho V g h}{t}$

$\because$ Water power $= \rho g Q h = \rho g\,(V/t)\,h$. Power decreasing linearly, $P_{avg} = P/2$

$$40 \times 10^6 = 0.75 \times \frac{1}{2} \times \frac{1025 \times V \times 9.81 \times 5.3}{8 \times 3600}$$

∴ $$V = 57.64 \times 10^6 \text{ m}^3$$ ... **Ans.**

ii) Annual Power Generation :

$$= P \times \text{No. of units} \times \text{No. of hrs/day} \times 365 \text{ days/hour}$$

$$= 40 \times 50 \times 8 \times 365$$

$$= \mathbf{5840 \times 10^3} \text{ MWh/year}$$ ... **Ans.**

Example 5.1.3 : *A simple single-basin type tidal power plant has a basin area of 22 km^2. The tide has a range of 10 m. The tubines stops operation when the head on it falls below 3 m. Calculate the average power generated during one filling/emptying process in MW if the turbine-generator efficiency is 74 %. Take specific gravity of sea water as 1.025.*

Solution :

$$\text{Energy potential, } E_f = A\rho g \int_3^{10} z \, dz$$

$$= \frac{1}{2} A\rho g (10^2 - 3^2)$$

where

$$A = 22 \times 10^6 \text{ m}^2$$

$$\rho = 1025 \text{ kg/m}^3$$

$$g = 9.81 \text{ m/s}^2$$

$$\text{Average power, } P_f = \frac{W}{\text{Time}} = \frac{1}{2 \times 22350} \times 22 \times 10^6 \times 1025 \times 9.81 (10^2 - 3^2) \text{ W}$$

$$= \frac{1}{44700} \times 22 \times 1025 \times 9.81 \times 91 \text{ MW}$$

or $$P = 450.3 \text{ MW}$$

Turbine generator efficiency is 74 %.

$$\text{Thus, power output P} = 450.3 \times \frac{74}{100} \text{ MW}$$

$$= 333.22 \text{ MW}$$

Example 5.1.4 : *For a typical tidal power plant shown in Fig. 5.1.4, the basin area is 25×10^6 m^2. The tide has a range of 10 m. However, turbine stops working when the head on it falls below 2 m. Assume that density of seawater is 1,025 kg/m^2, acceleration due to gravity is 9.81 m/s^2, combined efficiency of turbine and generator is 75 %, and period of energy generation is 6 h and 12.5 min. Calculate :*
1. Work done in filling or emptying the basin.
2. Average
3. The energy generated in one filling process.

Solution :

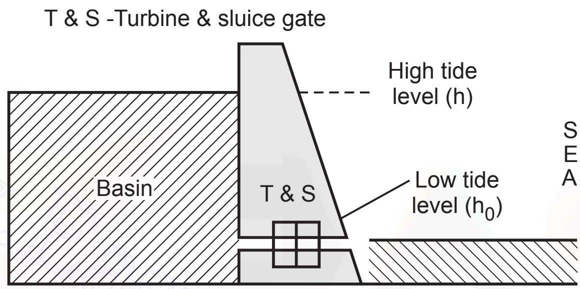


Fig. 5.1.15 Single-basin tidal plant

Total work done in filling or emptying the basin

$$W = \int \rho gAhd\,(h) = \tfrac{1}{2}\rho gA\,(h^2 - h_0{}^2)$$

$$= (1/2) \times [1{,}025 \times 9.81 \times 25 \times 10^6 \times (10^2 - 2^2)]$$

$$= 17.6 \times 10^{12}$$

2. Average power

$$P_{av} = W/t = 17.6 \times 10^{12} / 22{,}350 = 787.32 \times 10^6 \text{ W}$$

3. Energy generated

$$E = 0.75 \times 787.32 \times 106 \times 3{,}600/100 = 2.123 \times 10^9 \text{ kWh}$$

5.1.9 Problems in Tidal Power Generation

1. Environmental impact :

- Tidal Barrages cause a major disruption to the marine life on the estuary or the bay on which it is built.

- Several governments have been reluctant in recent times to grant approval for tidal barrages.
- Through research conducted on tidal plants, the tidal barrages are constructed at the mouths of estuaries pose to avoid environmental threats similar to large dams.

2. Turbidity

- Turbidity (the amount of matter in suspension in the water) decreases as a result of smaller volume of water being exchanged between the basin and the sea.
- This lets light from the sun to penetrate the water further, improving conditions for the phytoplankton.
- The changes propagate up the food chain, causing a general change in the ecosystem.

3. Tidal fences and turbines

- Tidal fences and turbines can have varying environmental impacts depending on whether or not fences and turbines are constructed with regard to the environment.
- The main environmental impact of turbines is their impact on fish. If the turbines are moving slowly enough, such as low velocities of 25-50 rpm, fish kill is minimalized and silt and other nutrients are able to flow through the structures.

4. Salinity

- As a result of less water exchange with the sea, the average salinity inside the basin decreases, also affecting the ecosystem.
- "Tidal Lagoons" do not suffer from this problem.

4. Sediment movements

- Estuaries often have high volume of sediments moving through them, from the rivers to the sea.
- The introduction of a barrage into an estuary may result in sediment accumulation within the barrage, affecting the ecosystem and also the operation of the barrage.

5. Fish

- Fish may move through sluices safely, but when these are closed, fish will seek out turbines and attempt to swim through them.
- Also, some fish will be unable to escape the water speed near a turbine and will be sucked through.

- Even with the most fish-friendly turbine design, fish mortality per pass is approximately 15 % (from pressure drop, contact with blades, cavitation, etc.).
- Alternative passage technologies (fish ladders, fish lifts, fish escalators etc.) have so far failed to solve this problem for tidal barrages, either offering extremely expensive solutions, or ones which are used by a small fraction of fish only.

5.1.10 Site Requirements for Tidal Power Plant

- The following are the main site requirements for tidal energy generation :

1. **Tidal Range :**
   - Tidal range is the vertical difference in height between consecutive high and low waters over a tidal cycle.
   - The range of the tide varies between locations and also varies over a range of time scales.
   - A favourable site for a tidal power plant should then have a large tidal range about 5 m or more.
2. **Enclosed area of basin :**
   - Electrical energy is proportional to the area of the enclosed basin.
   - Therefore, site contains more enclosed basin area are preferable for tidal power plant.
3. **Geographical Features** :
   - The Geographical Features of the plant must be encloses of large areas with short dams.
   - The sluice gate of the dam should allow water to or from the basins.

5.1.11 Advantages of Tidal Power Plant

1. Tidal power is predictable.
2. Available tidal power is firm as there are no wet or dry years, no dry or wet months, no influence of summer or winter on the availability of tidal energy.
3. It is free from pollution.
4. Tidal power is inexhaustible and a renewable source of energy.
5. Tidal power plants do not require valuable land, located on sea shores.
6. Tidal power when used in combination with a thermal plant can meet effectively the load demand.
7. After the capital cost of a tidal power scheme is paid off, the cost of power generated is very low.

5.1.12 Disadvantages of Tidal Power Plant

1. Tidal power plant output varies with the variation in tidal range.
2. Tidal power supply is intermittent.
3. Capital cost of a tidal plant is not economical when compared with conventional sources of energy.
4. Silting of basins is a problem with tidal power plants.

5.2 Wave Energy

- **Wave Energy** also known as **Ocean Wave Energy,** is another type of ocean based renewable energy source that uses the power of the waves to generate electricity.
- Unlike tidal energy which uses the ebb and flow of the tides, *wave energy* uses the vertical movement of the surface water that produces tidal waves.
- Wave power converts the periodic up-and-down movement of the oceans waves into electricity by placing equipment on the surface of the oceans that captures the energy produced by the wave movement and converts this mechanical energy into electrical power.
- Wave energy is actually a concentrated form of solar power generated by the action of the wind blowing across the surface of the oceans water which can then be used as a renewable source of energy.
- As the sun rays strike the Earth's atmosphere, they warm it up.
- Differences in the temperature of the air masses around the globe cause the air to move from the hotter regions to the cooler regions, resulting in winds.
- As the wind passes over the surface of the oceans, a portion of the winds kinetic energy is transferred to the water below, generating waves.
- In fact, the ocean could be viewed as a vast storage collector of energy transferred by the sun to the oceans, with the waves carrying the transferred kinetic energy across the surface of the oceans.
- Then we can say that waves are actually a form of energy and it is this energy and not water that moves along the ocean's surface.
- These waves can travel (or "propagate") long distances across the open oceans with very little loss in energy, but as they approach the shoreline and the depth of the water becomes shallower, their speed slows down but they increase in size.
- Finally, the wave crashes onto the shoreline, releasing an enormous amount of kinetic energy which can be used for electricity production.

- A breaking wave's energy potential varies from place to place depending upon its geographic location and time of year, but the two main factors which affect the size of the wave energy are the winds strength and the uninterrupted distance over the sea that the wind can blow.
- Then we can say that "Wave Energy" is an indirect form of wind energy that causes movement of the water on the surface of the oceans and by capturing this energy the motion of the waves is converted to mechanical energy and used to drive an electricity generator.

5.2.1 Estimation of Wave Energy and Wave Power

- The characteristics of an ideal deep-water surface wave (water depth more than about half the wavelength) are shown in Fig. 5.2.1.

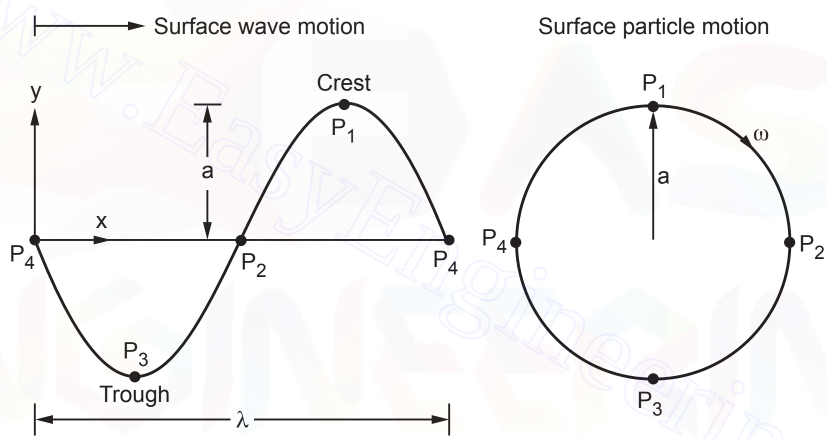


Fig. 5.2.1 Surface wave motion and surface particle motion

- The wave motion may be expressed mathematically by the following general travelling wave equation :

$$y = a \sin\left(\frac{2\pi}{\lambda} x - \frac{2\pi}{T} t\right) \quad ...(5.2.1)$$

where y = Displacement above mean sea level, m

a = Amplitude, m

λ = Wavelength, m

T = Period, s

t = Time, s

- Equation (5.2.1) can also be written as

$$y = a \sin (kx - \omega t) \qquad \text{...(5.2.2)}$$

where $k = \frac{2\pi}{\lambda}$, wave number and $\omega = \frac{2\pi}{T}$, angular frequency, rad/s

- As the wave moves in linear direction (along x-axis), every particle of water at the surface undergoes a circular motion of radius 'a' (amplitude of the wave) and angular speed ω.
- An object suspended in the water will show this type of motion.
- Viewing the vertical cross-section of the water column, the radius of circular motion of water particles continues to decreases with depth and becomes zero at sea bed as shown in Fig. 5.2.2

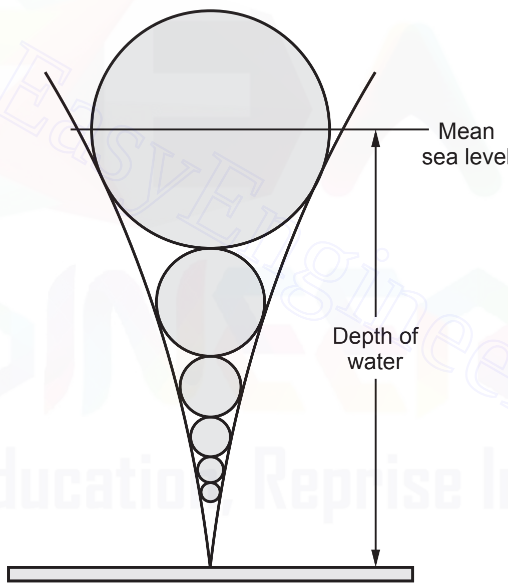


Fig. 5.2.2 Particle motion in water waves

- Thus, while the wave propagates in x-direction, there is no net flow of water.
- The wavelength of travelling wave can be shown to be :

$$\lambda = \frac{2\pi g}{\omega^2} \qquad \text{...(5.2.3)}$$

- The period of motion

$$T = \frac{2\pi}{\omega}\sqrt{\frac{2\pi\lambda}{g}} \qquad ...(5.2.4)$$

Or

$$\lambda = 1.5613\ T^2 \qquad ...(5.2.5)$$

- Linear velocity of the particle at the crest of the wave is a ω.
- The wave velocity (also known as phase velocity) in the direction x is given by:

$$v = \frac{\omega\lambda}{2\pi} = \frac{\lambda}{T} = \frac{\omega}{k} = \frac{g}{\omega} \qquad ...(5.2.6)$$

- From the above expression it is clear that the wave velocity does not depend on the amplitude of the wave.
- Now, consider unit width of wave front perpendicular to the direction of motion of wave as shown in Fig. 5.2.3.

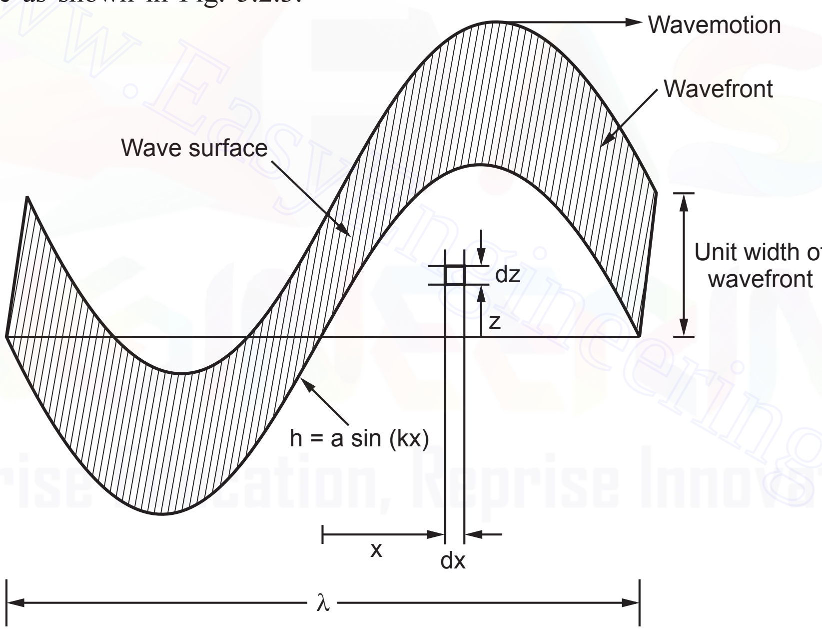


Fig. 5.2.3 Wave surface on one wave length and unit width at any instant of time

- Vertical displacement of water particles at any instant (say t = 0) is h = a sin (kx).
- Element of water mass (ρ dx dz) at distance x and height z, has moved from – z to +z and thus has potential energy of (ρ dx dz) g 2z.
- Total potential energy in one wavelength per unit width of wavefront is:

$$E_P = \int_{x=0}^{x=\lambda/2}\int_{z=0}^{z=h} (\rho dx\ dz)\ g\ 2z \qquad ...(5.2.7)$$

Or

$$E_P = \rho g \int_{x=0}^{x=\lambda/2} h^2 dx \qquad ...(5.2.8)$$

or

$$E_P = \rho g a^2 \int_{x=0}^{x=\lambda/2} \frac{(1 - \cos 2kx)}{2} dx$$

or

$$E_P = \frac{1}{4} \rho g a^2 \lambda$$

- **Potential energy** per unit length and per unit width of wave front (i.e. per unit surface area) is given by

$$E_P = \frac{1}{4} \rho g a^2 \qquad ...(5.2.9)$$

- In a harmonic motion, average kinetic and potential energy contribution are equal.
- Thus, **kinetic energy** per unit area :

$$E_K = \frac{1}{4} \rho g a^2$$

Total energy per unit surface area :

$$E = E_P + E_K$$

$$= \frac{1}{4} \rho g a^2 + \frac{1}{4} \rho g a^2$$

$$E = \frac{1}{2} \rho g a^2 \text{ J/m}^2 \text{ (or MJ/km}^2) \qquad ...(5.2.10)$$

- The power carried forward per unit width of wave front :

$$P = E u = \frac{\rho g a^2}{2} \frac{v}{2} \text{ W/m} \qquad ...(5.2.11)$$

where $u = \frac{v}{2}$ is called group velocity of deep water waves, i.e. the velocity at which the energy in the group of waves is carried forward.

5.2.2 Concept of Wave Energy Conversion

- The changes in water level due to tides or waves can cause the float to move or raise when generating linear motion from sinusoidal motion.
- The current of water runs a turbine to generate rotational mechanical energy, which drives a pump or generator.

- Slow rotation speeds of about 1 revolution per second to 1 revolution per minute do little harm to marine life.
- Turbines can reduce downstream energy and protect coastlines.

5.2.3 Wave Energy Conversion Devices

- The technologies developed to generate energy from waves and currents called hydrokinetic energy conversion devices are generally categorized as either Wave Energy Converters (WECs).

5.2.3.1 Wave Energy Conversion by Floats

- Wave motion is primarily horizontal, but the motion of water is primarily vertical.
- This latter motion is made use of by floats to obtain mechanical power.
- A large float is driven up and down by the water within relatively stationary guides. This reciprocating motion is converted to mechanical and then electric power.
- Fig. 5.2.4 shows a wave energy conversion system using floats.

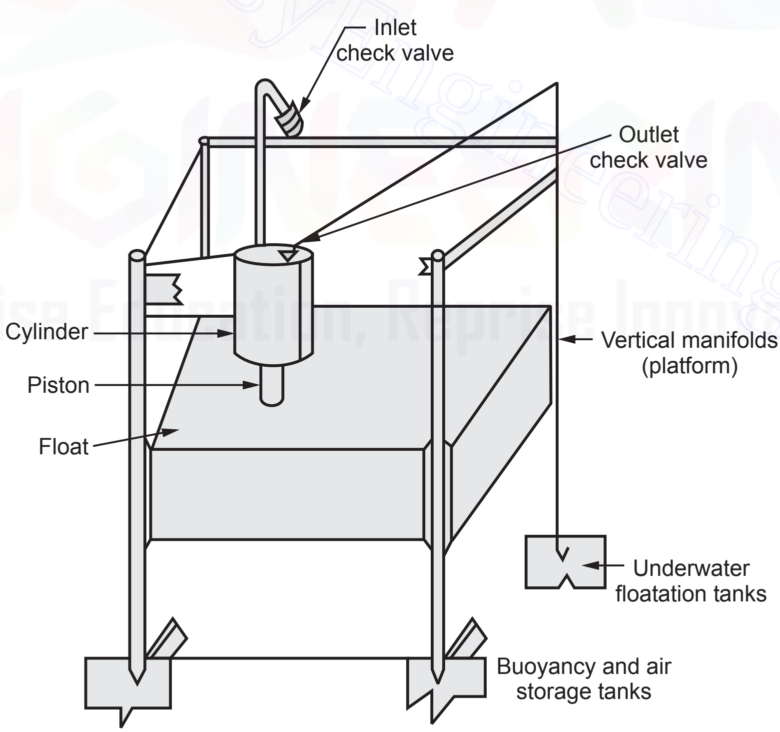


Fig. 5.2.4 Schematic of float wave-power conversion machine

- The square float moves up and down with the water, guided by four vertical manifolds that are part of a platform.
- The platform is stabilized within the water by four large underwater floatation tanks so that it is supported by buoyancy forces.
- Due to this, no significant vertical or horizontal displacement of the platform due to wave action occurs.
- Damping fins may be used to further reduce motion if necessary.
- The platform is therefore relatively stationary in space even in heavy seas.
- The platform can be made of moulded plastic with a foamed plastic core to arrive at the required density and strength.
- A piston attached to the float moves up and down inside a cylinder attached to the platform and is therefore relatively stationary.
- This piston cylinder arrangement is used as a reciprocating air compressor.
- The downward motion of the piston draws air into the cylinder via an inlet check valve.
- The upward motion compresses the air and sends it through an outlet check valve to the four underwater floatation tanks via the four manifolds.
- The four floatation tanks thus serve the dual purpose of buoyancy and air storage and the four vertical manifolds serve the dual purpose of manifolds and float guides. (Fig. 5.2.4).
- The compressed air in the buoyancy storage tanks is in turn used to drive an air turbine that drives an electrical generator.
- The electric current is transmitted to the shore via an underwater cable.

4. High Level Wave Reservoir Machine

- In these machines, instead of compressing air the water itself is pressurized and stored in a high-pressure accumulator or pumped to a high-level reservoir from which it flows through a water turbine electrical generator.
- This is done by transforming large volumes of low-pressure water at wave crest into small volumes of high-pressure water by the use of a composite piston.
- This piston is composed of a large diameter main piston and a small diameter piston at its centre.

- Fig. 5.2.5 shows a hydraulic accumulator in which the main large piston moves inside a submerged cylindrical generator while the small piston moves inside a power cylinder.

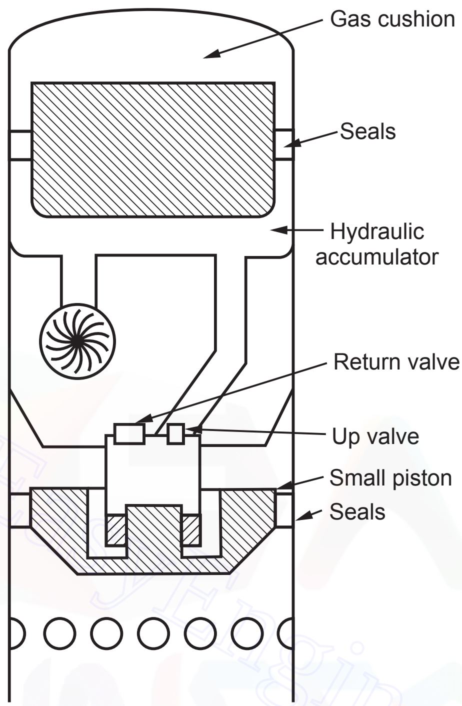


Fig. 5.2.5 High pressure accumulator wave machine

- Wave water enters and leaves through openings at the bottom hence causing the main piston to move up and down.
- A closed water loop exists above the small piston.
- On the upstroke, the pressure on the main piston is magnified on the small piston by the inverse ratio of the square of their diameters.
- The high-pressure water is passed through a one-way up valve to a hydraulic accumulator at the top of the generator.
- Two air (or other gas) volumes in the accumulator counterbalance and act as cushions in a chamber above the main piston and in a sealed compartment of the hydraulic accumulator.
- The latter also maintains high water pressure.

- Part of the high-pressure water flows through a Pelton wheel or Francis hydraulic turbine that drives an electrical generator and is then discharged to a storage chamber below the turbine.
- On the trough of the wave, the composite piston is pushed downward by the gas pressure above the main piston, which thus acts also as a spring.
- The turbine's exhaust water in the storage volume is sucked into the pump cylinder via a one-way return valve while the up valve is closed and the cycle is repeated.
- The hydraulic accumulator is large enough to permit continuous turbine operation even though the wave's arc cycle.
- Fig. 5.2.6 shows a high-level reservoir wave machine in which similar pressure magnification piston is used.
- The pressurized water is elevated to a natural reservoir above the wave generator near a shoreline or to an artificial water reservoir.
- The water in the reservoir is made to flow through a turbine back to sea level.
- A 20 m diameter generator of this type can produce 1 MW.

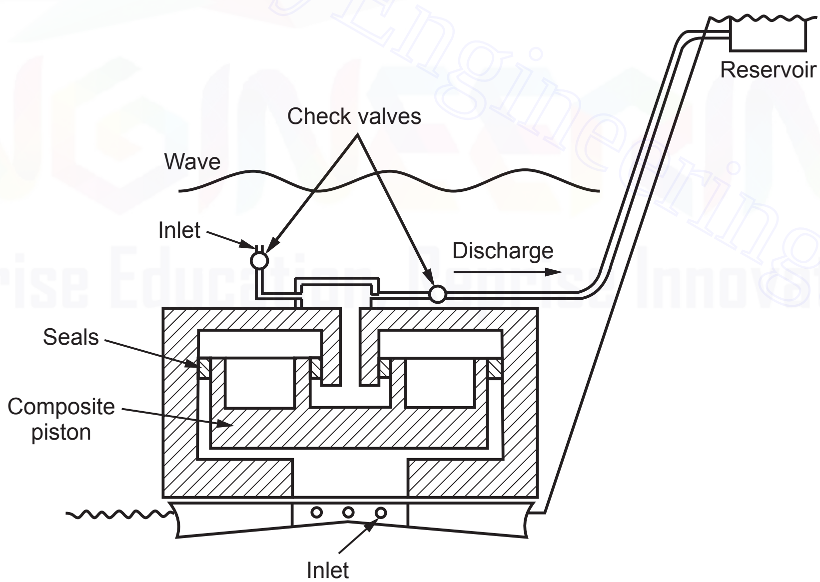


Fig. 5.2.6 High level wave reservoir machine

3. Dolphin Type Wave Power Machine

- This type of wave generator, which is designed by Tsu Research laboratories in Japan, is shown in the Fig. 5.2.7.

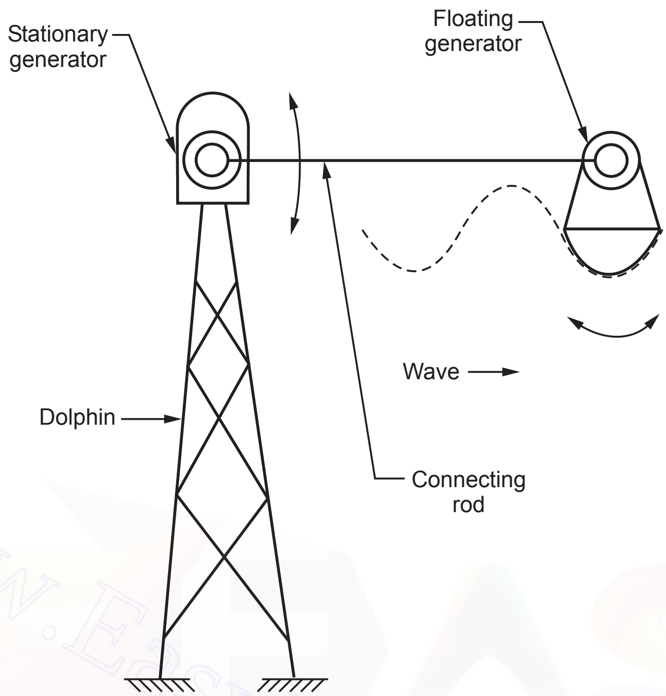


Fig. 5.2.7 Schematics of a dolphin type wave generators

- This device uses the float which has two motions.
- The first is a rolling motion about its own fulcrum with the connecting rod.
- Revolving movements are caused between the float and the connecting rod.
- The other is a nearly vertical or heaving motion about the connecting rod fulcrum.
- It causes relative revolving movements between the connecting rod and the stationary dolphin.
- In both that cases, the movements are amplified and converted by gears into continuous rotary motion that drive the two electrical generators.

4. Oscillating Type Wave Conversion Device

- The **Oscillating Water Column, (OWC)** is a popular shoreline wave energy device normally positioned onto or near to rocks or cliffs which are next to a deep sea bottom.
- They consist of a partly submerged hollow chamber fixed directly at the shoreline which converts wave energy into air pressure.

- The structure used to capture the waves energy could be a natural cave with a blow hole or a man-made chamber or duct with a wind turbine generator located at the top well above the water surface.
- Either way, the structure is built perpendicular to the waves with part of the ocean surface trapped inside the chamber which itself is open to the sea below the water line.
- The constant ebbing and flowing motion of the waves forces the trapped water inside the chamber to oscillate in the vertical up-down direction.

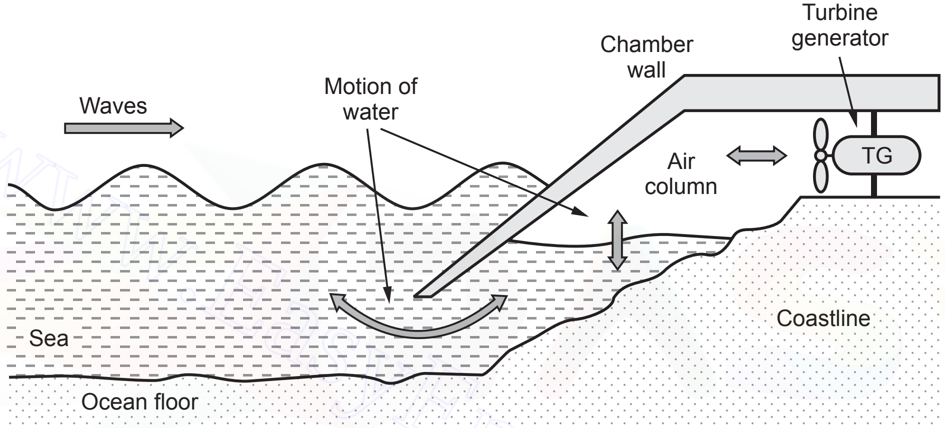


Fig. 5.2.8 Oscillating wave column

- As the incident waves outside enter and exit the chamber, changes in wave movement on the opening cause the water level within the enclosure to oscillate up and down acting like a giant piston on the air above the surface of the water, pushing it back and forth.
- This air is compressed and decompressed by this movement every cycle.
- The air is channelled through a wind turbine generator to produce electricity as shown in Fig. 5.2.8.
- The type of wind turbine generator used in an oscillating water column design is the key element to its conversion efficiency.
- The air inside the chamber is constantly reversing direction with every up-and-down movement of the sea water producing a sucking and blowing effect through the turbine.
- If a conventional turbine was used to drive the attached generator, this too would be constantly changing direction in unison with the air flow.
- To overcome this problem the type of wind turbine used in oscillating water column schemes is called a **Wells Turbine**.

- The Wells turbine has the remarkable property of rotating in the same direction regardless of the direction of air flow in the column.
- The kinetic energy is extracted from the reversing air flow by the Wells turbine and is used to drive an electrical induction generator.
- The speed of the air flow through the wells turbine can be enhanced by making the cross-sectional area of the wave turbines duct much less than that of the sea column.
- As with other wave energy converters, *oscillating wave column* technology produces no greenhouse gas emissions making it a non-polluting and renewable source of energy, created by natural transfer of wind energy through a wells turbine.

5.2.4 Environmental Impact of Wave Energy Technology

- Wave energy converters should be among the most environmentally benign of energy technologies for the following reasons :

1. They have little potential for chemical pollution. At most, they may contain some lubricating or hydraulic oil, which will be carefully sealed from the environment.
2. They have little visual impact, except where shore-mounted.
3. Noise generation is likely to be low - generally lower than the noise of crashing waves
4. They should present a small (though not insignificant) hazard to shipping.
5. They should present no difficulties to migrating fish.
6. Floating schemes are incapable of extracting more than a small fraction of the energy of storms so will not significantly influence the coastal environment. A scheme such as a new breakwater incorporating a wave energy device will provide coastal protection but may result in changes to the coastline. And concrete structures will need to be removed at the end of their operating life.
7. It is estimated that near-shore wave energy schemes will release (e.g. from, construction and material transport) some 11 g of CO_2, 0.03 g of SO_2 and 0.05 g of NOx for each kWh of electricity generated.

- This makes them very attractive in comparison to conventional coal, gas and nuclear plants.
- Thus wave energy could make a significant contribution in meeting climate change and acid rain targets.

5.2.5 Advantages and Disadvantages of Wave Energy

5.2.5.1 Advantages of Wave Energy

1. It is relatively pollution free.
2. It is a free and renewable energy source.
3. After removal of power, the waves are in placed state.
4. Wave-power devices do not require large land masses.
5. Whenever there is a large wave activity, a string of devices have to be used. The system not only produces electricity but also protects coast lines from the destructive action of large waves, minimises erosion and help create artificial harbour.

5.2.5.2 Disadvantages of Wave Energy

1. Lack of dependability.
2. Relative scarcity of accessible sites of large wave activity.
3. The construction of conversion devices is relatively complicated.
4. The devices have to withstand enormous power of stormy seas.
5. There are unfavourable economic factors such as large capital investment and costs of repair, replacement and maintenance.

5.3 Ocean Thermal Energy Conversion (OTEC)

- Oceans cover about 71 % of earth's surface.
- They receive, store and dissipate energy via several physical processes.
- As per current technological scenario, recoverable energy in oceans is present generally in the form of waves, tides and temperature difference (between surface and deep layers).
- Tides and waves produce mechanical energy whereas temperature difference produces thermal energy.
- Tidal energy technology is comparatively more developed than other two, which are still undergoing evaluation and initial development stages.
- Main disadvantages common to all of them are: (i) Low energy density, and (ii) In general the potential occurs remote from the consumption center.
- Since the diversity in physical processes involved, exploitation techniques and state of development, these are discussed in three different sections.

5.3.1 Principle of Ocean Thermal Energy Conversion (OTEC)

- The concept of Ocean Temperature Energy Conversion (OTEC) is based on the utilization of the temperature difference in a heat engine to generate power.
- In tropics, the ocean surface temperature often exceeds 25 °C, while 1 km below the temperature is usually no higher than 10 °C.
- Water density decreases with increase in temperature.
- Thus there will be no thermal convection currents between warmer, lighter water at the top and deep cooler heavier water so warm water stays at the top and the cool water stays at the bottom.
- The maximum temperature difference oil the earth is in the tropics and is about 15 ºC.
- The surface temperatures vary both with latitude and season, both being maximum in tropical, subtropical and equatorial waters i.e. between the two tropics, making these waters the most suitable for OTEC systems.
- In OTEC systems the average temperature difference may be 20 °C compared to 500 °C for modem fossil power plants.
- Taking the temperature difference of 20 °C and a surface temperature of 27 °C; the Carnot cycle efficiency would be

$$\eta_c = \frac{T_1 - T_2}{T_1} = \frac{20}{27 + 273} = 6.67\ \%$$

- The extremely low efficiency of an OTEC system implies extremely large power plant heat exchangers and components.
- There are two basic designs of OTEC system : the open cycle, also known as the Claude cycle and the closed cycle, also known as the Anderson cycle.

5.3.2 OTEC Process

i. Land-Based Power Plant :

- Land-based and near-shore facilities offer three main advantages over those located in deep water.
- Power plants constructed on or near land do not require sophisticated mooring, lengthy power cables, or the more extensive maintenance associated with open-ocean environments.
- They can be installed in sheltered areas so that they are relatively safe from storms and heavy seas.

- Electricity, desalinated water, and cold, nutrient-rich sea water could be transmitted from near-shore facilities via trestle bridges or causeways.
- In addition, land-based, or near-shore sites allow OTEC power plants to operate with related industries such as mariculture or those that need desalinated water.
- Favoured locations include those with narrow shelves (volcanic islands) steep (15-20 degrees) offshore slopes, and relatively smooth sea floors.
- These sites reduce the length of the cold-water intake pipe.
- A land-based power plant could be built well inland from the shore, offering more protection from storms, or on the beach, where the pipes would be shorter.
- In either case, easy access for construction and operation helps lower the costs.
- Land-based or near-shore sites can also support mariculture.
- Mariculture tanks or lagoons built on shore allow workers to monitor and control miniature marine environments.
- Mariculture products can be delivered to market with relative ease via standard transport (rail road's or highways).

ii. Shelf Based Power Plant :

- To avoid turbulent surf zone as well as to have closer access to the cold water resource, OTEC power plants can be mounted to the continental shelf at depths up to 100 m.
- A shelf-mounted plant could be built in a shipyard, towed to the site, and fixed to the bottom of the sea.
- Such construction is already used for offshore oil rigs.
- The additional problems of operating an OTEC plant in deep water, however, may make shelf-mounted facilities less desirable and more expensive than land-based counterparts.
- Problems with shelf-mounted plants include the stress of open- sea conditions and more difficult product delivery.
- Having to consider strong ocean currents and large waves requires additional engineering and construction expense.
- Platforms need extensive pilings to maintain a stable base for OTEC operation.
- Power delivery could also become costly due to requirement of long under water cables for reaching land.
- These reasons make the shelf-mounted plants less attractive.

iii. Floating Power Plant :

- Floating OTEC facilities could be designed to operate off-shore.
- Although potentially preferred for systems with a large power capacity, floating facilities present several difficulties.
- This type of power plant is more difficult to stabilize, and the difficulty of mooring it in very deep water may cause problems with power delivery.
- Cables attached to floating platforms are more susceptible to damage, especially during storms cables at depth exceeding 1,000 m are difficult to maintain and repair.
- Riser cables, which span the distance between the sea bed and the plant, need to be constructed to resist entanglement.
- As with shelf-mounted plants, floating plants require a stable base for continuous OTEC operation.
- Major storms and heavy seas can break the vertically suspended cold-water pipe and interrupt the intake of warm water as well.
- To reduce such problems pipes can be made of relatively flexible polyethylene attached to the bottom of the platform and gimbaled with joints or collars.
- Pipes may need to be uncoupled from the plant to prevent storm damage.
- As an alternative to a warm-water pipe, surface water can be drawn directly into the platform; however, it is necessary to prevent the intake flow from being interrupted during violent motions caused by heavy seas.
- If a floating power plant is to be connected to power delivery cables, it requires the plant to remain relatively stationary.
- Mooring is an acceptable method, but current mooring technology is limited to depths of about 2,000 metres.
- Even at shallower depths, the cost of mooring may prohibit commercial OTEC ventures.

5.3.3 OTEC Technology

- Ocean Thermal Energy Conversion (OTEC) is a technology for generating renewable energy that uses the temperature differential between the deep cold and relatively warmer surface waters of the ocean to generate baseload electricity.

- The technology is viable primarily in equatorial areas of the earth where the year round temperature differential between the deep cold and warm surface ocean waters is greater than 20 °C (36 °F).
- An OTEC facility continuously requires large volumes of both warm and cold water to generate electricity.
- There are two types of OTEC technologies as follows :

1. Open Cycle (Claude cycle, Steam cycle)
2. Closed Cycle (Anderson cycle, Vapour cycle)

5.3.3.1 Open Cycle OTEC System

- The Claude plant used an open cycle in which water itself plays the multiple role of heat source, working fluid, coolant and heat sink.
- Schematic flow and corresponding T-S diagrams of Open cycle OTEC system are shown in Fig. 5.3.1.

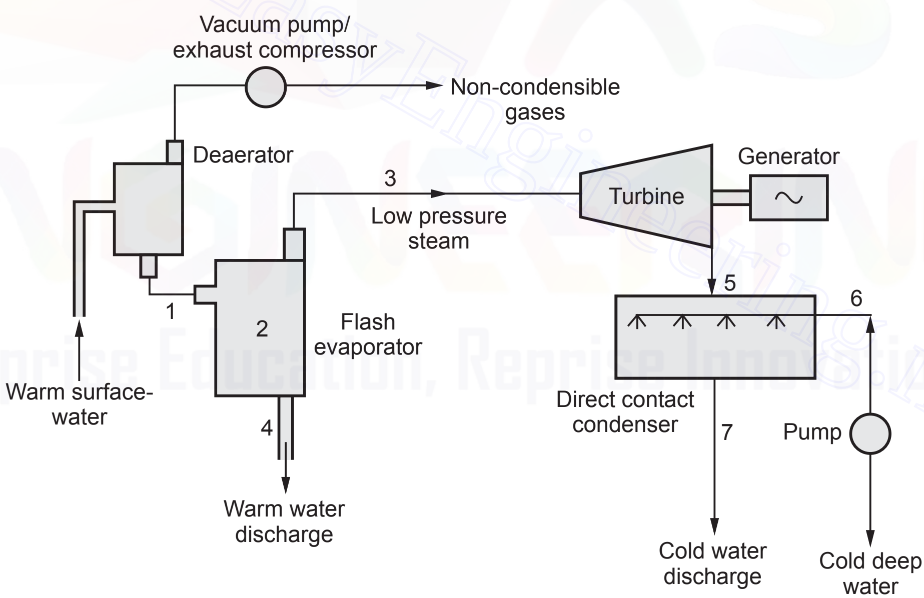


Fig. 5.3.1 (a) Schematic flow open cycle OTEC system

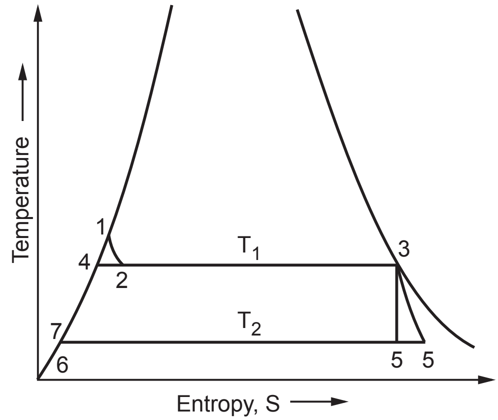


Fig. 5.3.1 (b) T-S diagrams of open cycle OTEC system

- In the cycle warm surface water admitted into an evaporator in which pressure is maintained at a value slightly below the saturation pressure corresponding to that water temperature.
- Water entering the evaporator; therefore, finds itself superheated at the new pressure.
- The warm water at 27 ºC has saturation pressure of 0.0356 bar, Point 1.
- The evaporator pressure is 0.0317 bar.
- This temporarily superheated water undergoes volume boiling causing that water to partially flash to steam to an equilibrium two phase condition at new pressure and temperature 0.0317 bar and 25 °C, point 2.
- Process 1-2 is throttling hence constant enthalpy process.
- The low pressure in the evaporator can be maintained by using vacuum pump.
- The steam is separated from the water as the saturated vapour at the point 3.
- The remaining water is saturated at 4 and is discharged as brine back to ocean.
- The quality of the steam at 3 is low pressure high specific volume.
- It expands in a specially designed turbine, condenser pressure and temperature at 5 are 0.017 bar and 15°C.
- The condenser used is direct contact type, in which the exhaust at 5 is mixed with cold water from the deep cold water pipe at 6, which results in ad near saturated water at 7.
- That Water is now discharged to ocean.

Disadvantages :

1) Volume flow rates of water required are high.
2) The special types of turbines are required.
3) The size of the turbines required is very large.
4) Use of degasifiers required to remove dissolved gases in the sea water
5) The cost of the open cycle system is more compared to closed cycle system.
6) The cost of the turbine is about half of the overall cost of power plant.

5.3.3.2 Closed Cycle OTEC System

- The closed cycle utilizes the ocean's warm surface and cold deep waters as heat source and sink, respectively, but requires separate working fluids that receives, and rejects heat to the source and sink via heat exchangers.
- Fig. 5.3.2 shows close OTEC cycle system

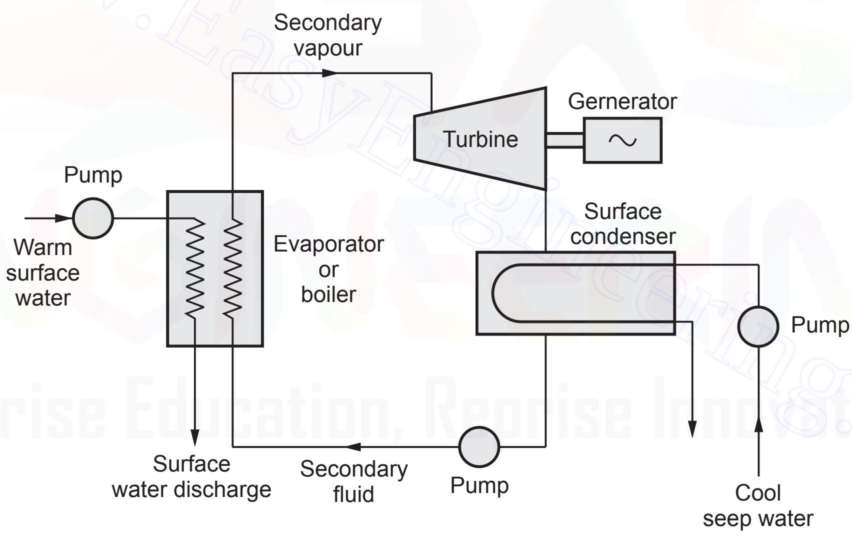


Fig. 5.3.2 Close or Anderson or-Rankine, OTEC cycle system

- The working fluid may be ammonia, propane, or Freon.
- When high pressure liquid ammonia, enters the evaporator absorbs heat from the wafer which is circulating and converted in to high pressure vapour.
- This vapour expanded in to low pressure vapour in the turbine.
- Low pressure ammonia vapour is condensed in to low pressure liquid ammonia in condenser.

- In order to remove the heat from vapour in the condenser cold water from depth of sea is used.
- Low pressure liquid ammonia is converted in to high pressure liquid ammonia using pump and supplied back in to the evaporator for repeating the cycle.
- The operating pressure is much higher compared open cycle thus smaller and hence less costly.
- But it requires very large-heat exchangers.
- Instead of usual heavier grid more expensive shell and tube heat exchangers.
- In Anderson cycle thin plate heat exchangers are used.

5.3.3.3 Hybrid Cycle OTEC System

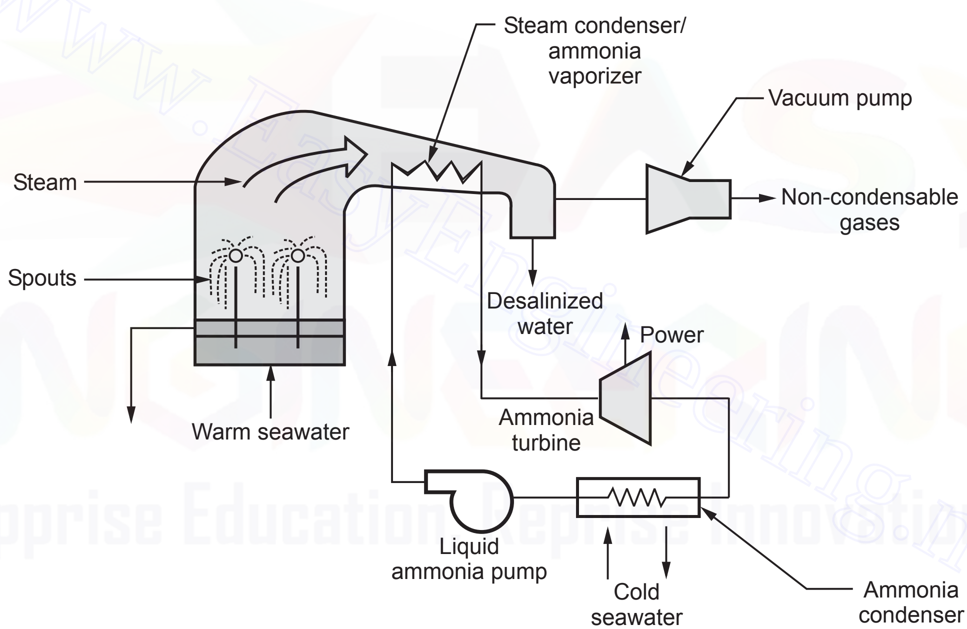


Fig. 5.3.3 Hybrid OTEC System

- A hybrid cycle combines the features of both the closed-cycle and open-cycle systems.
- In a hybrid OTEC system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, which is similar to the open-cycle evaporation process.
- The steam vaporizes the working fluid of a closed-cycle loop on the other side of an ammonia vaporizer.
- The vaporized fluid then drives a turbine that produces electricity.

- The steam condenses within the heat exchanger and provides desalinated water.
- The electricity produced by the system can be delivered to a utility grid or used to manufacture methanol, hydrogen, refined metals, ammonia and similar products.

5.3.4 Site Selection of OTEC

- During selection of a site for an OTEC system, a significant temperature difference between surface water and deep sea water is considered as an important criterion.
- The temperature difference should be at least about 20 °C for 700-900 m depth or more.
- If the temperature difference increases, the cost of generation of electricity reduces.
- The favourable sites are in the tropical belt between 20°N and 20°S latitude. Bio-fouling factor is also considered during selection of a site.
- The OTEC plant should be located offshore for having the deep colder water.
- The distance between the offshore plant and the shore should be minimum (should be less than about 30 km) to facilitate transmitting the electricity to the land by submarine cable with less cost.
- However, if the plant is required to be installed so far from the shore, a thought may have to be given to use the generated electricity at the plant site to produce energy-intensive materials, e.g. for decomposing sea water with the help of electrolysis process in producing hydrogen and oxygen.
- Particularly the produced hydrogen can be used for various purposes, e.g. as fuel or for producing ammonia for the use as fertilizer.

5.3.5 Advantages of OTEC

1. Power developed is continuous and it is independent of weather.
2. There is a small variation in power output from season to season.
3. The system uses conventional power plants needing only small changes in design.
4. It can produce simultaneously the desalinated water and nutrients for agriculture.
5. Electric power generated by OTEC could be used to produce hydrogen.
6. A floating OTEC plant can generate power even at mid sea and can be used to provide power for off shore mining and processing of manganese nodules.

5.3.6 Disadvantages of OTEC

1. Capital cost is very high.
2. Efficiency of energy conversion is very low.

3. Needs very large sized turbines due to use of low pressure of steam having high specific volume in case of open cycle.
4. It uses expensive power working fluids in case of closed cycle.
5. Cost of electric power generation per kWh is very high.

5.4 Small Scale Hydro Power

- Hydropower is a method of generating electricity that uses moving water (kinetic energy) to produce electricity.
- Small-scale hydropower has been used as a common way of generating electricity in isolated regions since end of 19^{th} century.
- Small-scale hydropower systems can be installed in small rivers, streams or in the existing water supply networks, such as drinking water or wastewater networks.
- In contrast with large-scale hydropower systems, small-scale hydropower can be installed with little or negligible environmental impact on wildlife or ecosystems, mainly because the majority of small hydropower plants are run-of-river schemes or implemented in existing water infrastructure.
- Due to its versatility, low investment costs and as a renewable energy source, small-scale hydropower is a promising option for producing sustainable, inexpensive energy in rural or developing areas.
- Particularly in rural or developing areas, small-scale hydropower can represent a locally available, reliable source of energy where no other energy generation is feasible.

Table 5.4.1 : State wise Details of identified Small Hydel sites up to 25 MW Capacity in India

Sr.No.	Name of the state	Identified Number of sites	Total capacity in MW
1.	Haryana	22	30.05
2.	Himachal Pradesh	323	1624.78
3.	Jammu and Kashmir	201	1207.27
4.	Punjab	78	65.26
5.	Rajasthan	49	27.26
6.	Uttar Pradesh and Uttaranchal	445	1472.93

7.	Gujarat	290	156.83
8.	Madhya Pradesh and Chhatisgarh	125	410.13
9.	Maharashtra	234	599.47
10.	Andhra Pradesh	286	254.63
11.	Karnataka	230	652.61
12.	Kerala	198	466.85
13.	Tamil Nadu	147	338.92
14.	Bihar and Jharkhand	171	367.97
15.	Orissa	161	156.76
16.	Sikkim	68	202.75
17.	West Bengal	145	182.62
18.	Arunachal Pradesh	492	1059.03
19.	Assam	46	118.00
20.	Manipur	96	105.63
21.	Meghalaya	98	181.50
22.	Mizoram	88	190.32
23.	Nagaland	86	181.39
24.	Tripura	8	9.85
25.	Andaman and Nicobar Islands	6	6.40
26.	Goa	3	2.60
	Total	**4096**	**10071.81**

5.4.1 Classification of Small Scale Hydro Power

- According to Central Electricity Authority and Bureau of Indian Standards, the small hydro power systems are classified depending on capacity and available head.

- The classification are as follows :

a) Depending on capacity :

Size	Unit size
Micro	upto 100 kW
Mini	101 to 1000 kW
Small	1001 to 6000 kW

b) Depending on Head :

Type	Head
Ultra low head	below 3 meters
Low head	less than 30 meters
Medium head	between 30 to 75 meters
High head	above 75 meters

5.4.2 Components of Small Scale Hydro Power

- A typical arrangement of a small hydro power plant is shown in Fig. 5.4.1 with its different components.

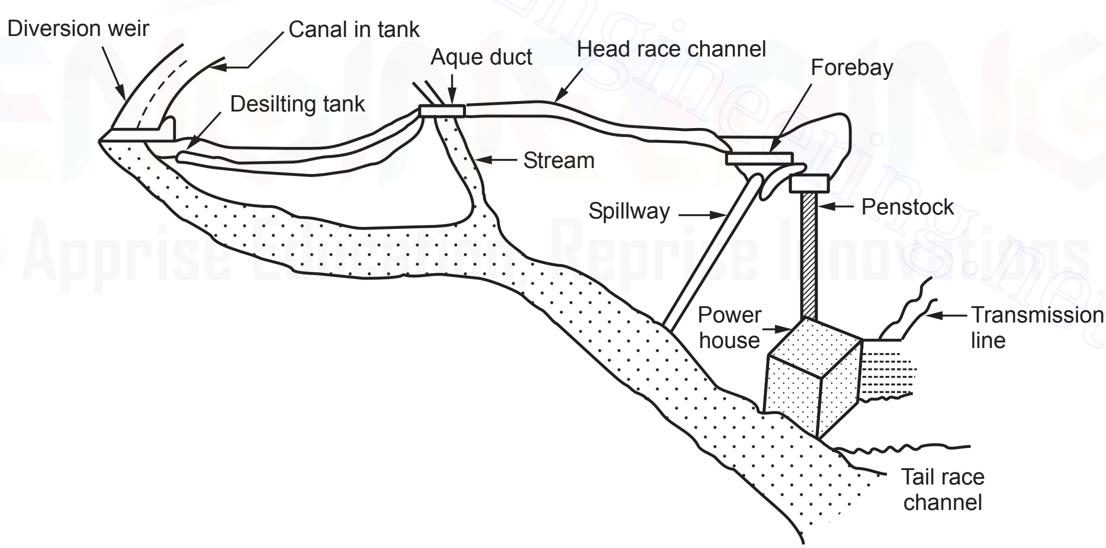


Fig. 5.4.1 Typical arrangement of a small hydro power plant

- The basic components are as
  (i) Diversion and intake
  (ii) Desilting chamber or tank

(iii) Water conductor system

(iv) Forebay/balancing reservoir

(v) Surge tank (if necessary)

(vi) Penstock

(vii) Power house comprising of turbine, generator, protection and control system, dewatering system, drainage system, auxiliary power system, grounding, emergency and stand by power system, lighting and ventilation

(viii) Tail race channel

1. Diversion System

- In hydro-electric power generation system, dam, barrages, solid boulder structure and trench type weir are used to divert the required flow from the river bed or streams to the intake structure.
- But for small hydro-electric power generating system, solid boulder structure and trench type weir are considered.
- The diversion weir should divert all the lean season flows and the structure should be safe during monsoon floods.
- Diversion structures in hill streams often face choking of intake.
- Underground structures may get damaged due to heavy boulders and bed loads.
- After all, this structure should be simple in construction and economical.
- Boulder weir is comparatively quite cheap.
- In the trench type, there will be a trapezoidal trough which will be located below the bed of the river.
- The top should be kept at the bed level of the river.
- The intake which is located at the end of the trench weir is provided with a gate to control the release of water as per requirement.
- The horizontal trash back is kept at the bed level with a slope in the downstream direction.
- It helps in tapping the water and rolling down the boulders.

2. Desilting Chamber or Tank

- Desilting chamber is required to exclude the coarser particles to achieve power without abrasion effects on the turbine and other parts.

- It is needed where the water contains large quantities of course silt, which causes erosion damage to the turbine runner etc.
- As the head increases, the abrasion effect increases.
- For medium head schemes, the desilting chamber should remove the silt of sizes typically from 0.2 to 0.5 mm, whereas for high head schemes, design of the desilting chamber will be an intricate one which should remove the silt particles of size from 0.1 to 0.2 mm.
- The typical value of depth of the tank is considered to be between 1.5 to 4 m.
- The recommended horizontal flow velocity is kept within 0.4 to 0.6 m/s to minimize the erosion damages to the turbine runner.

3. Water Conductor System

- Water conductor system should be designed to have minimum loss of head and loss of water due to seepage.
- The canal may be lined with tiles.
- The type of water conductor system depends on the site conditions and the materials available.
- Commonly trapezoidal section is used for the channel section of the water conductor system.
- Generally, LDPE (Low density poly ethylene) film liner is given on the channel to ensure minimum seepage.
- But ROT hume pipes are suitable in steep hill slope.

4. Forebay/Balancing Reservoir

- When forebay is used as a balancing reservoir, about 4 to 6 hours storage facility is to be provided.
- But when the forebay is used as a transit point, storage of about 2 minutes may be adequate.
- It is generally constructed with reinforced concrete of stone masonry.
- Forebay helps to provide a minimum head over the penstock.
- Steel Fibre Reinforced Concrete (SFRC) may also be used for forebay.
- It is having better characteristics as compared to ordinary concrete.
- But its cost is high.

5. **Surge Tank**

- Surge tank will be necessary for the water conductor conduit length of more than 5 times the head on the machine.

6. **Penstock**

- Penstock is used to feed the water to the machine through it.
- In its hydraulic design consideration, diameter of the penstock is determined by considering its economic aspect also.
- During structural design of penstock, its thickness is assessed.
- In some cases, RC hume pipes are also used for penstocks.
- Penstock can be an lsomade by SFRC.
- The materials for the penstock pipes may be mild steel and PVC depending on the design pressure.
- A bell mouth entry is preferred to ensure in reduction in head losses and a smooth entry of water from forebay tank into the penstock.

7. **Spillway**

- The presence of a spillway is important as it does not allow the water level to rise and flood the area during the load rejection of the plant.
- Its crest is kept at the permissible water level.
- The channel or pipe can be used for the spillway.

8. **Power House**

- In the power house, turbine, generator, control panels, auxiliary equipments etc. are kept.
- Therefore its building should accommodate them and it is usually constructed by RCC or stone masonry.
- Generally the height of the building is kept about 3 to 5 m.

9. **Tail Race**

- Tail race is a water channel or a cut and cover conduit.
- Through it, the water passes from the turbine outlet i.e. drafts tube to the river.
- In the tail race, generally, the allowed maximum water velocity is considered to be 1 metre/second.
- The shape of the channel is usually trapezoidal or rectangular.

- It is constructed by stone masonry or brick masonry depending on the availability of the material locally with minimum cost.

5.4.3 Advantages of Hydro Power Plant

1. No fuel charges.
2. It is highly reliable.
3. Maintenance and operation charges are very low.
4. Running cost of the plant is low.
5. The plant has no stand by losses.
6. The plant efficiency does not change with age.
7. It takes a few minutes to run and synchronise the plant.
8. Less supervising staff is required.
9. No fuel transportation problem.
10. No ash problem and atmosphere is not polluted since no smoke is produced in the plant.

5.4.4 Disadvantages of Hydro Power Plant

1. The initial cost of the plant is very high.
2. It takes considerable long time for the erection of such plants.
3. The efficiency of plant is less than the large hydro plant.
4. Quality of output is not good.

5.5 Geothermal Energy

- Geo" means earth and "therm" means heat energy i.e. geothermal energy is heat energy from the earth.
- Geothermal energy is recoverable in some form such as steam or hot water.
- The earth crust now averages about 20 to 40 km in thickness.
- Below that crust, the molten mass called magma, is still in the process of cooling.
- Earth tremors caused the magma to come close to the earth's surface in certain places and crust fissures to open up.
- The hot magma near the surface this causes active volcanoes, hot springs and geysers where water exists.
- It also causes the steam to vent through the fissures (furnaroles).

- A typical geothermal field is shown in the Fig. 5.5.1.

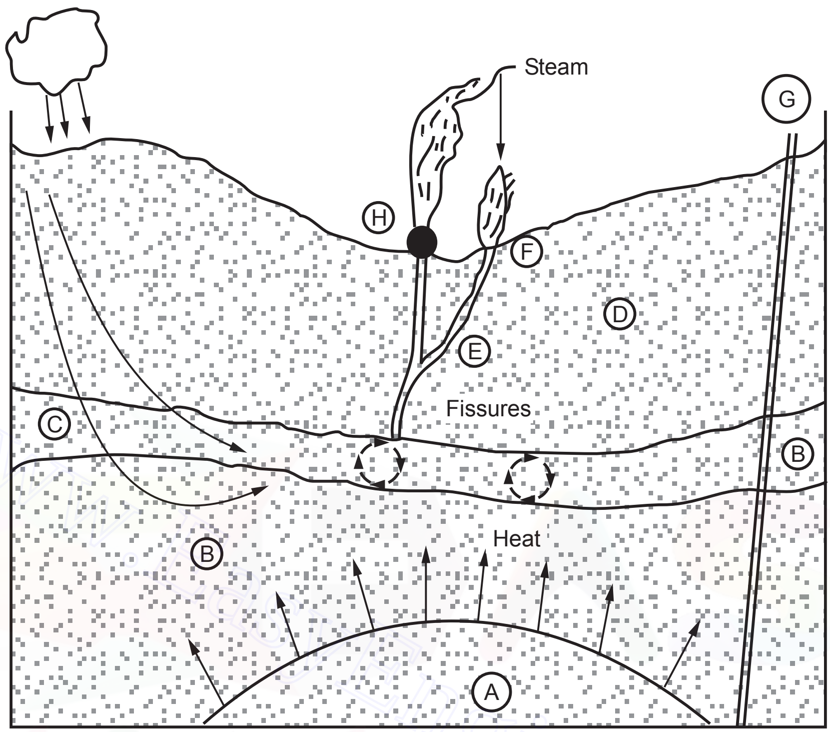


Fig. 5.5.1 Typical Geothermal field

- The hot magma near the surface (A) solidifies into igneous rock (B) The heat of the magma is conducted upward to this igneous rock.
- The ground water that finds its way down to this rock through fissures in it will be heated by the heat of the rock or by mixing with hot gases and steam emanating from the magma.
- The heated water will then rise convectively upward and into a porous and permpable reservoir C above the igneous rock.
- This reservoir is capped by a layer of impermeable solid rock D that traps the hot water in the reservoir.
- The solid rock however has fissures E that acts as vent of the giant underground boiler.
- The vents show up at the surface as geysers, fumaroles F or hot springs G.
- A well H traps steam from the fissures for use in a geothermal power plant.

- It can be seen that geothermal steam is of two kinds that originating from the magma itself, called magma tic steam and that from the ground water heated by the magma called meteoritic steam.
- The latter is the largest source of geothermal steam.

5.6 Geothermal Resources

- There are five types of geothermal resources
  1. Hydrothermal (convective) systems.
     a. Vapour dominated or dry steam system
     b. Liquid dominated or wet steam system.
        i. Liquid dominated - High temperature system (Flash System)
        ii. Liquid dominated - Low temperature system (Binary System)
     c. Hot water system
  2. Geo-pressure resources
  3. Petro-thermal or Hot dry rocks
  4. Magma resources
  5. Volcanoes

5.6.1 Hydrothermal Resources

- Hydrothermal resources occur when underground water has access to, high temperature porous rocks, capped by a layer of solid impervious rock.
- Thus, water is trapped in the underground reservoir and is heated by surrounding rocks.
- Heat is supplied by magma by upward conduction through solid rocks below the reservoir.
- Thus, it forms a giant underground boiler.
- Under high pressure, the temperature can reach as high as 350 °C.
- The hot water often escapes through fissures in the rock, thus forming hot springs or geysers.
- Sometimes steam escapes through cracks in the surface.
- These are called fumaroles.
- In order to utilize the hydrothermal energy, wells are drilled either to intercept a fissure or more commonly, into the hydrothermal reservoir as shown in Fig. 5.6.1.

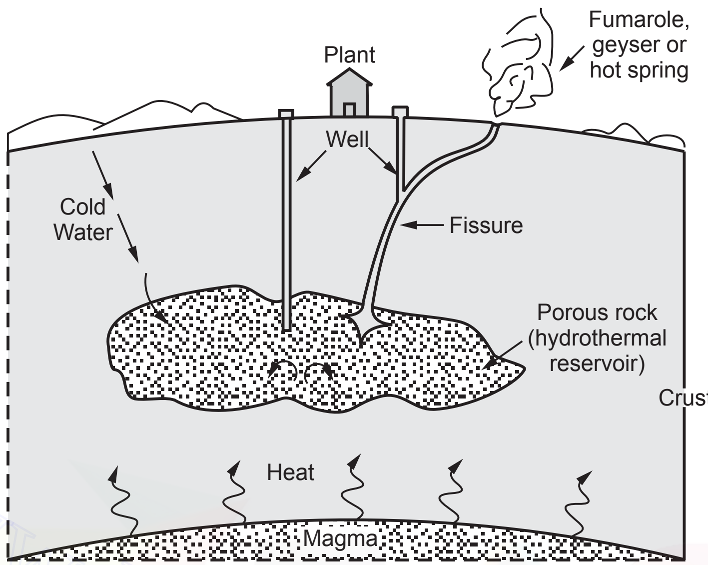


Fig. 5.6.1 Hydrothermal resources

- The hydrothermal resources are located at shallow to moderate depths (from approximately 100 m to 4500 m).
- Temperature for hydrothermal reserves used for electricity generation range from 90 °C to 350 °C but roughly two-thirds are estimated to be in the moderate temperature range (150 °C to 200 °C).

a) Vapour dominated system :

- In these systems the water is vaporized into steam that reaches the surface in a relatively dry condition at about 205 °C and rarely above 8 bar.
- This system is the most suitable for use in turboelectric power plants, with least cost.
- It does, however, suffer problems similar to those encountered by an geothermal systems namely, the presence of corrosive gases and erosive material and environmental problems.
- Vapour dominated systems, however, are a rarity.
- These systems account for about 5 percent of all geothermal sources.

Vapour dominated power plant :

- Vapour dominated geothermal system are the most developed of all geothermal system.
- They have the lowest cost and the least number of problems.

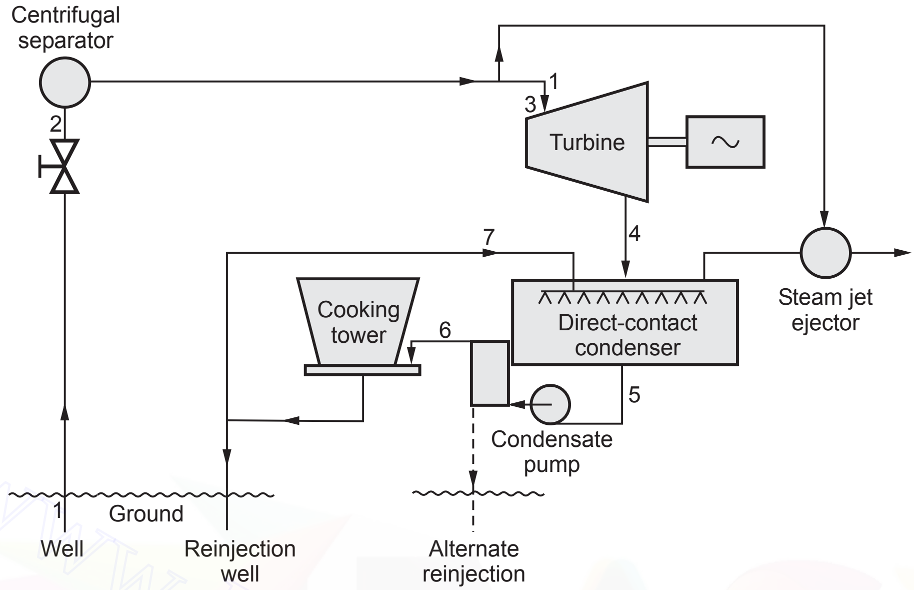


Fig. 5.6.2 Schematic of vapour dominated power plant

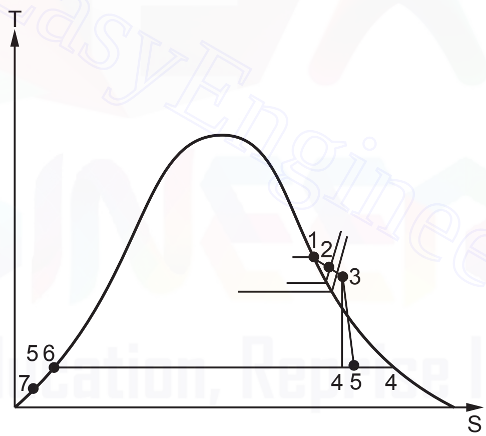


Fig. 5.6.3 T-S diagram of the cycle as shown in Fig. 5.6.2

- The vapour dominated power plant is as shown in the Fig. 5.6.2.
- Dry steam from the well (1) at 200 ºC is used.
- It is nearly saturated and may have a shut off pressure up to 35 bars.
- Pressure drops through the well causes it to slightly superheat at the well head. (2) The pressure there rarely exceeds 7 bar.
- It then goes through a centrifugal separator to remove particulate matter and then, enters the turbine after additional pressure drop.

  (3) Processes 1-2 and 2-3 are essentially throttling process with constant enthalpy.

- The steam expands through the turbine and enters the condenser at 4.
- The condenser used is of direct contact type.
- Turbine exhaust steam at 4 mixes with cooling water (7) that comes from a, cooling tower.
- The mixture of 7 and 4 is saturated water (5) that is pumped to the cooling tower (6).
- The greater part of the cooled water at 7 is recirculated to the condenser.
- The balance, which would normally be returned to the cycle in a conventional plant, is rejected in to the ground either before or after the cooling tower.
- No makeup water is necessary.

b) Liquid dominated system :

- In these systems the hot water circulating and trapped underground is at a temperature range 174 to 315 °C.
- When tapped by wells drilled in the right places and to the right depths, the water flows either naturally to the surface or is pumped up to it.
- The drop in pressure usually to 8 bar or less, causes it to partially flash to a two phase mixture of low quality liquid dominated.
- It contains relatively large concentrations of dissolved solids ranging between 3000 to 25000 ppm and sometimes higher.
- The power production is adversely affected by these solids due to formation of scaling, reducing flow and heat transfer.
- The liquid dominated systems, however are much more plentiful than vapour dominated systems.

i) Liquid dominated-high temperature system (Flash system)

- The schematic diagram of this system is as shown in the Fig. 5.6.4.
- The water from the underground reservoir at 1 reaches the well head at 2 at a lower pressure.
- Process 1-2 is essentially a constant enthalpy throttling process that results in two phase mixture of low quality at 2.
- This is further throttled in flash separator resulting in a still low but slightly higher quality at 3.

- This mixture is now separated in to dry saturated steam at 4 and saturated brine at 5.
- The latter is rejected in to the ground.
- The dry steam usually at pressure of less than 8 bar, is expanded in a turbine to 6 and mixed with cooling water in direct contact condenser with mixture at 7 is going to a cooling tower.
- The greater part of the cooled water at 7 is recirculated to the condenser.
- Remaining portion of the mixture is rejected in the ground.
- In order to improve the efficiency in splashing two stage flashing is used instead of Single stage flashing (double flash).

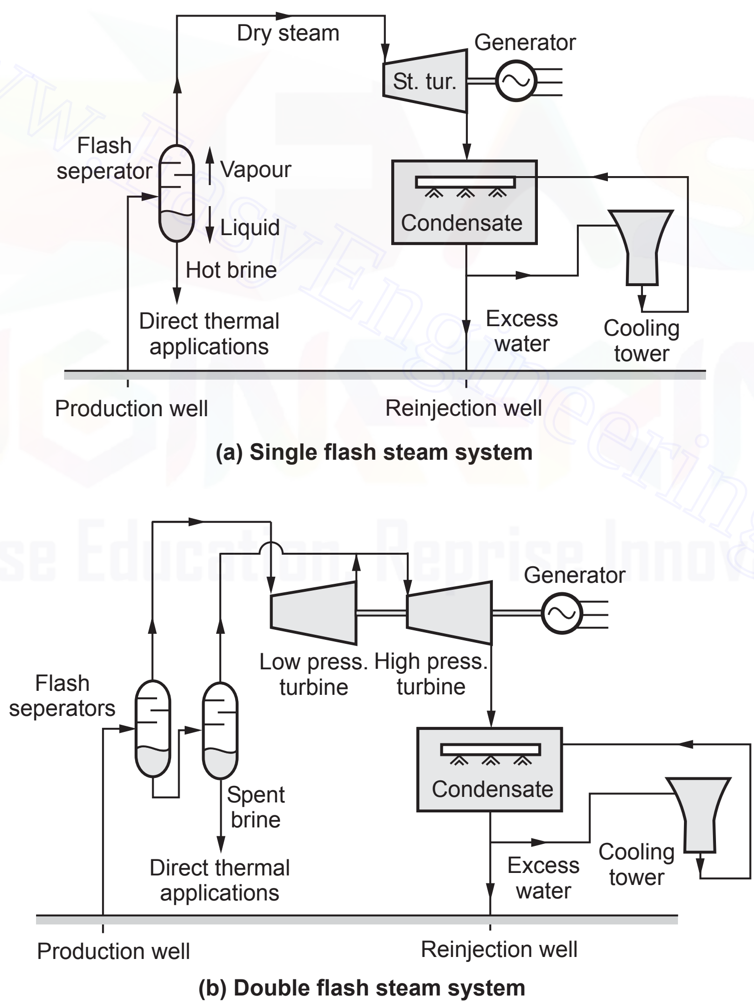


Fig. 5.6.4 Wet steam high-temperature hydrothermal system

ii. Liquid dominated - Low temperature system (Binary fluid)

- The Fig. 5.6.5 shows the schematic diagram of binary cycle system.
- Hot water or brine from the underground reservoir circulates through a heat exchanger and is pumped back to the ground.

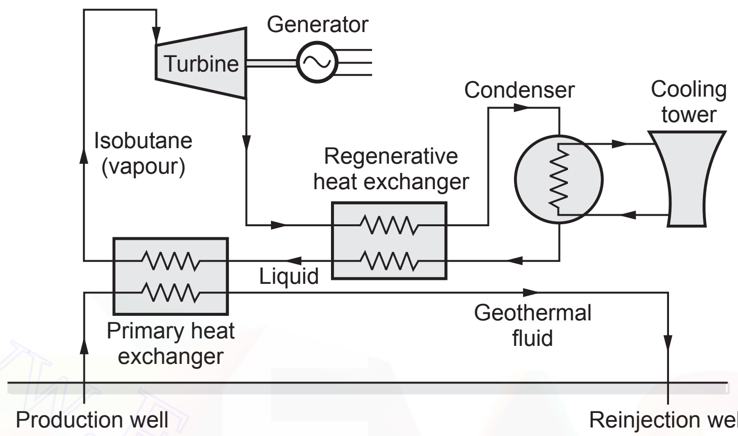


Fig. 5.6.5 Binary fluid hydrothermal system

c) Hot water system

- Hydrothermal reservoirs of low to moderate temperatures (20-150°C) can be used to provide direct heat for residential and industrial uses.
- The hot water is brought to the surface where, a heat exchanger system transfers its heat to another fluid (liquid or air); although the resource can be used directly if the salt and solid content is low.
- The geothermal fluid is reinjected into the ground after extraction of heat.
- The heated fluid transports heat to the place of use.
- Recent surveys have identified a large potential for direct use geothermal applications.
- Energy of hot water resource can also be utilized in a hybrid system consisting of geothermal-conventional thermal (fossil fuel or biomass based) system.
- In this system, hot water resource is used to preheat feed water and/or air for combustion.
- Geothermal heat replaces some or all of the feed water heaters, depending upon its temperature.
- A 30 MW, geothermal-wood waste hybrid plant is in operation at Honey Lake, California since 1989.

5.6.1.1 Comparison between Vapour Dominated and liquid Dominated

Sr.No.	Vapour dominated plants	Liquid dominated plants
1	It is simpler due to directly availability of dry steam.	It is more complex due to separation of dry steam from mixture (steam +water) available.
2	Less minerals or solids dissolved.	More minerals or solids dissolved.
3	Small environmental impact due to dry steam.	Large environmental impact due to higher content of dissolved minerals in geothermal fluids.
4	Less corrosion problem	More corrosion problem in various component of system
5	Power density is higher due to higher temperature of geothermal fluids.	Power density is less due to lower temperature of geothermal fluids.

5.6.2 Geopressured Resources

- Geopressured systems are sources of water or brine, that has been heated in a mariner similar to hydrothermal water, except that geopressured water is trapped in much deeper underground acquifers, at depth between 2400 m to 9100 m.
- This water is relatively at low temperature (160 °C) and under very high pressure of 1000 bar.
- It has relatively high salinity.
- In addition, it is saturated with natural gas, mostly methane CH_4.
- Such water is thought to have thermal and mechanical potential to generate electricity.
- Temperature, however is not high enough and the depth so great that there is tittle economic justification of drilling for this water for its thermal potential alone.
- However it is possible to generate electricity by recovering dissolved methane.

5.6.3 Petro-geothermal Resources or Hot Dry Rocks (HDR) Resources

- Hot dry rock resources are defined as heat stored in rocks within about 10 km of the surface, from which energy cannot be economically extracted by natural hot water or steam.
- Petro thermal systems are composed of hot dry rock (IIDR) but no underground water.
- They are the largest geothermal resources available.
- The rock occurring at moderate depths has very low permeability and needs to increase its heat transfer surface.
- Magma lying closes the earth's surface heats overlying rocks.
- When no ground water exists, there is simply hot, dry rock (HDR).
- The known temperatures of HDR vary between 150 to 290 °C.
- This energy is called petro thermal energy, represents by far the largest source of geothermal energy of any type.
- Much of the HDR occurs at relatively moderate depths, but it is largely impermeable.
- In order to extract thermal energy out of if, water will have to be pumped into it land back out to the surface.
- It is necessary for the heat transport mechanism that a way is found to render the impermeable rock into a permeable structure with a large heat transfer surface.
- Rendering the rock permeable is to be done by fracturing it.
- Fracturing methods that have been considered involve drilling wells into the rock and then fracturing by (1) High pressure water (2) Nuclear explosives.

1. **High pressure water method :**
   - Fracturing by high-pressure water is done by injecting water into HDR at very high pressure.
   - This water widths existing fractures and creates new ones through rock displacement.
   - This method is successfully used by the oil industry to facilitate the path of underground oil.

2. **Nuclear explosives :**

- Fracturing by nuclear explosives is scheme that has been considered as part of a program for using such explosives for peaceful uses, such as natural gas estimation and oil stimulation, creating cavities for large storage, canal and harbor construction and many other applications.
- The principal hazards associated with this are the ground shocks, the danger of radioactivity release to the environment, and the radioactive material that would surface with heated water and steam.
- Fig. 5.6.6 shows hot dry rock-binary fluid system.

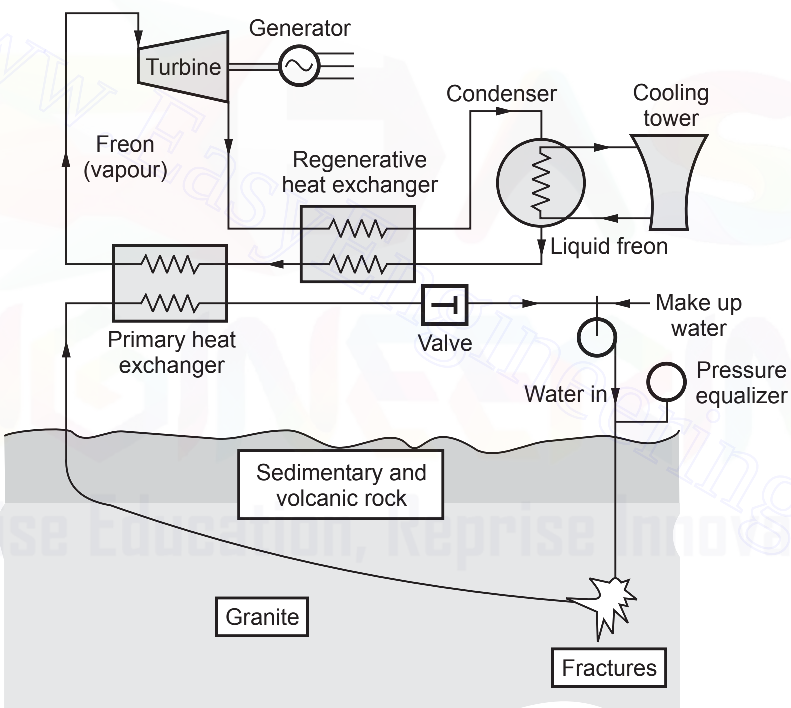


Fig. 5.6.6 Hot dry rock-binary fluid system

5.6.4 Magna Resources (Magmatic or Molten Rock Chambers Systems)

- The geothermal energy content of these resources is large, but these resources are restricted to very few locations.

- These Magma resources are made up of partially or completely / when rock at temperature greater than 650 °C and exist especially in recently active volcanic regions.
- The extraction of energy is a difficult task clue to high temperature.
- The heat extraction from hot magma at temperature of about 1450 °C is studied and, estimated that the operation of a 100 MW plant would require 400 m^2 of heat exchanger surface area at heat extraction rate of 250 kW/m^2.

5.7 Advantages and Disadvantages of Geothermal Energy over other Energy Forms

5.7.1 Advantages of Geothermal Energy

1) It is a renewable source of energy.
2) By far, it is non-polluting and environment friendly.
3) There is no wastage or generation of by-products.
4) Geothermal energy can be used directly. In ancient times, people used this source of energy for heating homes, cooking, etc.
5) Maintenance cost of geothermal power plants is very less.
6) Geothermal power plants don't occupy too much space and thus help in protecting natural environment.
7) Unlike solar energy, it is not dependent on the weather conditions.

5.7.2 Disadvantages of Geothermal Energy

1) Only few sites have the potential of Geothermal Energy.
2) Most of the sites, where geothermal energy is produced, are far from markets or cities, where it needs to be consumed.
3) Total generation potential of this source is too small.
4) There is always a danger of eruption of volcano.
5) Installation cost of steam power plant is very high.
6) There is no guarantee that the amount of energy which is produced will justify the capital expenditure and operations costs.
7) It may release some harmful, poisonous gases that can escape through the holes drilled during construction.

5.8 Geothermal Energy Scenario: World

- Geothermal power plants produce electricity in about 25 countries and over 78 countries use geothermal energy for direct applications (India uses geothermal energy for direct applications).
- Over 88 % of the total capacity of 10.7 GW (as of 2010) is produced in only seven countries; USA, Philippines, Indonesia, Mexico, Italy, New Zealand and Italy.
- The United States of America leads with the production and use of geothermal resources for energy production but Iceland raised almost 25% of its total electricity requirement from geothermal resources.
- Currently there are over 800 geothermal power projects totalling 23,313 megawatts in various stages of development around the world the balance is likely to tilt towards Asia with over 10,100 megawatts.

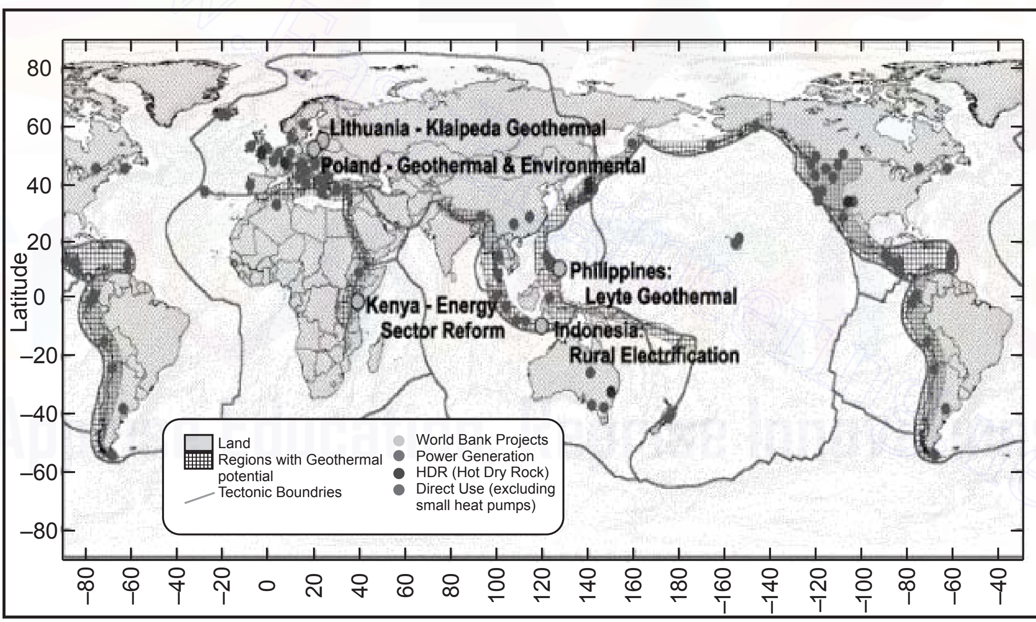


Fig. 5.8.1 Major geothermal resources in the world
(Source : IBC Conference Geothermal Power Asia 2000)

- The increased impetus to geothermal resources has only been due to the awareness of its potential in not only being renewable and much safer to the environment, extensive research and development in new generation geothermal power systems have reduced capital costs by almost 50 % and energy is produced with lower temperatures.

- In addition to this cascade methodology also helps in better utilisation of the drilled well by increased power production from the same number of wells.

5.9 Geothermal Energy Scenario : India

- India has reasonably good potential for geothermal; the potential geothermal provinces can produce over 10,000 MW of power.
- But the exploitation has been rather slow.
- The state Governments of Gujarat and Chhattisgarh have initiated in-principal approvals while Panax Geothermal along with Geosyndicate Power have been able to re-start exploration at Puga, Jammu & Kashmir in collaboration with Raya as operator and the project is high on viability as its close to 30 Kms from the nearest transmission line.
- India like most other countries joined the geothermal exploration during the oil crisis in 1970s and considerable progress was made in not just research but also commenced exploration and the details of the work is briefed below in the classification of geothermal resources in India.
- In India nearly 400 thermal springs occur, distributed in seven geothermal provinces. These provinces include
  1. The Himalaya province
  2. Cambay province
  3. West coast province
  4. SONATA province
  5. Bakreshwar province
  6. Godavari province
  7. The Barren Island (added after the volcanic eruption)
- **Indian organisations working in geothermal energy :**

1. Central Electricity Authority
2. Geological Survey of India
3. Indian Institute of Technology, Mumbai
4. Regional Research Laboratory, Jammu
5. National Geophysical Research Institute, Hyderabad
6. Oil and Natural Gas Corporation, Dehradun

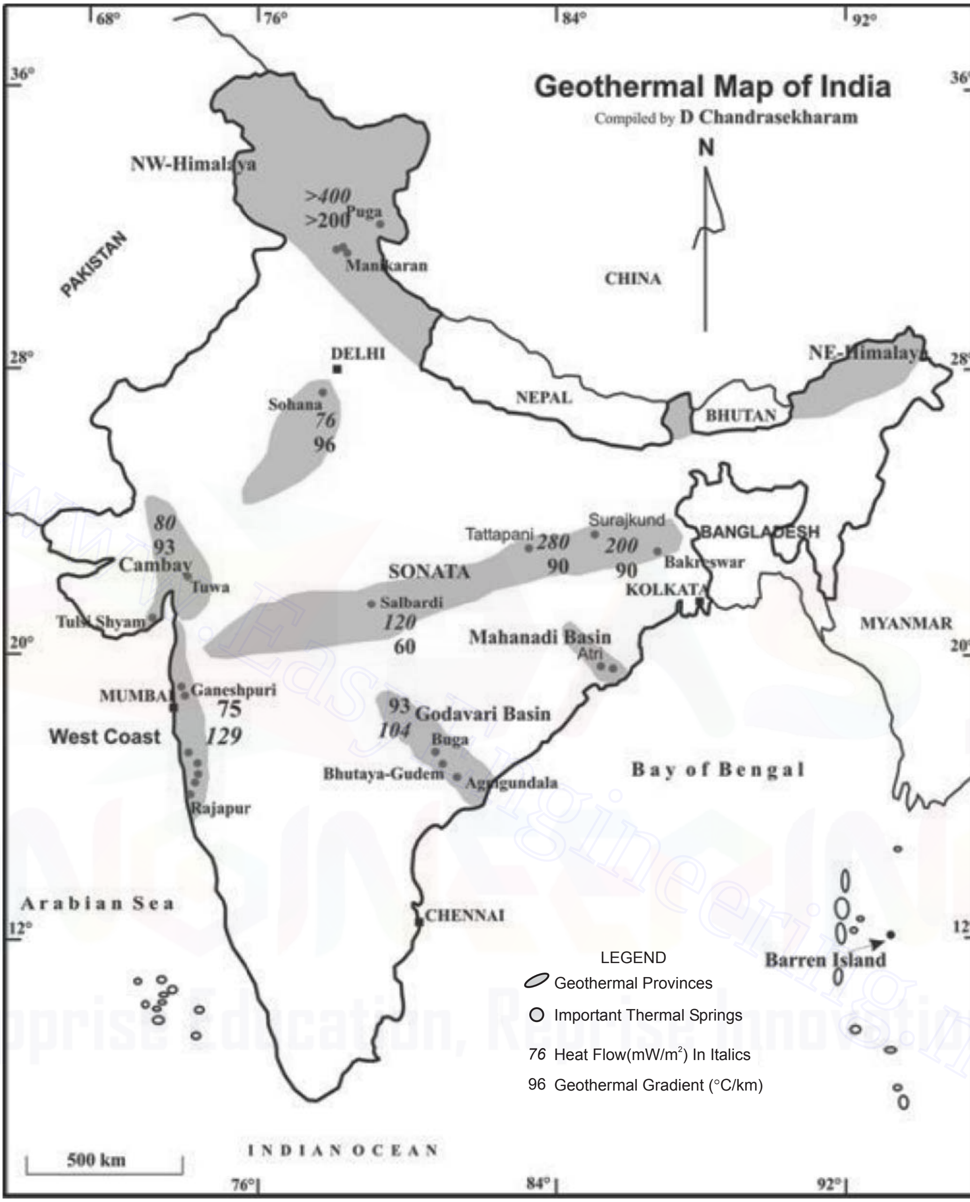


Fig. 5.9.1 Geothermal map of India
(Source : IBC Conference Geothermal Power Asia 2000)

- **Achievements:**

1. Geothermal Atlas of India, prepared by the Geological Survey of India(GSI) gives information/data for more than 300 geothermal potential sites. This Atlas is being updated by GSI with the support from MNES.
2. Applications of geothermal energy for small-scale power generation and thermal applications are being explored.

- **Historical Capacity & Consumption Data**
- There is no installed geothermal generating capacity as of now and only direct uses (eg.Drying) have been detailed.

Direct Uses

Total thermal installed capacity in MWt:	203.0
Direct use in TJ/year	1,606.30
Direct use in GWh/year	446.2
Capacity factor	0.25

- **Current Projects**

There are no operational geothermal plants in India.

Geothermal Field	Estimated (min.) reservoir Temp (Approx)	Status
Puga geothermal field	240 ºC at 2000 m	From geochemical and deep geophysical studies (MT)
Tattapani Sarguja (Chhattisgarh)	120 ºC - 150 ºC at 500 meter and 200 Cat 2000 m	Magnetotelluric survey done by NGRI
Tapoban Chamoli (Uttarakhand)	100 ºC at 430 meter	Magnetotelluric survey done by NGRI
Cambay Garben (Gujarat)	160 ºC at 1900 meter (From Oil exploration borehole)	Steam discharge was estimated 3000 cu meter/ day with high temprature gradient.
Badrinath Chamoli (Uttarakhand)	150 ºC estimated	Magneto-telluric study was done by NGRI Deep drilling required to ascertain geothermal field
Geothermal Field	Reservoir Temp (Approx)	Status
Surajkund Hazaribagh (Jharkhand)	110 ºC	Magneto-telluric study was done by NGRI. Heat rate 128.6 mW/m^2
Manikaran Kullu (H P)	100 ºC	Magneto-telluric study was done by NGRI Heat flow rate 130 mW/m^2
Kasol Kullu (H P)	110 ºC	Magneto-telluric study was done by NGRI

5.10 Magneto Hydro Dynamic (MHD) Generation

5.10.1 Introduction

- The **MHD generation** or, also known as **magneto hydrodynamic power generation** is a direct energy conversion system which converts the heat energy directly into electrical energy, without any intermediate mechanical energy conversion, as opposed to the case in all other power generating plants.
- Therefore, in this process, substantial fuel economy can be achieved due to the elimination of the link process of producing mechanical energy and then again converting it to electrical energy.
- The concept of MHD power generation was introduced for the very first time by Michael Faraday in the year 1832 in his Bakerian lecture to the Royal Society.
- He in fact carried out an experiment at the Waterloo Bridge in Great Britain for measuring the current, from the flow of the river Thames in earth's magnetic field.

5.10.2 Principle of Operation of MHD Generator

- The principal of **MHD power generation** is very simple and is based on Faraday's law of electromagnetic induction, which states that when a conductor and a magnetic field moves relative to each other, then voltage is induced in the conductor, which results in flow of current across the terminals.
- As the name implies, the magneto hydro dynamics generator shown in the Fig. 5.10.1 is concerned with the flow of a conducting fluid in the presence of magnetic and electric fields.

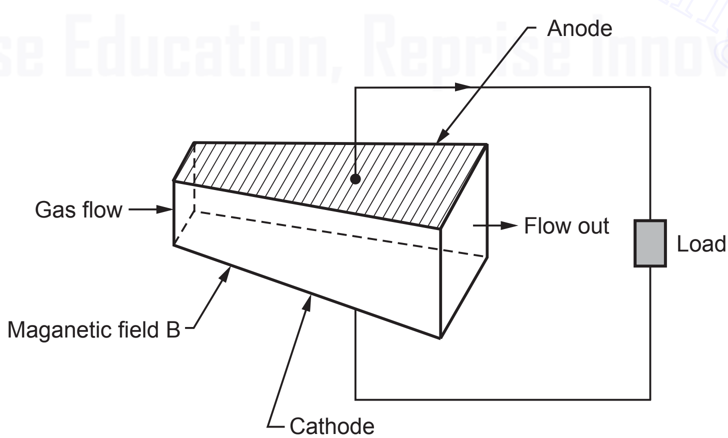


Fig. 5.10.1 Basic principle of MHD generator

- In conventional generator or alternator, the conductor consists of copper windings or strips while in an MHD generator the hot ionized gas or conducting fluid replaces the solid conductor.
- A pressurized, electrically conducting fluid flows through a transverse magnetic field in a channel or duct.
- Pair of electrodes are located on the channel walls at right angle to the magnetic field and connected through an external circuit to deliver power to a load connected to it.
- Electrodes in the MHD generator perform the same function as brushes in a conventional DC generator.
- The MHD generator develops DC power and the conversion to AC is done using an inverter.
- The power generated per unit length by MHD generator is approximately given by,

$$P = \frac{\sigma u B^2}{P}$$

- Where, u is the fluid velocity, B is the magnetic flux density, σ is the electrical conductivity of conducting fluid and P is the density of fluid.
- It is evident from the equation above that for the higher power density of an MHD generator there must be a strong magnetic field of 4-5 tesla and high flow velocity of conducting fluid besides adequate conductivity.

5.10.3 Types of MHD System

- The **MHD cycles** can be of two types, namely

1. Open Cycle MHD. 2. Closed Cycle MHD.

   (i) Seeded inert gas systems

   (ii) Liquid metal systems

1. Open Cycle MHD System

- In open cycle MHD system, atmospheric air at very high temperature and pressure is passed through the strong magnetic field.
- Coal is first processed and burnet in the combustor at a high temperature of about 2700 °C and pressure about 12 ATP with pre-heated air from the plasma.
- Then a seeding material such as potassium carbonate is injected to the plasma to increase the electrical conductivity.

- The resulting mixture having an electrical conductivity of about 10 Siemens/m is expanded through a nozzle, so as to have a high velocity and then passed through the magnetic field of MHD generator.
- During the expansion of the gas at high temperature, the positive and negative ions move to the electrodes and thus constitute an electric current.
- The gas is then made to exhaust through the generator.
- Since the same air cannot be reused again hence it forms an open cycle and thus is named as open cycle MHD.
- Block diagram of a typical open cycle MHD power plant is shown in Fig. 5.10.2.

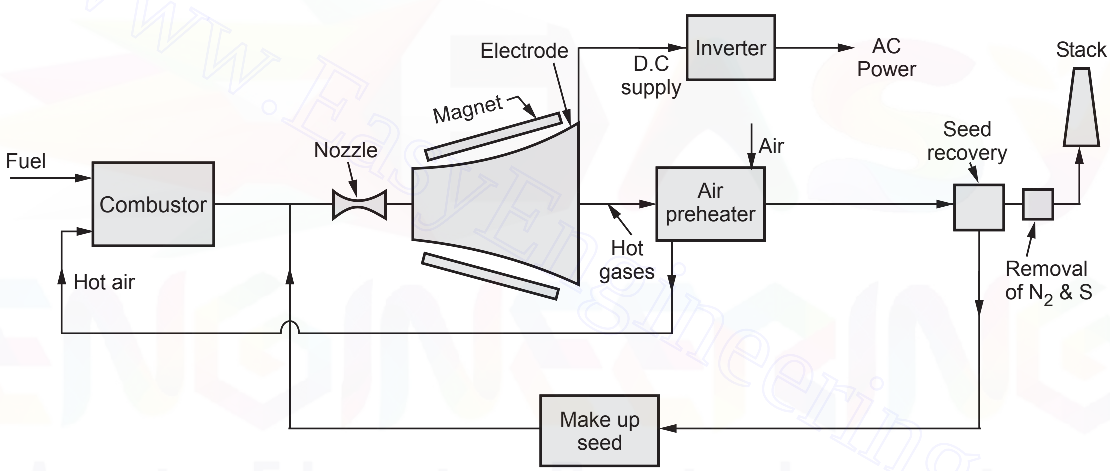


Fig. 5.10.2 Block diagram of open cycle MHD power station

2. **Closed cycle MHD System**

- As the name suggests the working fluid in a closed cycle MHD is circulated in a closed loop.
- Hence, in this case inert gas or liquid metal is used as the working fluid to transfer the heat. The liquid metal has typically the advantage of high electrical conductivity, hence the heat provided by the combustion material need not be too high.
- Contrary to the open loop system there is no inlet and outlet for the atmospheric air.

- Hence, the process is simplified to a great extent, as the same fluid is circulated time and again for effective heat transfer.
- Block diagram of a typical closed cycle MHD power plant is shown in Fig. 5.10.3.

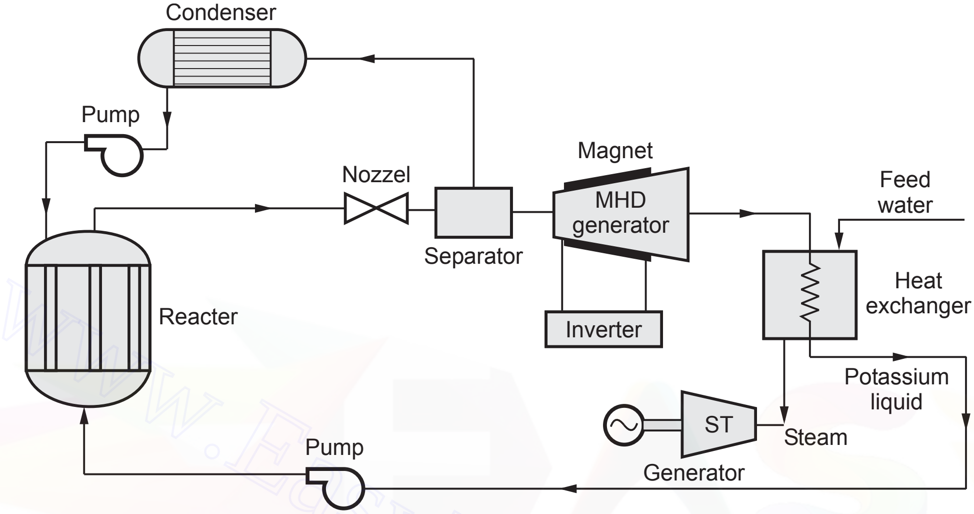


Fig. 5.10.3 Block diagram of closed cycle MHD power station

- Two types of closed loop system are

i) Seeded inert gas system

ii) Liquid metal system

i) Seeded inert gas MHD generator

- In a closed cycle system the carrier gas operates in the form of Brayton cycle.
- In a closed cycle system the gas is compressed and heat is supplied by the source, at essentially constant pressure, the compressed gas then expands in the MHD generator, and its pressure and temperature fall.
- After leaving this generator heat is removed from the gas by a cooler, this is the heat rejection stage of the cycle.
- Finally the gas is recompressed and returned for reheating.
- The complete system has three distinct but interlocking loops.
- On the left is the external heating loop.
- Coal is gasified and the gas is burnt in the combustor to provide heat.
- In the primary heat exchanger, this heat is transferred to a carrier gas argon or helium of the MHD cycle.

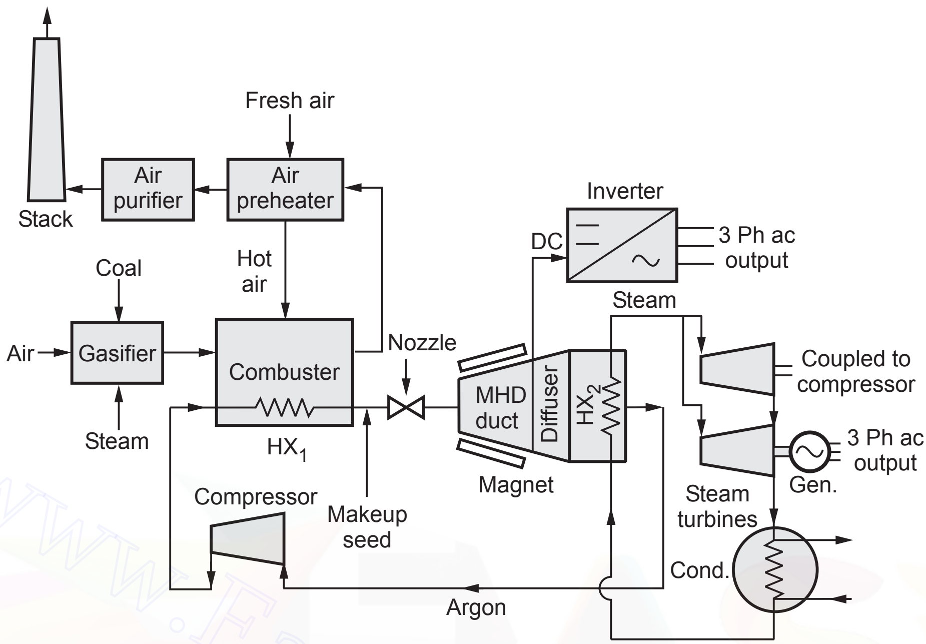


Fig. 5.10.4 Seeded inert gas MHD generator

- The combustion products after passing through the air preheated and purifier are discharged to atmosphere.
- Because the combustion system is separate from the working fluid, so also are the ash and flue gases.
- Hence the problem of extracting the seed material from fly ash does not arise.
- The fuel gases are used to preheat the incoming combustion air and then treated for fly ash and sulphur dioxide removal, if necessary prior to discharge through a stack to the atmosphere.
- The loop in the center is the MHD loop.
- The hot argon gas is seeding with cesium and resulting working fluid is passed through the MHD generator at high speed.
- The DC power out of MHD generator is converted in AC by the inverter and is then fed to the grid.

ii) Liquid Metal MHD System

- When a liquid metal provides the electrical conductivity, it is called a liquid metal MHD system.
- An inert gas is a convenient carrier.

- The carrier gas is pressurized and heated by passage through a heat exchanger within combustion chamber.
- The hot gas is then incorporated into the liquid metal usually hot sodium to form the working fluid.
- The latter then consists of gas bubbles uniformly dispersed in an approximately equal volume of liquid sodium.
- The working fluid is introduced into the MHD generator through a nozzle in the usual ways.
- The carrier gas then provides the required high direct velocity of the electrical conductor.
- After passage through the generator, the liquid metal is separated from the carrier gas.
- Part of the heat exchanger to produce steam for operating a turbine generator.
- Finally the carrier gas is cooled, compressed and returned to the combustion chamber for reheating and mixing with the recovered liquid metal.
- The working fluid temperature is usually around 800 ºC as the boiling point of sodium even under moderate pressure is below 900 ºC.
- At lower operating temperature, the other MHD conversion systems may be advantageous from the material standpoint, but the maximum thermal efficiency is lower.

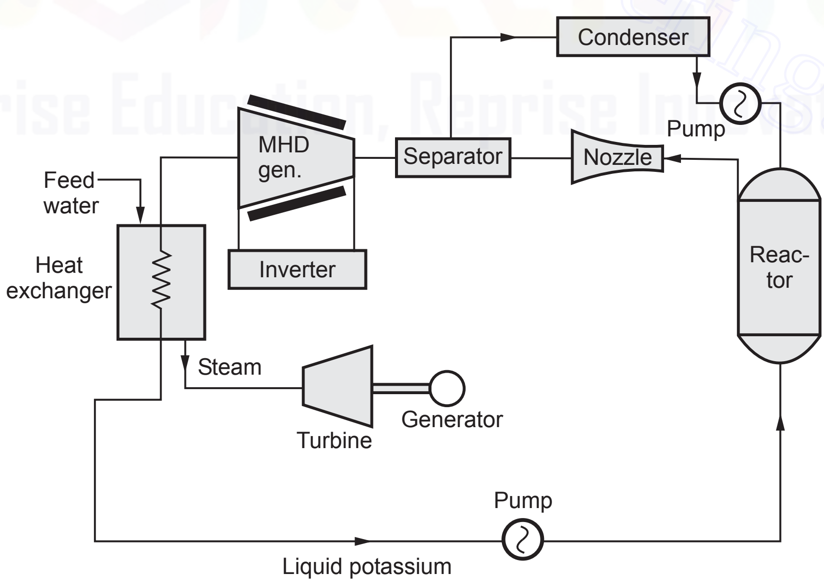


Fig. 5.10.5 Liquid metal MHD generator

- A possible compromise might be to use liquid lithium, with a boiling point near 1300 ºC as the electrical conductor lithium is much more expensive than sodium, but losses in a closed system are less.

5.10.4 Advantages of MHD Generation

1. Conversion efficiency of about 50 - 60 %.
2. Direct Energy Conversion Process
3. The MHD process requires less cooling water requirement hence, industrially attractive.
4. Less fuel consumption.
5. MHG generation is flexible in differed modes such as peak load, semi peak load or base load.
6. It can us all kinds of fuels such as coal, nuclear, gas, solar and nuclear energy.
7. Pollution free power generation.
8. Ability to reach full power level as soon as started.
9. Plant size is considerably smaller than conventional fossil fuel plants.
10. Less overall generation cost.
11. No moving parts, so more reliable.

5.10.5 Disdvantages of MHD Generation

1. Suffers from reverse flow (short circuits) of electrons through the conducting fluids around the ends of the magnetic field.
2. Needs very large magnets and this is a major expense.
3. High operating temperature.
4. The use of the superconductive coils to generate the external magnetic field.

5.10.6 Comparison between Open Cycle and Closed Cycle MHD System

	Open cycle system	Closed cycle system
(1)	Here the working fluid after generate electricity discharge to the atmosphere.	Here the working fluid is recycle to the heat source and can be used again and again.
(2)	The operation of MHD generator is done directly on the combustion product.	In closed cycle system helium or argon is used as working fluid.

(3)	Temperature required is very high i.e. about 2300 °C to 2700 °C.	Here the temperature required is comparatively less i.e. about 530 °C.
(4)	Less costly compare to closed cycle system	They are quite expensive.

5.11 Hydrogen

- Hydrogen (H), a colourless, odourless, tasteless, flammable gaseous substance that is the simplest member of the family of chemical elements.
- Hydrogen can be considered as a clean energy carrier, similar to electricity.
- Hydrogen can be produced from various domestic resources such as renewable energy and nuclear energy.
- In the long-term, hydrogen will simultaneously reduce the dependence on foreign oil and the emission of greenhouse gases and other pollutants.
- Hydrogen can be considered as the simplest element in existence.
- Hydrogen is also one of the most abundant elements in the earth's crust.
- However, hydrogen as a gas is not found naturally on Earth and must be manufactured.
- This is because hydrogen gas is lighter than air and rises into the atmosphere as a result.
- Natural hydrogen is always associated with other elements in compound form such as water, coal and petroleum.
- Hydrogen has the highest energy content of any common fuel by weight.
- On the other hand, hydrogen has the lowest energy content by volume.
- It is the lightest element, and it is a gas at normal temperature and pressure.

5.11.1 Hydrogen as an Energy Carrier

- Hydrogen is considered as a secondary source of energy, commonly referred to as an energy carrier.
- Energy carriers are used to move, store and deliver energy in a form that can be easily used.
- Electricity is the most well-known example of an energy carrier.
- Hydrogen as an important energy carrier in the future has a number of advantages.

- For example, a large volume of hydrogen can be easily stored in a number of different ways, including underground hydrogen storage, compressed hydrogen in tanks, or through chemical compounds that release hydrogen after heating.
- Hydrogen is also considered as a high efficiency, low polluting fuel that can be used for transportation, heating, and power generation in places where it is difficult to use electricity.
- In some instances, it is cheaper to ship hydrogen by pipeline than sending electricity over long distances by wire.

5.11.2 Hydrogen Production Methods

- Today, hydrogen fuel can be produced through several methods.
- The most common methods today are

1. Natural gas reforming (Thermal process)
2. Electrolysis
3. Solar-driven
4. Biological processes.

1. Thermal Processes

- Thermal processes for hydrogen production typically involve steam reforming, a high-temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen.
- Many hydrocarbon fuels can be reformed to produce hydrogen, including natural gas, diesel, renewable liquid fuels, gasified coal, or gasified biomass.
- Today, about 95 % of all hydrogen is produced from steam reforming of natural gas.

2. Electrolytic Processes

- Water can be separated into oxygen and hydrogen through a process called electrolysis.
- Electrolytic processes take place in an electrolyzer, which functions much like a fuel cell in reverse instead of using the energy of a hydrogen molecule, like a fuel cell does, an electrolyzer creates hydrogen from water molecules.

3. Solar-Driven Processes

- Solar-driven processes use light as the agent for hydrogen production.
- There are a few solar-driven processes, including photobiological, photoelectrochemical, and solar thermochemical.

- Photobiological processes use the natural photosynthetic activity of bacteria and green algae to produce hydrogen.
- Photoelectrochemical processes use specialized semiconductors to separate water into hydrogen and oxygen.
- Solar thermochemical hydrogen production uses concentrated solar power to drive water splitting reactions often along with other species such as metal oxides.

4. Biological Processes

- Biological processes use microbes such as bacteria and microalgae and can produce hydrogen through biological reactions.
- In microbial biomass conversion, the microbes break down organic matter like biomass or wastewater to produce hydrogen, while in photobiological processes the microbes use sunlight as the energy source.

5.11.3 Hydrogen Fuel Cell

- Fuel cells directly convert the chemical energy in hydrogen to electricity, with pure water and heat as the only by-products.
- Hydrogen-powered fuel cells are not only pollution-free, but a two- to three-fold increase in the efficiency can be experienced when compared to traditional combustion technologies.

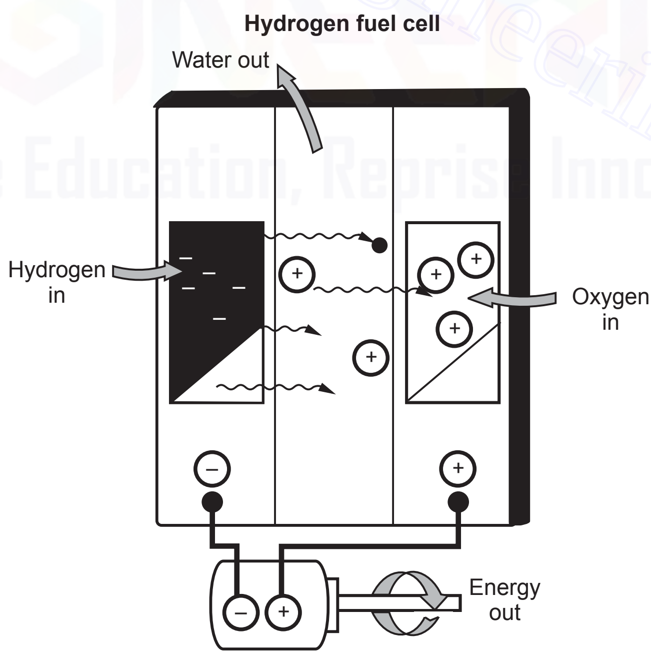


Fig. 5.11.1 Hydrogen fuel cell

- Fuel cells can power almost any portable devices that normally use batteries.
- Fuel cells can also power transportation such as vehicles, trucks, buses, and marine vessels, as well as provide auxiliary power to traditional transportation technologies.
- Hydrogen can play a particularly important role in the future by replacing the imported petroleum we currently use in our cars and trucks.

5.11.4 Advantages of Hydrogen Fuel Cells

- The key benefits of hydrogen fuel cells include the following :

1. Unlike gasoline - and diesel-powered vehicles, hydrogen fuel cells do not produce air pollutants. It only produces nitrogen oxides when burned in engines.
2. It reduces dependence on petroleum imports as hydrogen can be domestically produced from various sources.
3. Fuel cell vehicles powered by hydrogen do not produce green house gas emissions.

5.11.5 Disadvantages of Hydrogen Fuel Cells

- The following are some of the disadvantages of hydrogen fuel cells :

1. Hydrogen fuel cell vehicles are currently very expensive than conventional vehicles or any hybrids.
2. Fuel cell vehicles are not as durable as internal combustion engines in terms of temperature and humidity ranges.
3. Availability of hydrogen is limited to certain locations and hydrogen is quite expensive to produce as well.
4. Hydrogen fuel cell vehicles produce very less energy when compared other gasoline or diesel vehicles and hence it is difficult to achieve high driving range.
5. The systems used for delivering gasoline from refineries to gasoline stations cannot be used for hydrogen.

5.11.6 Uses of Hydrogen Fuel Cells

- The following are some of the applications of hydrogen fuel cells:

1. NASA is the primary user of hydrogen resources for its space program. NASA fuels the booster rockets of the space shuttle using liquid hydrogen and employs hydrogen batteries for electrical sources.
2. Hydrogen fuel cells can power any portable device that uses batteries. Unlike a typical battery, the hydrogen fuel cell continues to produce energy with the

continuous supply of fuel. This ability of the fuel cells enables them to power devices like hearing aids, video recorders, cellular phones and laptop computers.

3. Stationary hydrogen fuel cells are the largest and most powerful fuel cells. They are a clean, reliable source of power to cities, towns and buildings. These fuel cells are also used for back-up and remote power applications including remote weather stations and rural locations.

5.11.7 Hydrogen Storage

- Hydrogen storage is a key enabling technology for the advancement of hydrogen and fuel cell technologies in applications including stationary power, portable power, and transportation.
- Hydrogen has the highest energy per mass of any fuel; however, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density.

5.11.8 Classification of Hydrogen Storage Technologies

- Hydrogen storage technologies can be broadly classified into three main categories :

1. Physical method
2. Chemical methods (also called materials based hydrogen storage), and
3. Hybrid methods

1. Physical method

- Physical methods are compressed gaseous hydrogen, liquefied hydrogen, and cryo-compressed hydrogen.
- In physical methods of hydrogen storage, hydrogen does not interact with the storage media; however, in chemical methods of hydrogen storage, hydrogen interacts with the storage media via strong covalent/ionic bonds or via weak van der Waals forces (i.e., hydrogen is chemically bound to a storage material).

2. Chemical methods

- Chemical methods are solid-state storage (on-board regenerable) and chemical storage (off-board regenerable).
- Chemical methods always include a hydrogen storage material to store hydrogen.
- Chemical methods drew significant attention since 2000s due to drawbacks of physical methods.

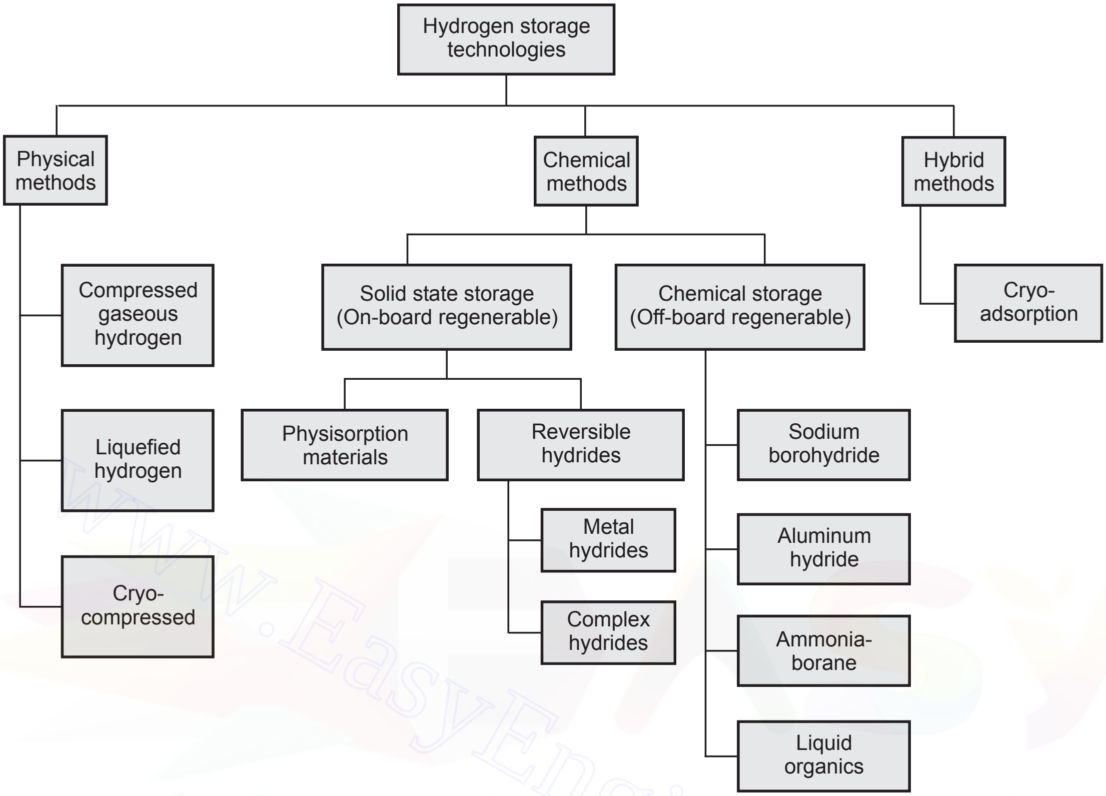


Fig. 5.11.2 Hydrogen storage technologies

- Chemical methods classified into two : (i) solid-state storage and (ii) chemical storage.
- The primary distinction between solid state (i.e., reversible hydrides and porous materials and chemical storage (i.e., ammonia-borane, liquid organics, etc.) is solid-state materials can be regenerated on-board simply by charging with hydrogen, whereas chemical storage materials need to be regenerated off-board in centralized facilities.
- On-board regenerable materials are visualized as the key element for the market penetration of fuel cell vehicles.

3. Hybrid methods

- Hybrid method of storage is cryo-adsorption and makes use of both physical and chemical methods.
- Cryo-adsorption is a hybrid (physical-chemical) method and takes advantage of compressed, liquefied and physisorption materials-based hydrogen storage technologies.

5.12 Fuel Cell

- Fuel cells are electrochemical devices that convert chemical energy from the reactants directly into electricity and heat.
- The device consists of an electrolyte layer in contact with a porous anode and cathode on either side.
- An illustration of a fuel cell with reactant/product gasses and the ion conduction flow directions through the cell is shown in Fig. 5.12.1.

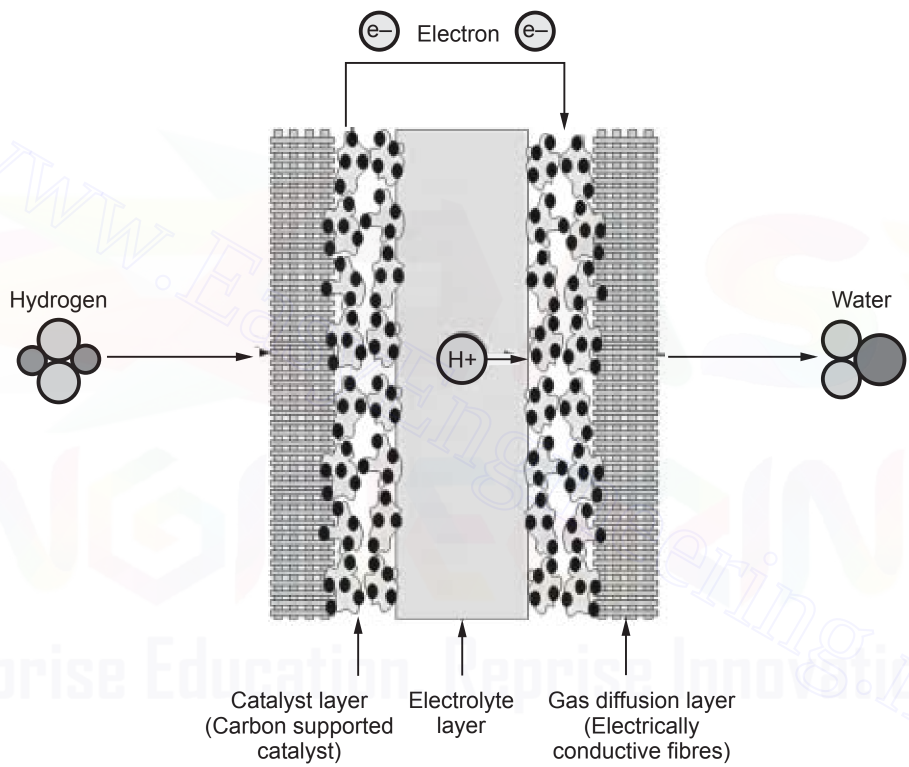


Fig. 5.12.1 A single PEM fuel cell configuration

- In a standard fuel cell, gaseous fuels are fed continuously to the anode (negative electrode), while an oxidant (oxygen from the air) is fed continuously to the cathode (positive electrode).
- Electrochemical reactions take place at the electrodes to produce an electric current.

Advantages of fuel cell

- Some of the advantages of fuel cell systems are :

i. A high operating efficiency that is not a function of system size.

ii. A highly scalable design.

iii. Several types of potential fuel sources are available.

iv. Zero or near-zero greenhouse emissions.

v. There are no moving parts in the fuel cell stack, which provides reliable, vibration-free operation. (There may be pumps or compressors in some fuel cell plant subsystems).

vi. Nearly instantaneous recharge capability when compared to batteries.

Limitations of fuel cell

- Some of the limitations common to all fuel cell systems include :

i. Cost-effective, mass produced pure hydrogen storage and delivery technology.

ii. Fuel Reformation technology may need to be considered if pure fuel is not used.

iii. Fuel cell performance may gradually decrease over time due to catalyst degradation and electrolyte poisoning if pure fuel is not used.

5.13 Hybrid Systems

- The combination of renewable energy system such as PV arrays or wind turbines, with engine-driven generators and battery storage, is widely recognized as a viable alternative to conventional Remote Area Power Supplies (RAPS).
- These systems are generally classified as Hybrid Energy Systems (HES).
- For eg. A Photovoltaic-diesel hybrid energy systems generate ac electricity by combining a photovoltaic array with an inverter, which can operate alternately or in parallel with a conventional engine-driven generator.

Need for hybrid energy systems.

1. Hybrid Systems are powered by sun and wind or any other renewable energy source to meet the increasing power demand.
2. Power electronics controllers manage multiple sources and monitor the status of the system voltage, power and frequency based on the load requirement.
3. During grid failure the alternative resources supply the power demand.
4. In remote areas renewable energy sources such as PV can be added to power systems using diesel and other fossil fuel powered generators to provide 24 - 53 hour power economically and efficiently. Such systems are called "hybrid energy systems.

Types of Hybrid System :

- They can be **classified** according to their configuration as :

1. Series hybrid energy systems.
2. Switched hybrid energy systems.
3. Parallel hybrid energy systems.

Series Configuration :

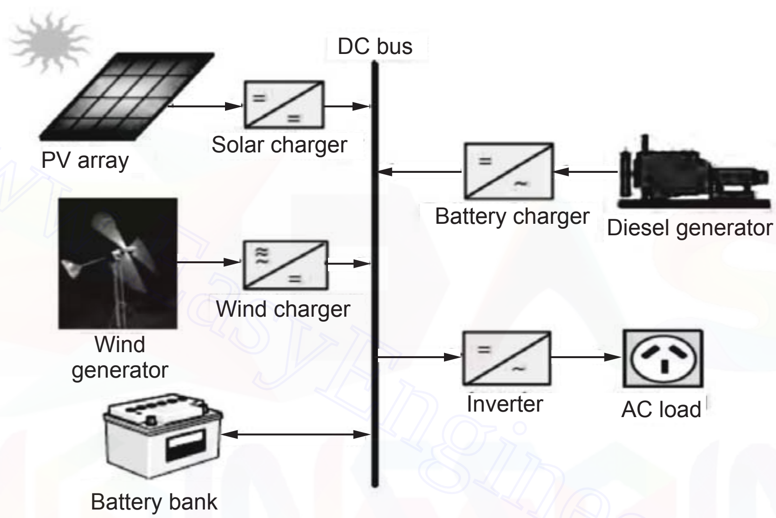


Fig. 5.13.1 Series hybrid energy system

- In the conventional series hybrid systems shown in Fig. 5.13.1, all power generators feed DC power into a battery.
- Each component has therefore to be equipped with an individual charge controller and in the case of a diesel generator with a rectifier.
- To ensure reliable operation of series hybrid energy systems both the diesel generator and the inverter have to be sized to meet peak loads.
- This results in a typical system operation where a large fraction of the generated energy is passed through battery bank, therefore resulting in increased cycling of the battery bank and reduced system efficiency.
- AC power delivered to the load is converted from DC to regulated AC by an inverter or a motor generator unit.

- The power generated by the diesel generator is first rectified and subsequently converted back to AC before being supplied to the load, which incurs significant conversion losses.
- The actual load demand determines the amount of electrical power delivered by the PV array, wind generator, the battery bank, or the diesel generator.
- The solar and wind charger prevents overcharging of the battery bank from the PV generator when the PV power exceeds the load demand and the batteries are fully charged.
- It may include MPPT to improve the utilization of the available PV energy, although the energy gain is marginal for a well-sized system.
- The system can be operated in manual or automatic mode, with the addition of appropriate battery voltage sensing and start/stop control of the engine-driven generator.

Advantages :

1. The engine-driven generator can be sized to be optimally loaded while supplying the load and charging the battery bank, until a battery SOC of 70 - 80 % is reached.
2. No switching of AC power between the different energy sources is required, which simplifies the electrical output interface.
3. The power supplied to the load is not interrupted when the diesel generator is started.
4. The inverter can generate a sine-wave, modified square wave, or square-wave depending on the application.

Disadvantages :

1. The inverter cannot operate in parallel with the engine driven generator, therefore the inverter must be sized to supply the peak load of the system.
2. The battery bank is cycled frequently, which shortens its lifetime.
3. The cycling profile requires a large battery bank to limit the Depth-Of-Discharge (DOD).
4. The overall system efficiency is low, since the diesel cannot supply power directly to the load.
5. Inverter failure results in complete loss of power to the load, unless the load can be supplied directly from the diesel generator for emergency purposes.

Switched configuration :

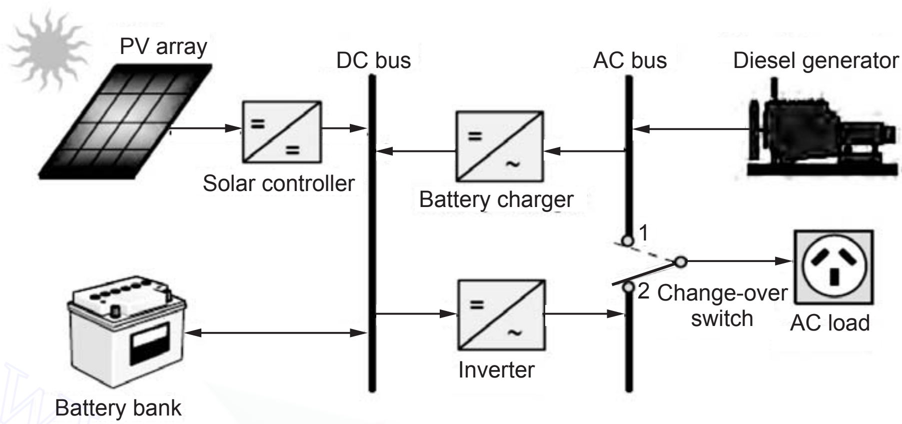


Fig. 5.13.2 Switched PV-diesel hybrid system

- Despite its operational limitations, the switched configuration remains one of the most common installations in some developing countries.
- It allows operation with either the engine driven generator or the inverter as the AC source, yet no parallel operation of the main generation sources is possible.
- The diesel generator and the RES can charge the battery bank.
- The main advantage compared with the series system is that the load can be supplied directly by the engine-driven generator, which results in a higher overall conversion efficiency.
- Typically, the diesel generator power will exceed the load demand, with excess energy being used to recharge the battery bank.
- During periods of low electricity demand the diesel generator is switched off and the load is supplied from the PV array together with stored energy.
- Switched hybrid energy systems can be operated in manual mode, although the increased complexity of the system makes it highly desirable to include an automatic controller, which can be implemented with the addition of appropriate battery voltage sensing and start/stop control of the engine-driven generator (Fig. 5.13.2).

Advantages :

1. The inverter can generate a sine-wave, modified square wave, or square-wave, depending on the particular application.

2. The diesel generator can supply the load directly, therefore improving the system efficiency and reducing the fuel consumption.

Disadvantages :

1. Power to the load is interrupted momentarily when the AC power sources are transferred.
2. The engine-driven alternator and inverter are typically designed to supply the peak load, which reduces their efficiency at part load operation.

3. Parallel configuration :

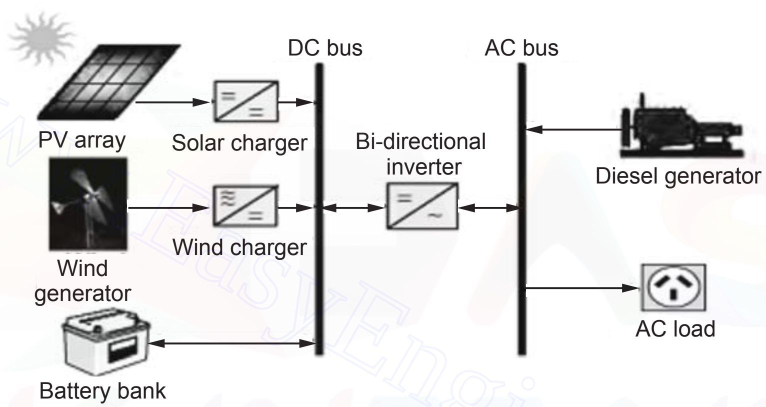


Fig. 5.13.3 Parallel PV-diesel hybrid energy system : a) DC decoupling and b) AC coupling

- The parallel hybrid system can be further classified as DC and AC couplings as shown in Fig. 5.13.3. In both schemes, a bi-directional inverter is used to link between the battery and an AC source (typically the output of a diesel generator).
- The bi-directional inverter can charge the battery bank (rectifier operation) when excess energy is available from the diesel generator or by the renewable sources, as well as act as a DC-AC converter (inverter operation).
- The bidirectional inverter may also provide "peak shaving" as part of a control strategy when the diesel engine is overloaded.
- In Fig. 5.13.3, the Renewable Energy Sources (RES) such as photovoltaic and wind are coupled on the DC side.
- DC integration of RES results in "custom" system solutions for individual supply cases requiring high costs for engineering, hardware, repair, and maintenance.
- Furthermore, power system expandability for covering needs of growing energy and power demand is also difficult.

- A better approach would be to integrate the RES on the AC side rather than on the DC side as shown in Fig. 5.13.3.
- Parallel hybrid energy systems are characterized by two significant improvements over the series and switched system configuration.
- The inverter plus the diesel generator capacity rather than their individual component ratings limit the maximum load that can be supplied.
- Typically, this will lead to a doubling of the system capacity.
- The capability to synchronize the inverter with the diesel generator allows greater flexibility to optimize the operation of the system.
- Future systems should be sized with a reduced peak capacity of the diesel generator, which results in a higher fraction of directly used energy and hence higher system efficiencies.

Advantages :

1. The system load can be met in an optimal way.
2. Diesel generator efficiency can be maximized.
3. Diesel generator maintenance can be minimized.
4. A reduction in the rated capacities of the diesel generator, battery bank, inverter, and renewable resources is feasible, while also meeting the peak loads.

Disadvantages :

1. Automatic control is essential for the reliable operation of the system.
2. The inverter has to be a true sine-wave inverter with the ability to synchronize with a secondary AC source.
3. System operation is less transparent to the untrained user of the system.

Two Marks Questions with Answers

Part A

Q.1 *What is the geothermal energy ?*

Ans. :

- Geothermal energy is the energy obtained from the earth(geo) from the hot rocks present inside the earth.
- It is produced due to the fission of radioactive materials in the earth's core and some places inside the earth become very hot.

Q.2 *What is ocean thermal energy ?*

Ans. :

- Sun's heat warms the surface of the water more than deep ocean water, due to this temperature difference thermal energy occurs.
- This is known as ocean thermal energy.

Q.3 *What is wave energy ?*

Ans. :

- Ocean waves are powerful sources of energy.
- At a wave power station, the waves arriving cause the water in chamber to rise and fall, as the air is forced in and out of the hole in top of the chamber.
- The air rushing in and out turns a turbine placed in this hole to generate electric power.

Q.4 *What are ocean energy resources ?*

Ans. :

- Ocean energy resources includes
  - i. Tidal Energy
  - ii. Wave Energy
  - iii. Ocean Thermal Energy Conversion (OTEC)

Q.5 *Define ocean energy.*

Ans. :

- The movement of water in the oceans creates a vast storage of kinetic energy is called ocean energy.

Q.6 *What is the working principle of ocean thermal energy ?*

Ans. :

- Ocean thermal energy works in principle of thermal conductivity, where surface water as heat source and deep cold water as heat sink due to this temperature difference ocean thermal energy occurs.

Q.7 *List two advantages of ocean thermal energy.*

Ans. :

- It will not pollute environment.
- This energy is produce all around the year in any climate.

Q.8 *What are limitations of ocean thermal energy ?*

Ans. :

- It has lower capacity, need more technical improvement for higher energy
- Production capacity.
- Power production depends on size and geographical area of the power plant.

Q.9 *What are types of OTEC systems ?*

Ans. :

- Closed cycle systems
- Open cycle systems
- Hybrid systems

Q.10 *What are working fluids in OTEC ?*

Ans. :

- OTEC working fluids are,
  i. Ammonia
  ii. Fluorinated carbons such as CFCS and HCFCs
  iii. Pentane

Q.11 *What is tidal energy ?*

Ans. :

- Tidal energy is a form of hydropower that converts the energy of tides into useful forms of power mainly electricity.

Q.12 *List out any two merits of tidal energy.*

Ans. :

i. It is inexhaustible sources of energy.
ii. The life of tidal energy power plant is very long.
iii. The energy density of tidal energy is higher than renewable energy.

Q.13 *State any two limitations of tidal energy.*

Ans. :

- The high and low tides must reach16 feet.
- Construction cost is high.
- Limited availability of sites.

Q.14 *What is meant by wave machines ?*

Ans. :

- The device which is used to convert wave energy into mechanical energy called wave machines.

Q.15 *List out wave energy conversion device.*

Ans. :

- Oscillating water column
- Tapchan
- Pendulor device (or) dolphin type device.

Q.16 *How are tides produced ? Or what is the basic principle of tidal energy ?*

Ans. :

- The tide rise and fall of the water is accomplished by periodic horizontal to and from motion of water called tidal currents. The tidal currents flow in horizontal direction and have kinetic energy. This energy is called tidal current energy.

Q.17 *What is OTEC ?*

Ans. :

- OTEC is the abbreviation of Ocean Thermal Energy Conversion
- The tidal spring is maximum on full moon and new moon and such tides are called spring tides.

Q.18 *What are the applications of geothermal energy ?*

Ans. :

1. Generation of electric power
2. Industrial process heat
3. Space heating for building

Q.19 *What are the advantages of geothermal energy ?*

Ans. :

1) It is a renewable source of energy.
2) By far, it is non-polluting and environment friendly.
3) There is no wastage or generation of by-products.
4) Geothermal energy can be used directly. In ancient times, people used this source of energy for heating homes, cooking, etc.
5) Maintenance cost of geothermal power plants is very less.

6) Geothermal power plants don't occupy too much space and thus help in protecting natural environment.

7) Unlike solar energy, it is not dependent on the weather conditions.

Q.20 *List some geothermal fluids.*

Ans. :

1. Hot water
2. Hot brine
3. Wet stream
4. Combination of above

Q.21 *Name the different types of MHD generators.*

Ans. :

- Open cycle MHD
- Closed cycle MHD
- Closed cycle MHD with liquid metal

Q.22 *What is the working principle of magneto hydrodynamic power plant ?*

Ans. :

- The working principle of MHD is as like that of dynamo.
- Instead of solid conductor high temperature plasma is passed through the magnetic field at sonic speed.
- When the gas is passed through magnetic field, current is induced. Electrodes collect this induced current.

Q.23 *What is fuel cell and mention its specification.*

Ans. :

- Basically, a fuel cell is a device that converts directly the chemical energy stored in gaseous molecules of fuel and oxidant into electrical energy.
- When the fuel is hydrogen the only by-products are pure water and heat.
- The overall process is the reverse 31 of water electrolysis. In electrolysis, an electric current applied to water produces hydrogen and oxygen; by reversing the process, hydrogen and oxygen are combined to produce electricity and water (and heat).
- Fuel cells rely on an electrochemical reaction involving the fuel, and not on its combustion.
- A Carnot cycle involving the transformation of heat into mechanical and electrical energy is involved in conventional methods for generating electricity.

Q.24 *Show fuel cell characterization.*

Ans. :

i. Overall performance (i-V curve, power density)

ii. Kinetic properties

iii. Ohmic properties

iv. Mass transport properties reactant/product homogeneity

v. Parasitic losses

vi. Electrode structure

vii. Catalyst structure

viii. Flow structure

ix. Heat generation/heat balance;

x. Lifetime issues (lifetime testing, degradation, cycling, startup/shutdown, failure, corrosion, fatigue).

Q.25 *Classify the types of fuel cell.*

Ans. :

- PEMFC, Proton Exchange Membrane Fuel Cell
- DMFC, Direct Methanol Fuel Cell
- PAFC, Phosphoric Acid Fuel Cell
- AFC, Alkaline Fuel Cell
- MCFC, Molten Carbonate Fuel Cell
- SOFC, Solid Oxide Fuel Cell

Q.26 *What is Hydrogen energy ?*

Ans. :

- The hydrogen alone or mixed with natural gas is used in a combustion based power generation such as gas turbine for stationary power generation in standalone power plants or in a fuel cell based generation unit.
- Hydrogen is an optimum choice for fuel cell, which are efficient energy conversion devices.
- The HFI (HYDROGEN FUE CELL) is a cost effective project to produce fuel cell vehicles at low cost developed by George Bush in 2003 in US.

Q.27 *Define hybrid systems ?*

Ans. :

- The combination of renewable energy system such as PV arrays or wind turbines, with engine-driven generators and battery storage, is widely recognized as a viable alternative to conventional Remote Area Power Supplies (RAPS).
- These systems are generally classified as Hybrid Energy Systems (HES).
- For eg. A **Photovoltaic-diesel hybrid energy systems** generate ac electricity by combining a photovoltaic array with an inverter, which can operate alternately or in parallel with a conventional engine-driven generator.

Q.28 *Summarize the need for hybrid energy systems.*

Ans. :

- Hybrid Systems are powered by sun and wind or any other renewable energy source to meet the increasing power demand.
- Power electronics controllers manage multiple sources and monitor the status of the system voltage, power and frequency based on the load requirement.
- During grid failure the alternative resources supply the power demand.
- In remote areas renewable energy sources such as PV can be added to power systems using diesel and other fossil fuel powered generators to provide 24-hour power economically and efficiently. Such systems are called "hybrid energy systems.

Q.29 *List out some of the hybrid systems used in industries.*

Ans. :

i) Solar PV- Diesel Hybrid system

ii) PV-Diesel Hybrid system

iii) Wind-PV Hybrid system

iv) Wind-Diesel Hybrid system

Q.30 *List the merits and demerits of PV-Diesel hybrid system.*

Ans. :

The advantages of **parallel configuration over other system configurations** is

1. The system load can be met in an optimal way.
2. Diesel generator efficiency can be maximized.
3. Diesel generator maintenance can be minimized.
4. A reduction in the rated capacities of the diesel generator, battery bank, inverter, and renewable resources is feasible, while also meeting the peak loads.

The disadvantages are :

1. Automatic control is essential for the reliable operation of the system.
2. The inverter has to be a true sine-wave inverter with the ability to synchronize with a secondary ac source.
3. System operation is less transparent to the untrained user of the system.

- **The switched configuration** remains one of the most common installations today.

Q.31 *What are the limitations of open cycle OTEC system?*

Ans. :

1. Turbine is physically large
2. The cost of plant is high
3. It can allow a very large flow of ocean water in terms of mass and volume.

Q.32 *List down the components of closed cycle OTEC system.*

Ans. :

1. Evaporator
2. Vapour turbine (Turbogenerator)
3. Vapour condensor
4. Liquid pressuriser

Q.33 *What are the working fluid in closed cycle OTEC ?*

Ans. :

a) Ammonia
b) Freon
c) Butane

Q.34 *Define Anti-fouling.*

Ans. : Anti-fouling is the process of removing the accumulation or preventing its accumulations.

Q.35 *Define the term range of tides.*

Ans. :

Range is the difference between high and low water levels denoted by R.

R = Water elevation at high tide – Water elevation at low tide

Q.36 *List down the types of tidal energy technologies.*

Ans. :

i) Tidal barrages

ii) Tidal steam generators

iii) Dynamic tidal power

Q.37 *What are the components of tidal power plants ?*

i. Dam or dyke

ii. Sluice ways

iii. Embankments

iv. Power House

Q.38 *List any four disadvantages of OTEC.*

Ans. :

1. Degradation of heat exchanger performance as dissolved gases.
2. Degradation of heat exchanger performance by microbial fouling
3. Improper sealing
4. Parasitic power consumption by exhaust compressor

Q.39 *List any four benefits of OTEC.*

Ans. :

1. Airconditioning
2. Chilled soil agriculture
3. Aquaculture
4. Desalination

Q.40 *List the various types of turbines used in tidal power station.*

Ans. :

1. Buld turbine
2. Rim turbine
3. Tubular turbines

Q.41 *List any four advantages of tidal power generation.*

Ans. :

1. Renewable and sustainable energy
2. No liquid or Solid pollution

3. Little visual impact
4. Reduces dependence upon fossil fuels

Q.42 *List the limitations of tidal energy.*

Ans. :

1. Orientation problem
2. Requires storage devices
3. Available at a lower rating and time
4. High capital cost

Q.43 *What are the main parts of geothermal power plant ?*

Ans. :

1. Production well
2. Vaporizer
3. Circulating pump
4. Expansion turbine
5. Generator
6. Condenser
7. Transformer

Q.44 *What are the classifications of geothermal energy conversion system ?*

Ans. :

1. Single cycle geothermal power plant
2. Binary cycle power plant

Q.45 *What are the advantages of geothermal energy ?*

Ans. :

1. Cheaper
2. Versatile in its use
3. Delivers greater amount of energy

Q.46 *What are the disadvantages of geothermal energy ?*

Ans. :

1. Drilling operation is noisy
2. It needs large areas of exploitation of geothermal energy
3. Low overall power production efficiency.

Q.47 *What are the classifications of MHD system ?*

Ans. :

1. Open cycle systems
2. Closed cycle systems

   (a) Seeded inert gas systems

   (b) Liquid metal systems

Q.48 *What are the advantages of MHD systems ?*

Ans. :

1. Large amount of power is generated
2. No moving parts, so more reliable.
3. Closed cycle system produces power, free of pollution
4. Ability to reach its full power as soon as started.

Q.49 *List the disadvantages of MHD systems.*

Ans. :

1. Needs very large magnets(high expenses)
2. Very high friction and heat transfer losses
3. It suffers from the reverse flow of electrons through the conducting fluids around the ends of the magnetic field.

Q.50 *What are the advantages of Hydro power plant ?*

Ans. :

1. No fuel charges
2. It is highly reliable
3. Maintenance and operation charges are very low
4. Running cost of the plant is low
5. Less supervising staff is required.
6. No fuel transportation problem

Q.51 *List the disadvantages of Hydro Power Plant.*

Ans. :

1. The initial cost of the plant is very high
2. It takes considerable long time for the erection of such plants.

3. The efficiency of plant is less than the large hydro plant.
4. Quality of output is not good.

Q.52 *What are the components of Small Hydro Power Plant.*

Ans. :

1. Diversion and intake
2. Desilting chamber or tank
3. Water conductor system
4. Balancing reservoir
5. Surge tank
6. Penstock

Review Questions

Part B

1. *Write a short note on 'ocean thermal energy'.*
2. *Explain in detail about the ocean thermal energy ? Discuss it's availability.*
3. *What is the basic principle of OTEC ?*
4. *What are the main types of OTEC power plants ? Describe their working principle in brief.*
5. *Describe the 'closed-cycle' OTEC systems. Write its advantages over 'open-cycle systems'.*
6. *Explain Carrot efficiency for an OTEC plant with the help of a thermodynamic cycle on a T-S plane.*
7. *What is the limitation of open-cycle OTEC systems ?*
8. *State the merits and demerits of OTEC plants.*
9. *State the expression for energy and power in ocean waves.*
10. *Explain how the ocean temperature differences can be used to generate electrical power.*
11. *Discuss in detail OTEC systems based on (i) open cycle (ii) closed cycle.*
12. *What is geothermal power ?*
13. *Discuss the disadvantages of geothermal plant.*
14. *Discuss the advantages of geothermal plant.*
15. *What are the special problems in construction of barriers for tidal scheme ?*
16. *Give the advantages of tidal power plant*
17. *Classify the geothermal sources.*

18. *Explain how ocean tides are generated and how the power can be tapped ? Discuss the limitations of this method.*
19. *Describe the construction and principle of operation of a turbine used for tidal power.*
20. *Explain with neat sketches, the operation of a geothermal power plant*
21. *What is geothermal energy ? How can geothermal energy are utilized for electric power generation ?*
22. *Write short notes on wave energy conversion machines.*
23. *What are the advantages and limitations of small scale hydroelectric power ?*
24. *What are the classifications of MHD system ?*
25. *What are the advantages of MHD systems ?*
26. *List the disadvantages of MHD systems.*
27. *Discuss the advantages and limitations of MHD power plant*
28. *Explain in detail MHD open cycle system. What are the advantages of MHD power generation ?*
29. *Describe in detail about the closed cycle system of MHD.*
30. *Differentiate open cycle and closed cycle MHD system*
31. *Write the advantages of geothermal Energy. Explain Liquid dominated geothermal plant.*
32. *Explain the working principle of magneto hydrodynamic generator ? Also compare with conventional power plants.*
33. *What is wave energy ? How it can be used for power generation.*
34. *Write a short note on vapour dominated hydrothermal system*

Other Renewable Energy Sources Ends...

Notes

Notes

Notes

Chapter 4
Bio Mass Energy

1 Write short notes on Biomass Resources.

2 Explain the Biomass Energy Conversion process.

3 Write short notes on cogeneration in Biomass.

4 What do you understand by geothermal energy?

5 What are the merits and demerits of geothermal energy?

6 Explain various types of geothermal resources.

7 Describe various energy extraction technologies used with hydrothermal resources.

8 What are the environmental impacts of geothermal energy?

9 What are the principles on which turbines work?

10 What are the various components of a small hydropower plant or a micro hydel scheme?

11 Explain various types of turbines considered for use in micro hydro resources.

12 Compare the relative advantages and disadvantages of Pelton and Turgo turbines.

Chapter 5
Energy Storage Systems

Q. 1 List different types of Energy storage system.

Q.2 Explain in detail Electrochemical storage system.

Q.3 Explain in detail Mechanical Energy storage system.

Q.4 Explain in detail Electrical Energy storage system.

Q.5 Explain in detail Thermal Energy storage system.

Q.6 Explain in detail Battery Management System.

Q.7 Explain the role of Energy storage system by view point of Electrical Network Operator.

Q.8 Explain the role of Energy storage system by view point of End User.

Q.9 Explain the role of Energy storage system by view point of Electrical Energy Generator.

Q.10 Explain the role of Distributed Generation and inter-connection to power Grid.