GOVERNMENT POLYTECHNIC, SONEPUR

LECTURE NOTE

RENEWABLE ENERGY

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INTRODUCTION TO RENEWABLE ENERGY

- 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 enrgon, which means "in-work" or "work content",,. The work output depends on the energy input. Energy is one among the main inputs for the economic development of any country. Within the case of the developing countries, the energy sector assumes a critical importance in sight of the ever- increasing energy needs requiring huge investments to satisfy them.

1.1 CLASSIFICATIONS OF ENERGY RESOURCES:

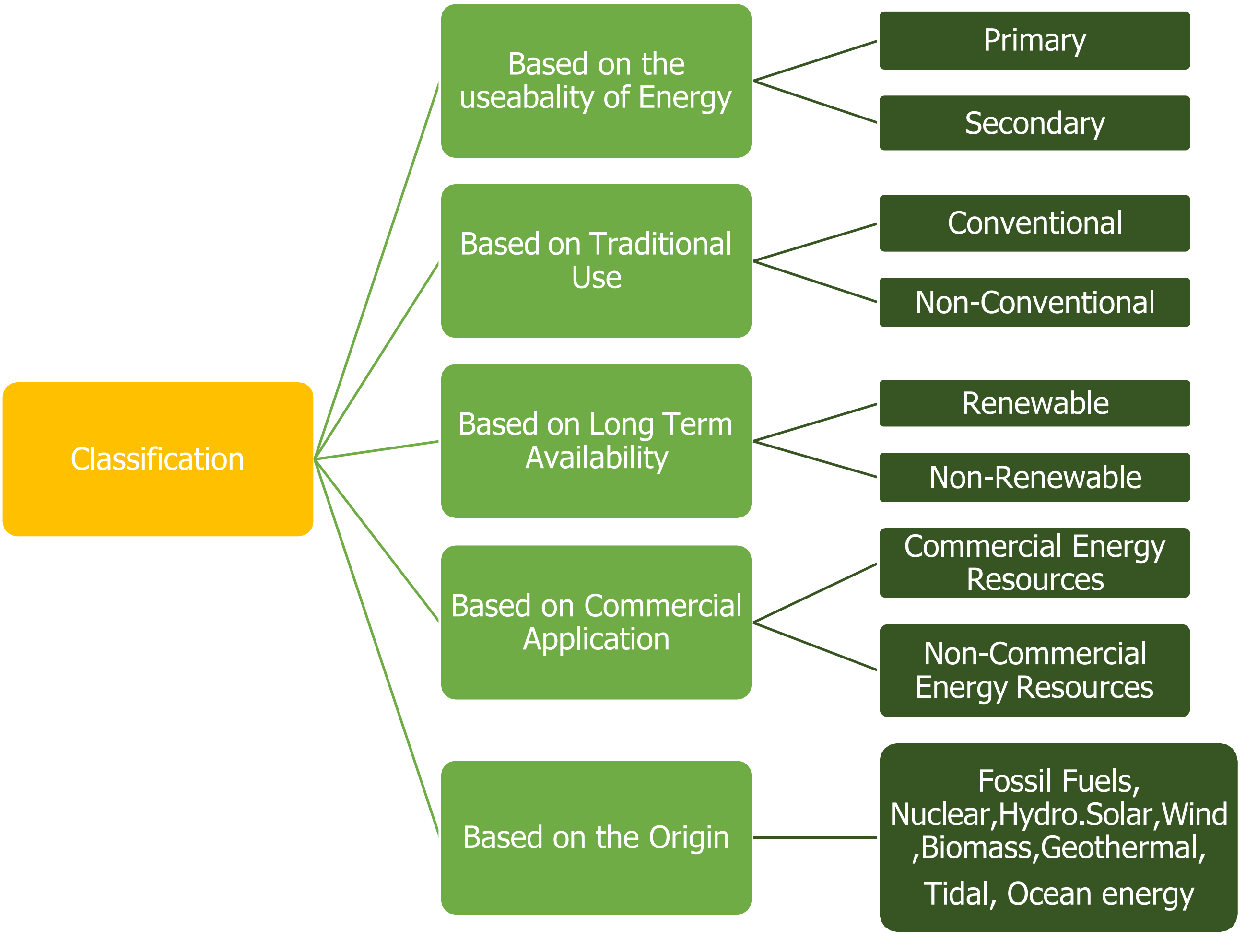


Figure 1.1

1.1.1 Primary and secondary energy resources:

Primary resources:

Resources available in the nature that are available in raw form are calledprimary resources.

Ex: Fossil fuels (coal, oil and gas), uranium and hydropower.

Secondary resources:

Secondary energy resources are obtained from primary energy resources by processing. Processing helps in transformation of primary resources into the secondary or usable energy form so that it can be utilized by consumers.

Ex: Electricity, steam, hot water, petrol, diesel, LNG and CNG

1.1.2 Conventional and non-conventional energy resources:

Conventional:

Resources that have been used traditionally for may years are called as Conventional energy resources. These resources are also widely used at present and likely to be depleted.

Ex: Coal, Petrol, Diesel, Nuclear, CNG and LPG

Non-conventional:

These are alternate energy resources to the conventional energy resources which are being considered to be used on large scale. The conventional energy resource are likely to be depleted in about 50–60 years were as non- conventional resources will not deplete.

Ex: Solar, Wind, Tidal, Geothermal and biogas

1.1.3 Renewable and non-renewable energy resources:

Renewable:

Renewable energy is energy obtained from sources that are essentially inexhaustible Or Resources which can be renewed by nature again and again. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants

Ex: wind power, solar power, geothermal energy, tidal power and hydroelectricpower.

Non-renewable: Resources which are available in certain finite quantity andcannot be replenished are called non-renewable.

Ex: Fossil fuel

1.1.4 Commercial and non-commercial energy resources:

Commercial energy resources:

The secondary usable energy resources such as electricity, CNG, LPG, petrol and diesel are essential for commercial activities. The economy of a nation highly depends on its ability to process and transform the natural raw energy sources into usable commercial energy sources.

Non-commercial energy:

The energy which can be derived directly from nature so as to be used without passing through any commercial outlet is known as the non- commercial energy.

1.1.5 Energy resources of different origins:

The energy resources based on their origin can be nuclear, fossil fuel, hydro, solar, biomass, wind, geothermal, ocean thermal and ocean tidal resources.

1.2 ENVIRONMENTAL CONSEQUENCES OF FOSSIL FUEL USE:

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

The environmental pollution has reached such a high level that it becomes a serious threat for vegetables growth, wild life and human health. Air pollution can cause health problems and it can also damage the environment and property. It has caused thinning of the protective ozone layer, which is leading to climate change. Hundreds of elements and compounds such as benzene and formaldehyde are known to be emitted during the combustion of coal, oil, natural gas, engine of vehicles, furnaces and even fireplaces. Dust storms in desert areas and smoke from forest fires and grass fires contribute to chemical and particulate pollution of the air. The source of pollution may be in one country but the impact of pollution may be felt elsewhere.

1.2.1 Major air pollutants and their sources are listed below: Carbon

monoxide (CO):

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

Carbon dioxide (CO_2):

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

Chlorofluorocarbons (CFC):

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

Lead:

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

Ozone (O_3):

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

Nitrogen oxide (NOx):

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

Suspended particulate matter (SPM):

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

Sulfur dioxide (SO_2):

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

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

1.2.2 Vital Problems Because of Environmental Issues: Acid Rain:

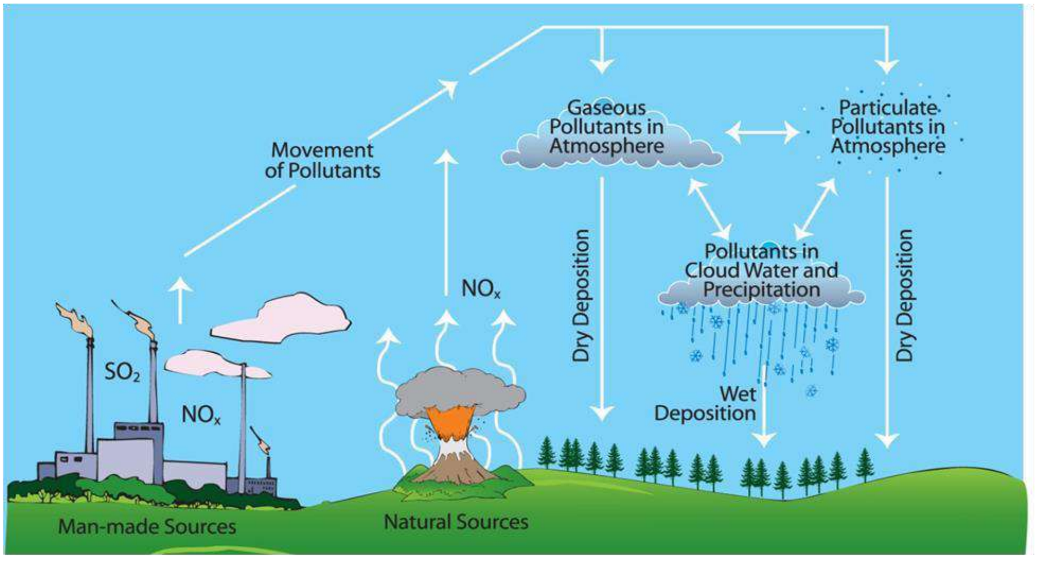
Acid rain is a widespread term used to describe all forms of acid precipitation (rain, snow, hail, fog, etc.) Atmospheric pollutants, particularly oxides of sulfur and nitrogen, can cause precipitation to become more acidic when converted to sulfuric and nitric acids, hence the term acid rain. Motor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

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

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

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

Figure 1.2



Depletion of Ozone Layer:

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

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

Global Warming and Climate Change (Greenhouse Effect):

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

The greenhouse effect is also experienced on a larger scale on Earth. This warms up as a result of the absorption of solar energy (shortwave length) during the day, cools down at night by radiating part of its energy into deep space as infrared radiation (long wavelength). Carbon dioxide (CO2), water vapour and trace amounts of some other gases such as methane (CH4) and nitrogen oxides act like a blanket and keep the Earth warm at night by blocking the heat radiation from the Earth, as shown in the Figure 1.3 Therefore, they are called „„„greenhouseeffect‟‟‟ gases. In this case, the CO_2 is the primary component.

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

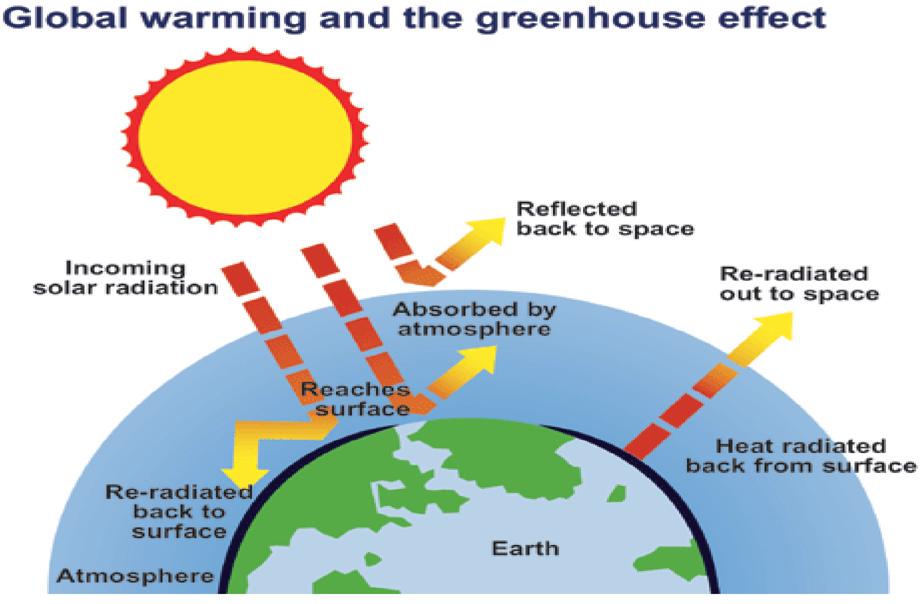


Figure 1.3

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

1.3 SIGNIFICANCE OF RENEWABLE ENERGY SYSTEM:

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

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

fossil fuels is taking place at a rapid pace.

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

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

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

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

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

1.4 ADVANTAGES AND DISADVANTAGES OF NON-RENEWABLE ENERGY SYSTEM:

Advantages:

- Cost: At present these are cheaper than Renewable sources.
- Security: As storage is easy and convenient, by storing certain quantity, theenergy availability can be ensured for certain period.
- Convenience: These sources are very convenient to use as technology fortheir conversion and use is universally available.

Disadvantages:

- Fossil fuels generate pollutants. Main pollutants generated in the use of these sources are CO, CO_2, NOx, SOx, particulate matter and heat. These pollutants degrade the environment, pose health hazards and cause various other problems. CO_2 is mainly responsible for global warming also.
- Coal is used as raw material for various chemical, pharmaceuticals and paints, etc. industries. From long-term point of view it is desirable to conserve coal for future needs.
- There are safety and technical issues with nuclear energy. Major problems associated with nuclear energy are as follows:
    - The waste material generated in nuclear plants has radioactivity of dangerous level. Its safe disposal, which is essential to prevent radioactive pollution, is a challenging task. Also the disposed radioactive waste is required to be guarded for a long period (till its radioactivity level comes down to a safe limit) in order to prevent against going in wrong hands.

    - Possibility of accidental leakage of radioactive material from reactor
    - Uranium resource, for which the technology presently exists, has limitedavailability.
    - Sophisticated technology is required for using nuclear resources. Onlyfew countries possess the required expertise to use nuclear energy.
- Hydroelectric plants are cleanest but large hydro-reservoirs cause followingproblems:
    - As large land area submerges into water, it leads to deforestation
    - Causes ecological disturbances such as earthquakes
    - Affects wild life
    - Causes dislocation of large population and their rehabilitation Problems

1.5 ADVANTAGES AND DISADVANTAGES OF RENEWABLEENERGY SYSTEM:

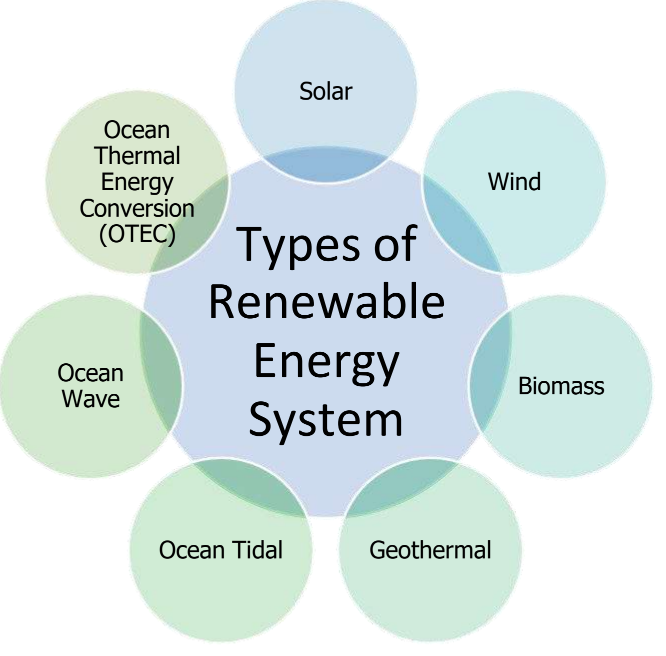
Advantages:

- These sources of energy are renewable and there is no threat of depletion. These persist in nature and are in-exhaustible.
- Don‟t have any fuel cost and hence negligible running cost.
- Renewable are more site specific and are used for local processing and application. There is no need for transmission and distribution of power.
- Renewable have low energy density and more or less there is no pollution or ecological balance problem.
- Most of the devices and plants used with the renewable are simple in design and construction which are made from local materials, local skills and by local people. The use of renewable energy can help to save foreign exchange and generate local employment.
- The rural areas and remote villages can be better served with locally available renewable sources of energy. There will be huge savings from transporting fuels or transmitting electricity from long distances.

Disadvantages:

- Low energy density of renewable sources of energy need large sizes of plantresulting in increased cost of delivered energy.
- Intermittency and lack of dependability are the main disadvantages ofrenewable energy sources.
- Low energy density also results in lower operating temperatures and hencelow efficiencies.
- Although renewables are essentially free, there is definite cost effectivenessassociated with its conversion and utilization.
- Much of the construction materials used for renewable energy devices are themselves very energy intensive.
- The low efficiency of these plants can result in large heat rejections andhence thermal pollution.
- The renewable energy plants use larger land masses.

1.6 TYPES OF RENEWABLE ENERGY SYSTEM:



1.6.1 Solar Energy:

Solar energy is energy derived from sun in the form of solar radiation. It is hardness by either direct sources (like solar cooker, solar steam systems, solar dryer, solar cells, etc.), or indirect sources (biomass production, wind, tidal, etc.). The output of the sun is 2.8 x 1023 Kw per Year. The energy reaching the earth is 1.5x 108 Kw per Year. It is used for drying, cooking, heating, generating power etc.

Advantages

- Almost limitless source of energy
- Solar energy is available freely in nature
- Does not produce air pollution

Disadvantages

- It is available only during daytimes and clear days
- Solar energy obtainable also depends on seasonal variations
- It requires a large area to entrap appreciable solar energy for the generationof an economical amount of electricity.

1.6.2 Wind Energy:

Wind is induced in atmosphere by uneven heating of earth"s surface by the sun. The wind energy can be used to run windmill, which in turn will drive a generator to produce electric power or run water pumps. The energy available in the wind is about $1.5*10^7$

Advantages

- Renewable
- It is freely and abundantly available in nature
- Relatively inexpensive to generate
- Does not produce air pollution
- Windmills require minimal maintenance and operating cost

Disadvantages

- Only suitable in windy areas
- Produces less energy
- Wind mill is big, bulky and inconvenient to use as compared to other formsof energy

1.6.3 Biomass:

Organic material made from plants and animals (microorganisms).
Biomass has an existing capacity of over 7,000 MW. Biomass as a fuel consists oforganic matter such as industrial waste, agricultural waste, wood, and bark.
Biomass can also be used indirectly, since it produces methane gas as it decays orthrough a modern process called gasification. Methane can produce power by burning in a boiler to create steam to drive steam turbines or through internal combustion in gas turbines and reciprocating engines.

Advantages

- It's a Clean & Renewable Energy SourceIt
- Reduces Soil & Water Pollution Cleaner
- burning than oil
- Abundant

Disadvantages

- It is dispersed and land intensive source
- Produces smoke
- It has low energy density

1.6.4 Geothermal:

Geothermal energy is energy derived by tapping the heat of the earth itself like volcano, geysers, hot springs (etc.). These volcanic features are called geothermal hotspots. Basically a hotspot is an area of reduced thickness in the mantle which expects excess internal heat from the interior of the earth to the outer crust. The heat from these geothermal hotspots is altered in the form of steam which is used to run a steam turbine that can generate electricity.

Advantages

- Reliable and Sustainable
- Environmentally friendly
- It has a good potential to meet the power requirement

Disadvantages

- High cost of investment
- Emission of greenhouse gases during extraction of heat from ground.
- Groundwater is likely to be polluted from gaseous effluents Components of
- the plants are liable to be corroded

1.6.5 Ocean Tidal:

Tidal energy is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity. Tides are defined as the rise and fall of sea level caused by the gravitational pull of the moon and the sun on the Earth. They are not only limited to the oceans, but can also occur in other systems whenever a gravitational field exists

Advantages

- It is free from pollution
- The tidal basin can also be used for fish farmingIt is
- best suited to meet peak power demands
- It is superior to hydel energy as it does not depend on rains

Disadvantages

- Tidal power plant is costly compared to thermal and hydel power plants
- Limited locations are available for the construction of tidal power stations
- Power generation is not continuous and depends on the capacity of tidalbasin

1.6.6 Ocean Wave:

Wave energy, also known as ocean energy is defined as energy harnessed from oceanic waves. As the wind blows across the surface of the ocean, it creates waves and thus they can also be referred to as energy moving across the surface of the water.

Advantages

- Running cost is negligible
- Continuous power supply

Disadvantages

- Low efficiency
- High installation cost

1.6.7 Ocean Thermal Energy Conversion (OTEC):

Ocean thermal energy (OTE) is the temperature differences (thermal gradients) between ocean surface waters and that of ocean depths. Energy from the sun heats the surface water of the ocean. In tropical regions, surface water can be much warmer than deep water. This temperature difference can be used to produce electricity and to desalinate ocean water

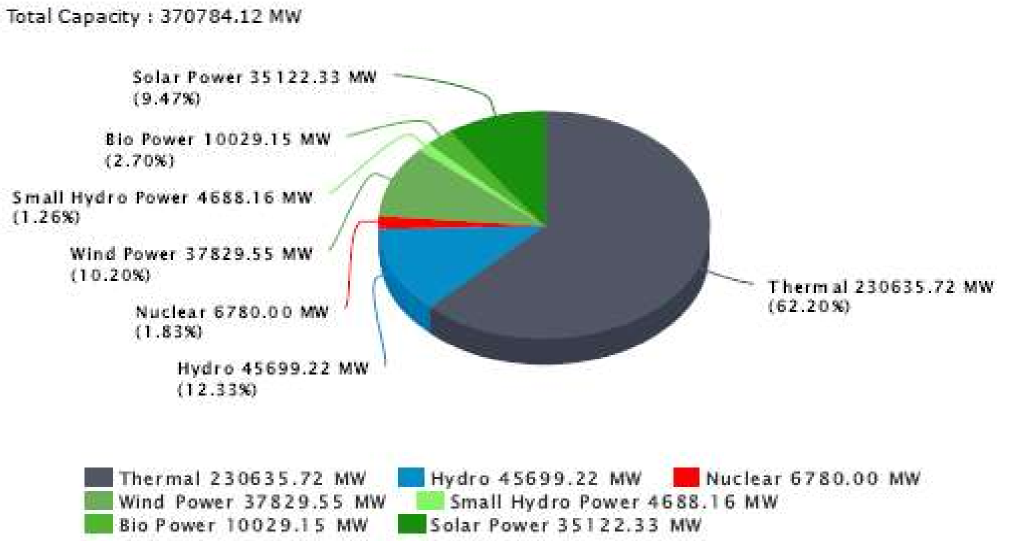
Advantages

- Power generation is continuous throughout the year.
- Energy is available from nature at no cost.

Disadvantages

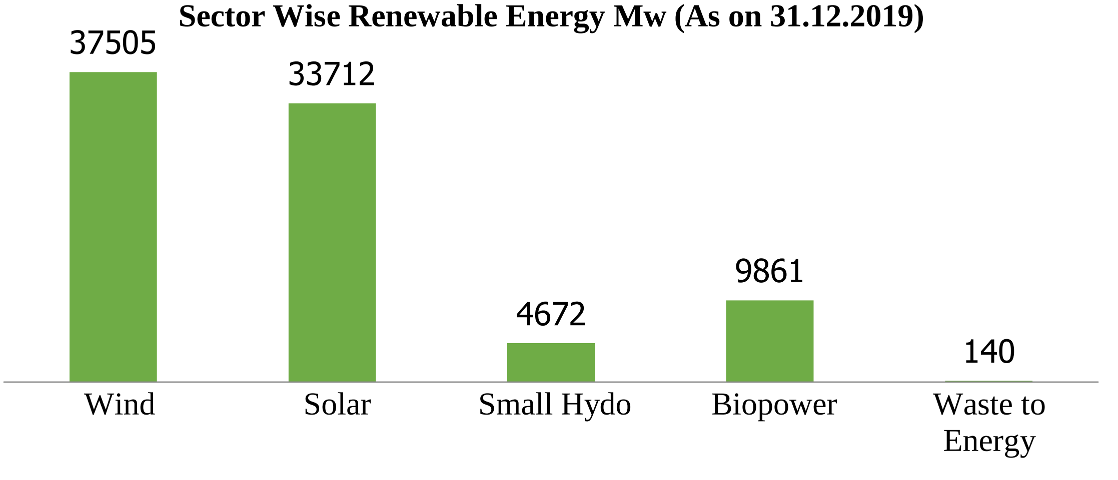
- It has a small temperature gradient which gives a small thermodynamicefficiency.
- Capital cost is high due to necessity of heat exchanger, boiler and condenser.

❁ 1.7 INDIAN ENERGY SENERIO:



The economic development of the country is strongly depends on its energy utilization. Presently, India ranks as the world‟s third largest producer. This country is also the world‟s third largest energy consumer. The total energy production in India is 371054 MW (as on 30.6.2020) out of which 35.90% i.e 1, 33,368 MW of energy is generated by renewable energy and 64% i.e 2, 37,686 MW. The conventional energy production has been dominated by Coal. The graph given below has shown the total power production as on date.

In 1982, a separate Department of Non-Conventional Energy Sources (DNES) was created in the Ministry of Energy to look after all the aspects relatingto New and Renewable Energy. The Department was upgraded into a separate Ministry of Non-Conventional Energy Sources (MNES) in 1992 and was rechristened as Ministry of New and Renewable Energy (MNRE), in October 2006.



1.7.1.1 Solar Energy:

National Solar Mission (NSM), launched on 11th January, 2010, had set a target for development and deployment of 20 GW solar power by the year 2022. The Cabinet in its meeting held on 17/6/2015 had approved revision of target under NSM from 20 GW to 100 GW.

This scheme covered large solar power plants of total 1,000 MW capacity connected to grid at 33 kV and above - 500 MW capacity each based on Solar Thermal (ST) and Solar Photovoltaic (SPV) technologies. It included three stages:
(i) Migration Scheme (ii) NSM Phase-I, Batch-I and (iii) NSM Phase-I, Batch-II.

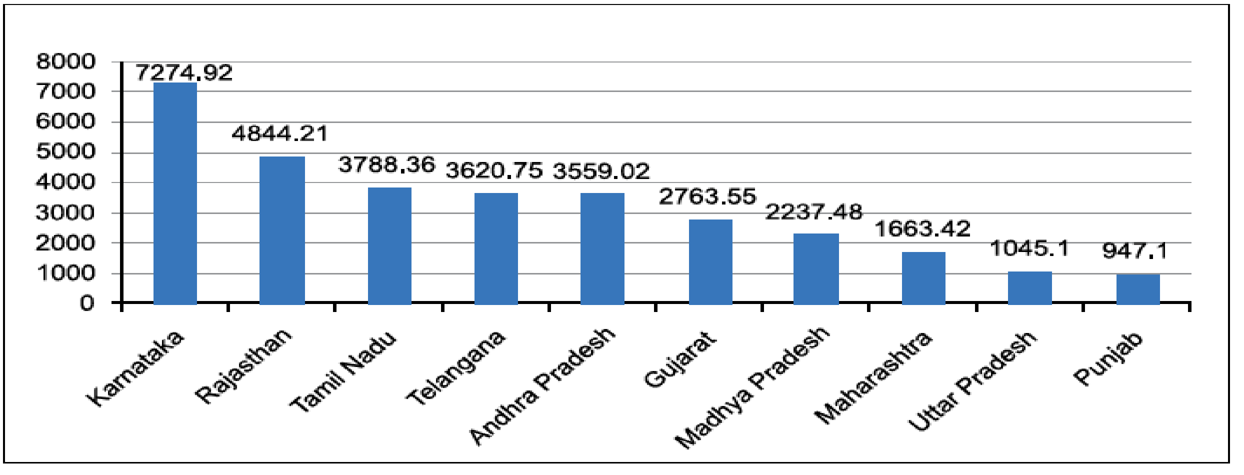


Figure 1.7 Top Ten states in Solar Power Production (As on 31.12.19)

1.7.1.2 Wind Energy:

India"s wind energy sector is led by indigenous wind power industry and has shown consistent progress. The expansion of the wind industry has resulted in a strong ecosystem, project operation capabilities and manufacturing base of about 10,000 MW per annum. The country currently has the fourth highest wind installed capacity in the world with total installed capacity of 37.50 GW (as on 31stDecember, 2019)

1.7.1.3 Biomass:

Ministry has been promoting Biomass Power and Biogases Co-generation Programme with the aim to recover energy from biomass including biogases, agricultural residues such as shells, husks, de-oiled cakes and wood from dedicated energy plantations for power generation. A new scheme to support promotion of biomass based cogeneration in sugar mills and other industries has been notified.

The potential for power generation from agricultural and agro-industrial residues is estimated at about 18,000 MW. With progressive higher steam temperature and pressure and efficient project configuration in new sugar mills and modernization of existing ones, the potential of surplus power generation through biogases cogeneration in sugar mills is estimated at around 8,000 MW. Thus the total estimated potential for biomass power is about 26,000 MW.

Over 500 biomass power and cogeneration projects with aggregate capacity of 9186.50 MW have been installed in the country up to December 2019.

1.7.1.4 Green Energy Corridor:

In order to facilitate integration of large scale renewable generation capacity addition, the Cabinet Committee of Economic Affairs (CCEA) in FY 2015- 16, approved the creation of Intra-state Transmission System in the states of Andhra Pradesh, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu, rich in renewable resource potential and where large capacity renewable power projects are planned, at an estimated cost of Rs.10,141.68 crore with Government of India contribution of Rs.4056.67 crore.

The activities envisaged under the project includes establishment of Grid sub-stations of different voltage levels with aggregate transformation capacity of approx. 22600 Mega Volt Ampere (MVA) and installation of approx. 9700 circuit kilometers (ckm) of transmission lines in these eight states. The creation of the Intra-State Transmission System will facilitate the evacuation of over 20 GW of power from renewable energy generation stations to load centers. The project is anticipated to be completed by 2021 with funding mechanism consisting of 40% Central Grant, 40% KfW loan (Euro 500 million) and the remaining 20 percent as State contribution

1.7.2 World Energy Scenario:

- The decade-long trend of strong growth in renewable energy capacity continued in 2018 with global additions of 171 GW, according to new data released by the International Renewable Energy Agency (IRENA) on April 2,2019.
- A third of global power capacity is now based on renewable energy.
- IRENA‟s annual Renewable Capacity Statistics 2019, the most comprehensive, up-to-date and accessible figures on renewable energy capacity indicates growth in all regions of the world, although at varyingspeeds.
- While Asia accounted for 61% of total new renewable energy installations and grew installed renewable capacity by 11.4%, growth was fastest in Oceania that witnessed a 17.7% rise in 2018. Africa‟s 8.4% growth put it inthird place just behind Asia.
- Nearly two-thirds of all new power generation capacity added in 2018 wasfrom renewables, led by emerging and developing economies.

- IRENA"s analysis also compared the growth in generation capacity of renewables versus nonrenewable energy, mainly fossil-fuels and nuclear.
- While non-renewable generation capacity has decreased in Europe, North America, and Oceania by about 85 GW since 2010, it has increased in bothAsia and the Middle East over the same period.
- Net electricity generation (to the grid) in countries that are not part of the Organization of Economic Cooperation and Development (OECD) increases an average of 2.3% per year from 2018 to 2050, compared with 1.0% per year in OECD countries.
- Renewable (including hydropower) are the fastest-growing source of electricity generation during the 2018 to 2050 period, rising by an average of3.6% per year. Technological improvements and government incentives in many countries support their increased use.
- By 2050, China, India, OECD Europe, and the United States have almost 75% of the world"s renewable generation. Growth in these regions results from both policy and, in the case of India and China, increasing demand fornew sources of generation.
- Natural gas generation grows by an average of 1.5% per year from 2018 to 2050, and nuclear generation grows by 1.0% per year. The level of coal-firedgeneration remains relatively stable, but its share of electricity generation declines from 35% in 2018 to 22% by 2050 as total generation increases.
- By 2025, in the Reference case, renewable surpasses coal as the primary source for electricity generation, and by 2050, renewable account for almosthalf of total world electricity generation.
- With modest growth, hydropower"s share of renewable generation falls from 62% in 2018 to 28% in 2050 because resource availability in OECD countries and environmental concerns in many countries limit the number of new mid- and large-scale projects.
- Generation from non-hydropower renewable increases an average of 5.7%per year from 2018 to 2050. By 2050, China, India, OECD Europe, and the United States are responsible for more than 80% of the world"s non- hydropower renewable generation.
- Among renewable energy sources, electricity generation from wind and solar resources increase the most between 2018 and 2050, reaching 6.7 trillion and 8.3 trillion kilowatt-hours (kWh), respectively, as these technologies become more cost competitive and are supported by government policies in many countries.
- By 2050, wind and solar account for over 70% of total renewable generation.

Solar Photovoltaic System

INTRODUCTION

Photovoltaic power generation is a method of producing electricity using solar cells. A solar cell converts solar optical energy directly into electrical energy. A solar cell is essentially a semiconductor device fabricated in a manner which generates a voltage when solar radiation falls on it.

In semiconductors, atoms carry four electrons in the outer valence shell, some of which can be dislodged to move freely in the materials if extra energy is supplied. Then, a semiconductor attains the property to conduct the current. This is the basic principle on which the solar cell works and generates power.

SEMICONDUCTOR MATERIALS AND DOPING

A few semiconductor materials such as silicon (Si), cadmium sulphide (CdS) and gallium arsenide (GaAs) can be used to fabricate solar cells. Semiconductors are divided into two categories—intrinsic (pure) and extrinsic. An intrinsic semiconductor has negligible conductivity, which is of little use. To increase the conductivity of an intrinsic semiconductor, a controlled quantity of selected impurity atoms is added to it to obtain an extrinsic semiconductor. The process of adding the impurity atoms is called *doping*.

In a pure semiconductor, electrons can stay in one of the two energy bands—the conduction band and the valence band. The conduction band has electrons at a higher energy level and is not fully occupied, while the valence band possesses electrons at a lower energy level but is fully occupied (Figure 6.1).

The energy level of the electrons differs between the two bands and this difference is called the band gap energy, E_g. Photons of solar radiation possessing energy E higher than the band gap energy E_g, when absorbed by a semiconductor material, dislodge some of the electrons.

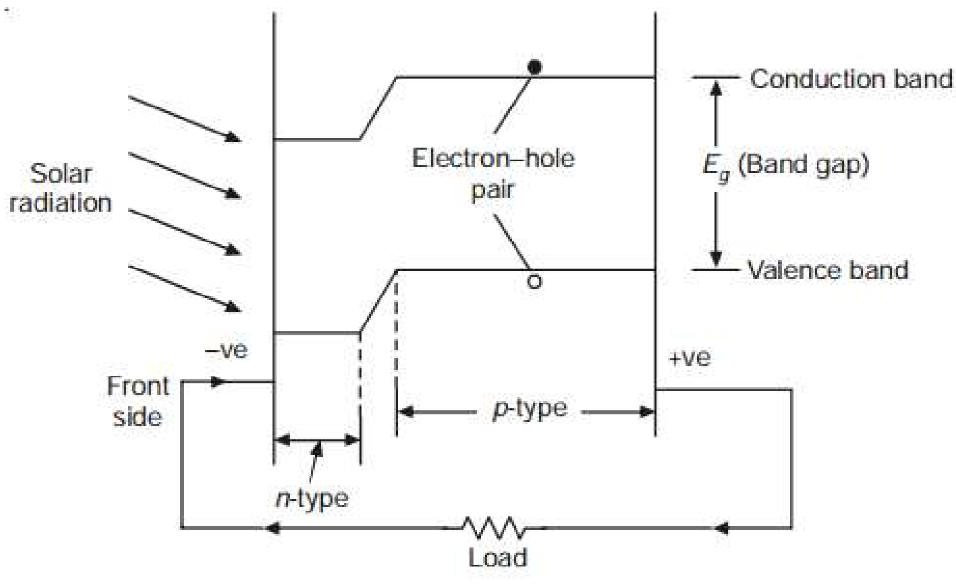


Figure 6.1 Semiconductor diode band structure.

These electrons possess enough energy to jump over the band gap from the valence band into the conduction band. In this process, vacant electron positions or *holes* are left behind in valence band. These holes act as positive charges and can *move* if a neighboring electron leaves its position to fill the *hole* site.

Mobile electrons and holes can thus enable a current flow through an external circuit if a potential gradient exists in the cell material.

SOLAR PHOTOVOLTAIC SYSTEM (SPS)

A PV module produces dc power. To operate electrical appliances used in households, inverters are used to convert dc power into 220 V, 50 Hz, ac power. Components other than PV module are collectively known as Balance of System (BOS) which includes storage batteries, an electronic charge controller, and an inverter.

Storage batteries with charge regulators are provided for back-up power supply during periods of cloudy day and during nights. Batteries are charged during the day and supply power to loads as detailed in Figure 6.10.

The capacity of a battery is expressed in ampere-hours (Ah) and each cell of the lead-acid type battery is of 2 volts. Batteries are installed with a microprocessor-based charge regulator to monitor the voltage and temperature and to regulate the input and the output currents to obviate overcharging and excessive discharge, respectively.

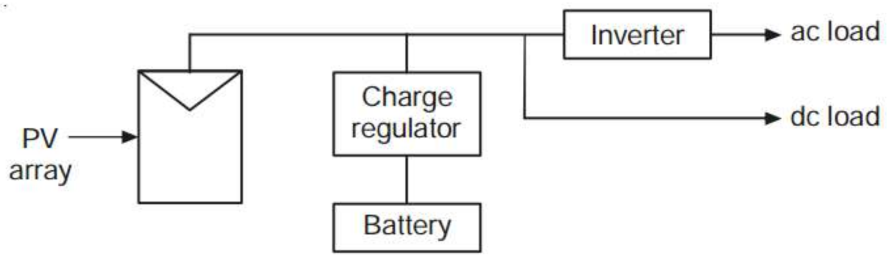
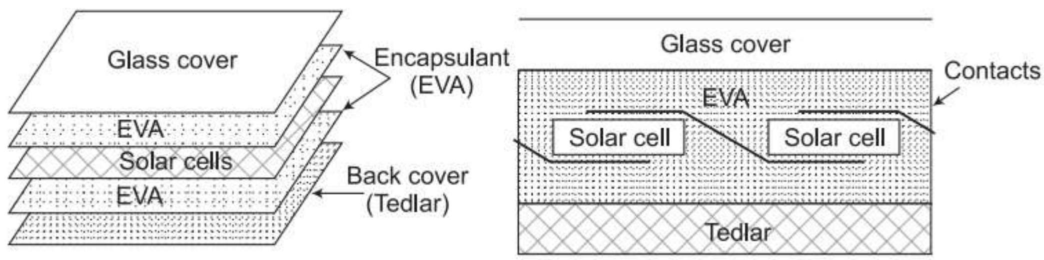


Figure 6.10 Block diagram of an SPS.

An inverter is provided for converting dc power from battery or PV array to ac power. It needs to have an automatic switch-off in case the output voltage from the array is too low or too high. The inverter is also protected against overloading and short circuit.

solar cell

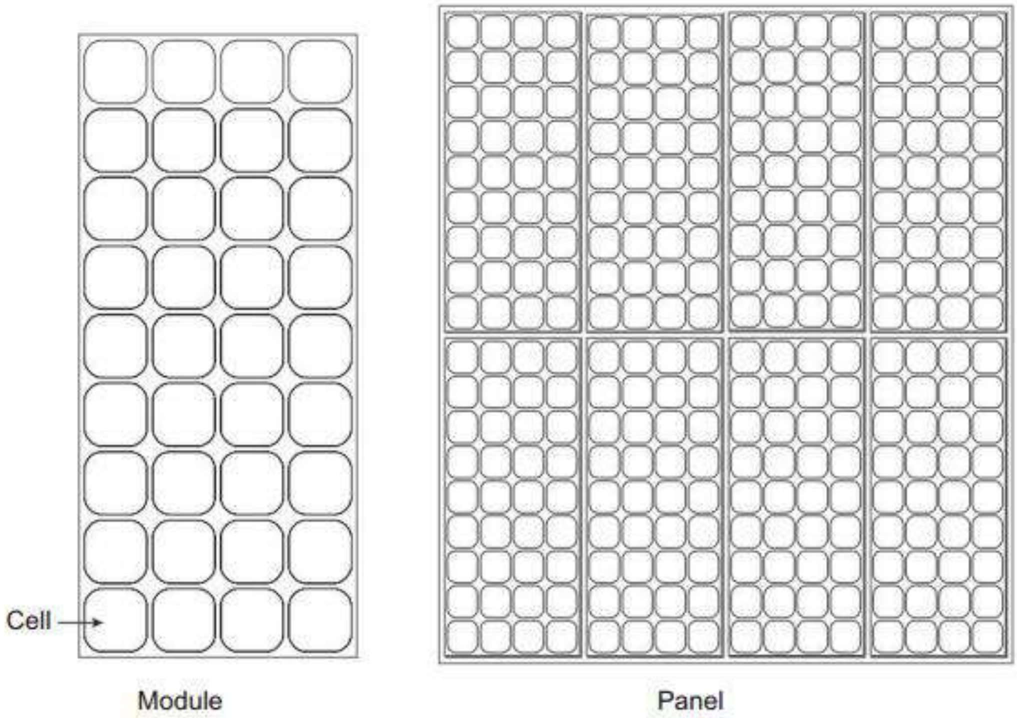
A single solar cell cannot provide required useful output. So to increase output power level of a PV system, it is required to connect number of such PV solar cells. A solar module is normally series connected sufficient number of solar cells to provide required standard output voltage and power. One solar module can be rated from 3 watts to 300 watts.



(a) Components of wafer based PB module (b) Series connection of cells

SOLAR PV PANEL

Several solar modules are connected in series/parallel to increase the voltage/current ratings. When modules are connected in series, it is desirable to have each module's maximum power production occur at the same current. When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage.



SOLAR PV ARRAY

In general, a large number of interconnected solar panels, known as solar PV array, are installed in an array field.

These panels may be installed as stationary or with sun tracking mechanism.

It is important to ensure that an installed panel does not cast its shadow on the surface of its neighboring panels during a whole year.

The layout and mechanical design of the array such as tilt angle of panels, height of panels, clearance among the panels, etc., are carried out taking into consideration the local climatic conditions, ease of maintenance, etc

6.8 MAXIMUM POWER POINT TRACKER

When a solar PV system is deployed for practical applications, the *I-V* characteristic keeps on changing with insolation and temperature. In order to receive maximum power the load must adjust itself accordingly to track the maximum power point. The I-V characteristics of PV system, along with some common loads, are shown in Fig. 6.36. An ideal load is one that tracks the maximum power point.

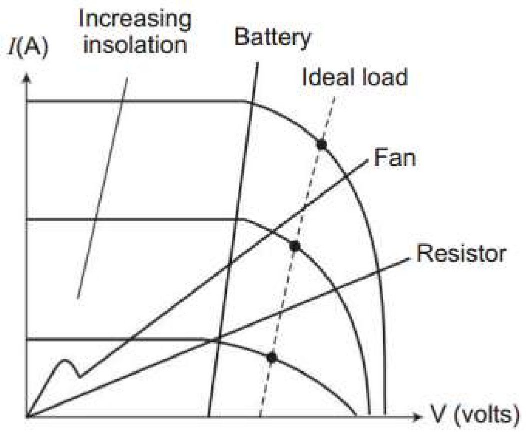


Figure 6.36 Characteristics of PV and some loads

If the operating point departs significantly from maximum power point, it may be desirable to interpose an electronic maximum power point tracker (MPPT) between PV system and load. Generally MPPT is an adaptation of dc-dc switching voltage regulator. Coupling to the load for maximum power transfer may require either providing higher voltage at a lower current or lower voltage for higher current. A buck-boost scheme is commonly used with voltage and current sensors tied into a feedback loop using a controller to vary the switching times. Basic elements of a buck boost converter that may be used in an MPPT are shown in Fig. 6.37. The output voltage of the buck-boost converter is given by:

$$V_{out} = \frac{D}{1-D} V_{in} \tag{6.38}$$

where D is the duty cycle of the MOSFET, expressed as fraction ($0 < D < 1$). Details of operation and design of the converter may be found in any standard book of power electronics.

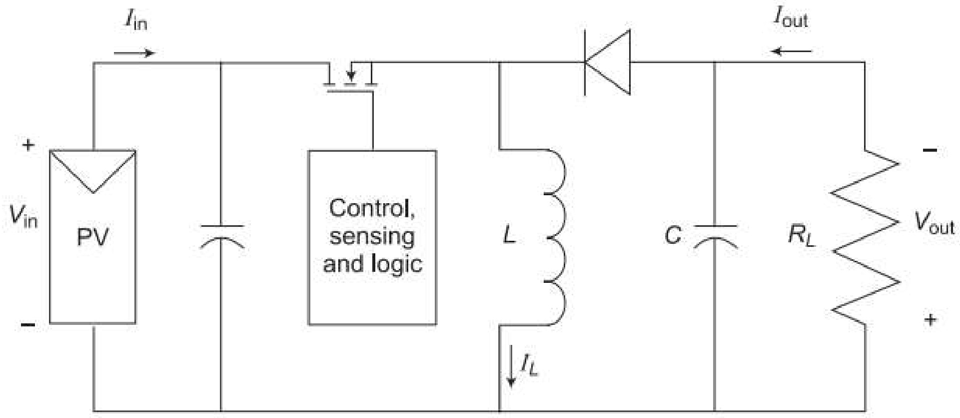


Figure 6.37 Maximum point tracker using buck-boost converter

There are 3 possible strategies for operation of a MPPT

(a) By Monitoring Dynamic and Static Impedances A small signal current is being periodically injected into an array bus and the dynamic as well as static bus impedances (Z_d and Z_s respectively) are being measured. The operating voltage is then adjusted until the condition $Z_d = -Z_s$ is achieved.

(b) By Monitoring Power Output From the shape of P-V characteristics given in Fig. 6.14(c) it is clear that the slope, dP/dV is zero at maximum power point. This property is utilized to track the maximum power point. Voltage is adjusted and power output is sensed. The operating voltage is increased as long as dP/dV is positive. That is, voltage is increased as long as we get increased output. If dP/dV is sensed negative, the operating voltage is decreased. The voltage is held unaltered if dP/dV is near zero within a preset dead band.

(c) By Fixing the Output Voltage as a Fraction of V_{oc} This method makes use of the fact that for most PV cells the ratio of the voltage at maximum power point to the open circuit voltage, is approximately constant (say k). This is also evident from Fig. 6.14. For high quality crystalline silicon cell $k = 0.72$. In order to implement this principle, an additional identical unloaded cell is installed on the array to face same environment as the module in use and its open circuit voltage V_{oc} is continuously measured. The operating voltage of the array is then set at $k.V_{oc}$. The implementation of this scheme is simplest among all the available schemes.

SOLAR CONSTANT

The sun, being at a very large distance from the earth, solar rays subtend an angle of only 32 minutes on earth, as shown in Figure 3.1. Energy flux received from the sun before entering the earth's atmosphere, is a constant quantity.

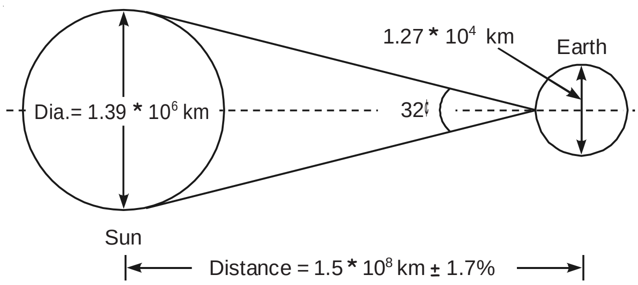


Figure 3.1 Sun–Earth geometry

The solar constant, I_{sc}, is the energy from the sun received on a unit area perpendicular to the solar rays at the mean distance from the sun outside the atmosphere. Based on the experimental measurements, the standard value of the solar constant is 1367 W/m^2

EXTRATERRESTRIAL RADIATION

- Extraterrestrial radiation is the measure of solar radiation that would be received in the absence of atmosphere.

TERRESTRIAL SOLAR RADIATION

- For utilisation of solar energy, a study is required to be carried out of radiations received on the earth's surface.
- Solar radiations pass through the earth's atmosphere and are subjected to scattering and atmospheric absorption.
- A part of scattered radiation is reflected back into space. Short wave ultraviolet rays are absorbed by ozone and long wave infrared rays are absorbed by CO_2 and water vapors. Scattering is due to air molecules, dust particles and water droplets that cause attenuation of radiation as detailed in Figure 3.3. Minimum attenuation takes place in a clear sky when the earth's surface receives maximum radiation.

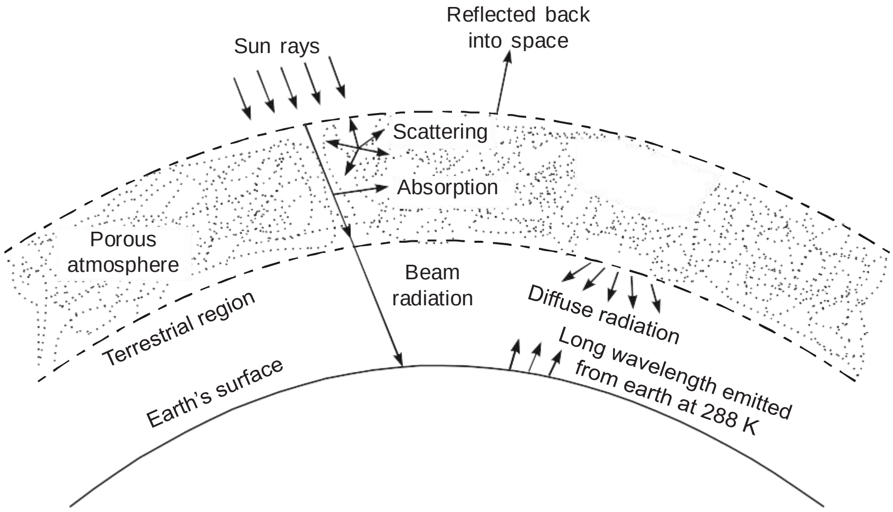


Figure 3.3 Solar radiation atmospheric mechanisms.

The terms pertaining to solar radiation are now defined as below:

Beam radiation (I_b): Solar radiation received on the earth's surface without change in direction, is called *beam* or *direct radiation*.

Diffuse radiation (I_d): The radiation received on a terrestrial surface (scattered by aerosols and dust) from all parts of the sky dome, is known as *diffuse radiation*.

Total radiation (I_T): The sum of beam and diffuse radiations (I_b + I_d) is referred to as total radiation. When measured at a location on the earth's surface, it is called *solar insolation* at the place. When measured on a horizontal surface, it is called *global radiation* (I_g).

Sun at zenith: It is the position of the sun directly overhead.

Irradiance (W/m^2): The rate of incident energy per unit area of a surface is termed *irradiance*.

Solar radiation varies in intensity at different locations on the earth, which revolves elliptically around the sun. For the calculation of solar radiation, the position of a point P on the earth's surface with regard to sun's rays can be located, if the latitude f, the hour angle w for the point and the sun's declination d are known. These basic angles for a location P on the northern hemisphere are shown in Figure 3.5 and defined as follows:

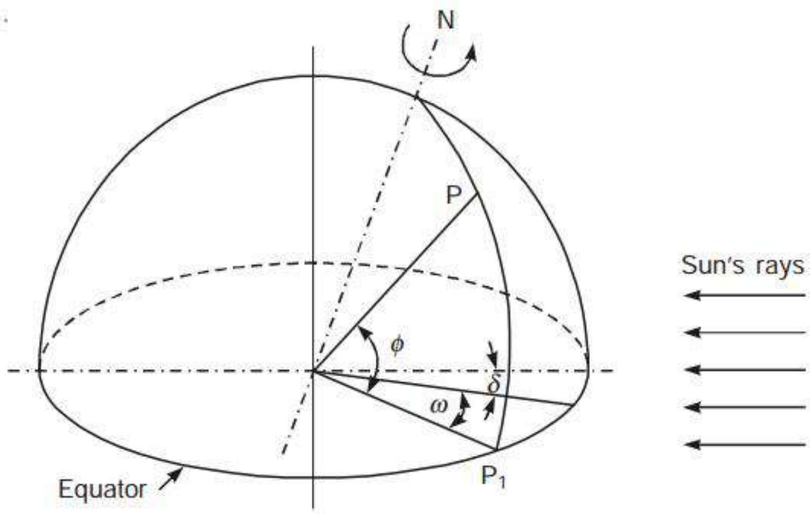


Figure 3.5 Latitude ϕ, hour angle ω and sun's declination δ.

Hour angle (w): Hour angle w is the angle through which the earth must rotate to bring the meridian of the point directly under the sun (Figure 3.5). It is the angular measure of time at the rate of 15° per hour. Hour angle is measured from noon, based on local apparent time being positive in the afternoon and negative in the forenoon.

Altitude angle (a): It is a vertical angle between the direction of the sun's rays (passing through the point) and its projection on the horizontal plane (Figure 3.8).

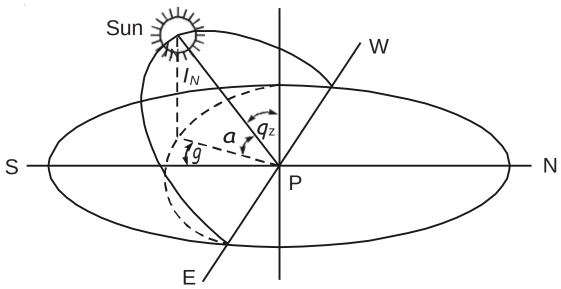


Figure 3.8 Sun's zenith, altitude and azimuth angles (northern hemisphere).

Zenith angle (q_z): It is the vertical angle between the sun's rays and the line perpendicular to the horizontal plane through the point. It is the complimentary angle of the sun's altitude angle. Thus,

$$q_z + a = \frac{p}{2}$$

Surface azimuth angle (g): It is an angle subtended in the horizontal plane of the normal to the surface on the horizontal plane (Figure 3.8). By convention, the angle is taken positive if the normal is west of south and negative when east of south in northern hemisphere, and vice versa for southern hemisphere.

Solar azimuth angle ***(g_s)***

It is an angle in the horizontal plane between the line due south and projection of beam radiation on the horizontal plane. Conventionally, the solar azimuth angle is considered positive if the projection of the sun beam is west of south and negative if east of south in the northern hemispher

Solar Collectors

A solar thermal energy collector is equipment in which solar energy is collected by absorbing radiation in an absorber and then transferring to a fluid. In general, there are two types of collectors:

Flat-plate solar collector: It has no optical concentrator. Here, the collector area and the absorber area are numerically the same, the efficiency is low, and temperatures of the working fluid can be raised only up to 100°C.

Concentrating-type solar collector: Here the area receiving the solar radiation is several times greater than the absorber area and the efficiency is high. Mirrors and lenses are used to concentrate the sun's rays on the absorber, and the fluid temperature can be raised up to 500°C. For better performance, the collector is mounted on a tracking equipment to face the sun always with its changing position.

In this chapter, both the above types of solar collectors are discussed in detail.

4.1 FLAT-PLATE COLLECTOR

A schematic cross-section of a flat-plate collector is shown in Figure 4.1. It consists of five major parts as mentioned below:

(i) A *metallic flat absorber plate* of high thermal conductivity made of copper, steel, or aluminum, and having black surface. The thickness of the metal sheet ranges from 0.5 mm to 1 mm.

(ii) *Tubes* or *channels* are soldered to the absorber plate. Water flowing through these tubes takes away the heat from the absorber plate. The diameter of tubes is around 1.25 cm, while that of the header pipe which leads water in and out of the collector and distributes it to absorber tubes, is 2.5 cm.

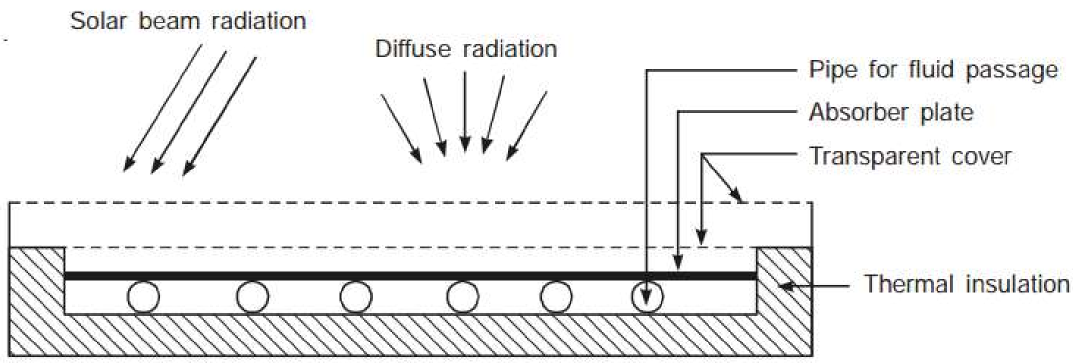


Figure 4.1 Schematic cross section of a flat-plate collector.

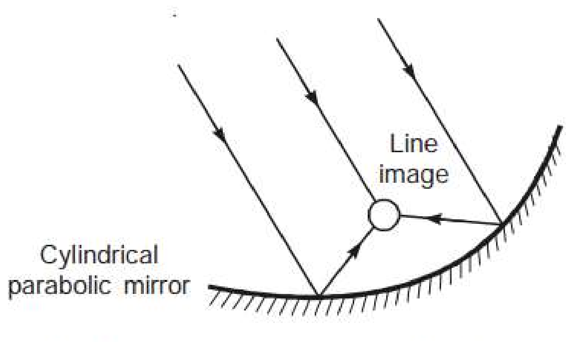


Figure 4.11 Cross section of a cylindrical parabolic collector.

(i) A *transparent toughened glass sheet* of 5 mm thickness is provided as the cover plate. It reduces convection losses through a stagnant air layer between the absorber plate and the glass. Radiation losses are also reduced as the spectral transmissivity of glass is such that it is transparent to short wave radiation and nearly opaque to long wave thermal radiation emitted by interior collector walls and absorbing plate.

(ii) Fiber glass insulation of thickness 2.5 cm to 8 cm is provided at the bottom and on the sides in order to minimize heat loss.

(iii) A container encloses the whole assembly in a box made of metallic sheet or fiber glass. In Figure 4.1, since the heat transfer fluid is liquid, so, this type of flat-plate collector is also known as liquid flat-plate collector.

The commercially available collectors have a face area of 2 m^2. The whole assembly is fixedon a supporting structure that is installed in a tilted position at a suitable angle facing south in the northern hemisphere. For the whole year, the optimum tilt angle of collectors is equal to the latitude of its location. During winter, the tilt angle is kept 10 – 15° more than the latitude of the location while in summer it should be 10 – 15° less than the latitude.

SOLAR CONCENTRATING COLLECTORS

While dealing with flat-plate collectors with heat transport medium as water or air, the area of glass cover and that of absorber plate are practically the same. Thus, solar radiation intensity is uniformly distributed over the glass cover and the absorber, keeping the temperature rise of the solar device up to 100°C. If solar radiation falling over a large surface is concentrated to a smaller area of the absorber plate or receiver, the temperature can be enhanced up to 500°C. Concentration is achieved by an optical system either from the reflecting mirrors or from the refracting lenses. These concentrators are used in medium temperature or high temperature energy conversion cycles.

An optical system of mirrors or lenses projects the radiation on to an absorber of smaller area. This process compensates the reflection or absorption losses in mirrors or lenses and losses on account of geometrical imperfections in the optical system. A term called ‘optical efficiency’ takes care of all such losses. For higher collection efficiency, concentrating collectors are supported by a tracking arrangement that tracks the sun all the time, so that beam radiation is on to the absorber surface. As collectors provide a high degree of concentration, a continuous adjustment of collector orientation is required.

Some new terms that will be encountered in the text hereinafter are defined now for greater clarity. These are:

- ‘Concentrator’ is for the optical subsystem that projects solar radiation on to the absorber. The term ‘receiver’ shall be used to represent the sub-system that includes the absorber, its cover and accessories.
- ‘Aperture’ (W) is the opening of the concentrator through which solar radiation passes.
- ‘Acceptance angle’ ($2q_a$) is the angle across which beam radiation may deviate from the normal to the aperture plane and then reach the absorber.
- ‘Concentration ratio’ (CR) is the ratio of the effective area of the aperture to the surface area of the absorber. The value of CR may change from unity (for flat-plate collectors) to a thousand (for parabolic dish collectors). The CR is used to classify collectors by their operating temperature range.

4.2 TYPES OF CONCENTRATING COLLECTORS

Plane receiver with plane collectors

It is a simple concentrating collector, having up to four adjustable reflectors all around, with a single collector as shown in Figure 4.9. The CR varies from 1 to 4 and the non-imaging operating temperature can go up to 140°C.

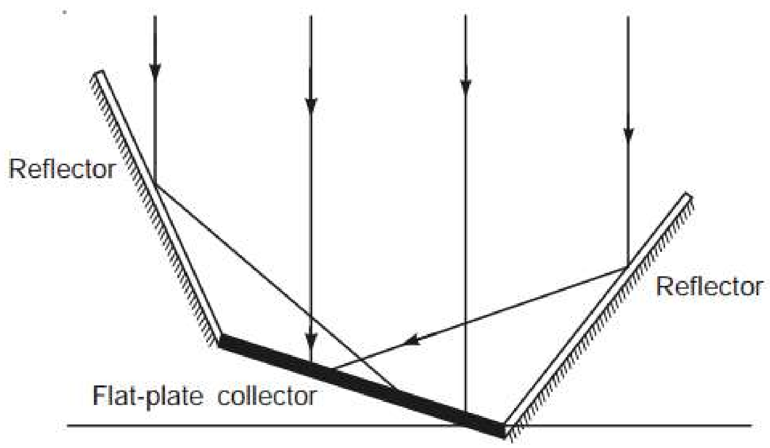


Figure 4.9 Plane receiver with plane reflectors.

Compound parabolic collector with plane receiver

Reflectors are curved segments that are parts of two parabolas (Figure 4.10). The CR varies from3 to 10. For a CR of 10, the acceptance angle is 11.5° and tracking adjustment is required aftera few days to ensure collection of 8 hours a day.

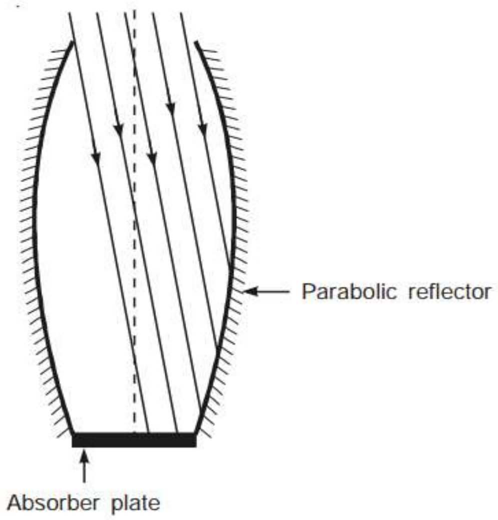


Figure 4.10 Compound parabolic collector with a plane receiver.

Cylindrical parabolic collector

The reflector is in the form of trough with a parabolic cross section in which the image is formed on the focus of the parabola along a line as shown in Figure 4.11. The basic parts are: (i) an absorber tube with a selective coating located at the focal axis through which the liquid to be heated flows, (ii) a parabolic concentrator, and (iii) a concentric transparent cover.

The aperture area ranges from 1 m^2 to 6 m^2, where the length is more than the aperture width. The CR range is from 10 to 30.

Collector with a fixed circular concentrator and a moving receiver

The fixed circular concentrator consists of an array of long, narrow, flat mirror strips fixed over a cylindrical surface as shown in Figure 4.12. The mirror strips create a narrow line image that follows a circular path as the sun moves across the sky. The CR varies from 10 to 100.

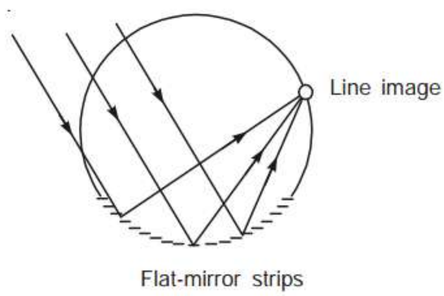


Figure 4.12 Cross section of a collector with a fixed circular concentrator and a moving receiver.

Fresnel lens collector

Fresnel lens refraction type focusing collector is made of an acrylic plastic sheet, flat on one side, with fine longitudinal grooves on the other as shown in Figure 4.13. The angles of grooves are designed to bring radiation to a line focus. The CR ranges between 10 and 80 with temperature varying between 150°C and 400°C.

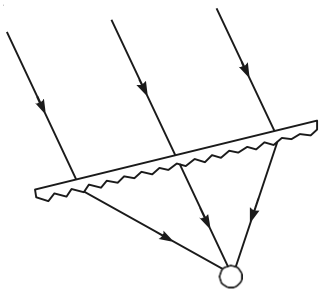


Figure 4.13 Fresnel lens collectors.

Paraboloid dish collector

To achieve high CRs and temperature, it is required to build a point-focusing collector. A paraboloid dish collector is of point-focusing type as the receiver is placed at the focus of the paraboloid reflector (Figure 4.14).

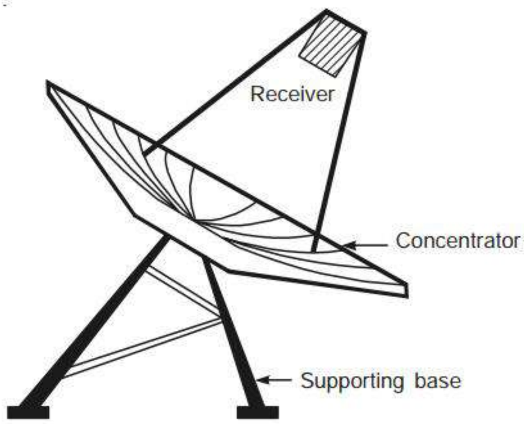


Figure 4.14 Paraboloid dish collector.

As a typical case, a dish of 6 m in diameter is constructed from 200 curved mirror segments forming a paraboloidal surface. The absorber has a cavity shape made of zirconium–copper alloy, with a selective coating of black chrome. The CR ranges from 100 to a few thousands with maximum temperature up to 2000°C. For this, two-axis tracking is required so that the sun may remain in line with the focus and vertex of the paraboloid.

Central receiver with heliostat

To collect large amounts of heat energy at one point, the 'Central Receiver Concept' is followed. Solar radiation is reflected from a field of heliostats (an array of mirrors) to a centrally located receiver on a tower (Figure 4.15).

Heliostats follow the sun to harness maximum solar heat. Water flowing through the receiver absorbs heat to produce steam which operates a Rankine cycle turbo generator to generate electrical energy.

With a central receiver optical system, a large number of small mirrors are installed, each steerable to have an image at the absorber on the central receiver. A curvature is provided to the mirrors so as to focus the sunlight in addition to directing it to the tower.

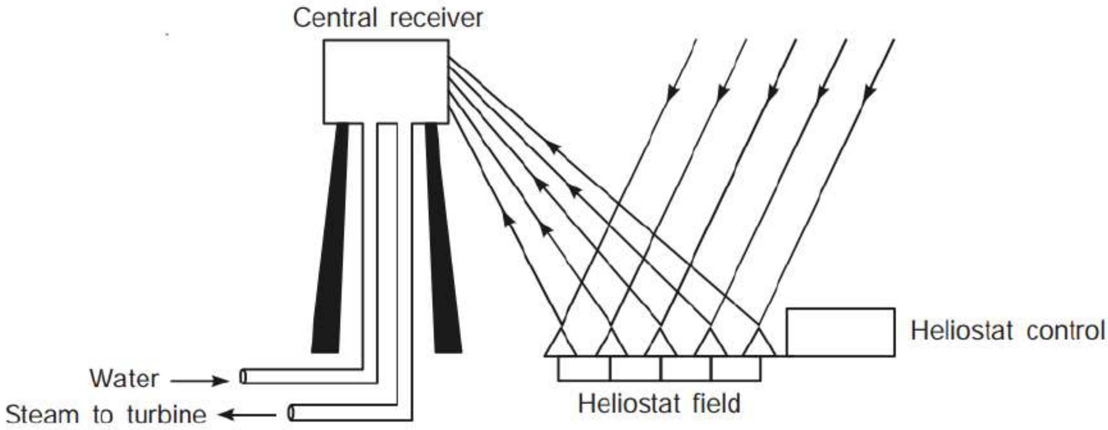


Figure 4.15 Central receiver tower with a field of heliostats.

Performance Characteristic
The important performance characteristic of a solar collector are:
(i) Collector efficiency
(ii) Concentration ratio
(iii) Temperature range

Collector efficiency is defined as the ratio of the energy actually absorbed and transferred to heat transporting fluid by the collector (useful energy) to the energy incident on the collector.

Concentration ratio (CR) 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.

Temperature range is the range of temperature to which the heat transport fluid is heated up by the collector.

APPLICATION OF PV SYSTEMS

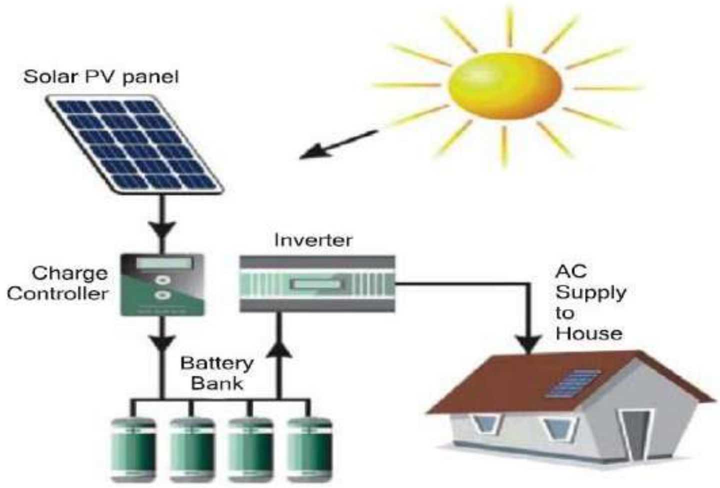
Photovoltaic battery charger

A solar charger is a charger that employs solar energy to supply electricity to devices or batteries. They are generally portable.
Solar chargers can charge lead acid banks up to 48 V and hundreds of ampere hours (up to 4000 Ah) capacity.

DOMESTIC LIGHT

Solar home lighting system

Home lighting System is powered by solar energy using solar cells that convert solar energy (sunlight) directly to electricity. The electricity is stored in batteries and used for the purpose of lighting whenever required.



Places where it can be used

- Non-electrified rural areas
- As an emergency lighting system in houses and commercial establishments

Parts and operation of a solar Home Lighting system

The Solar Home Lighting system is a fixed installation designed for domestic application.
The system comprises of

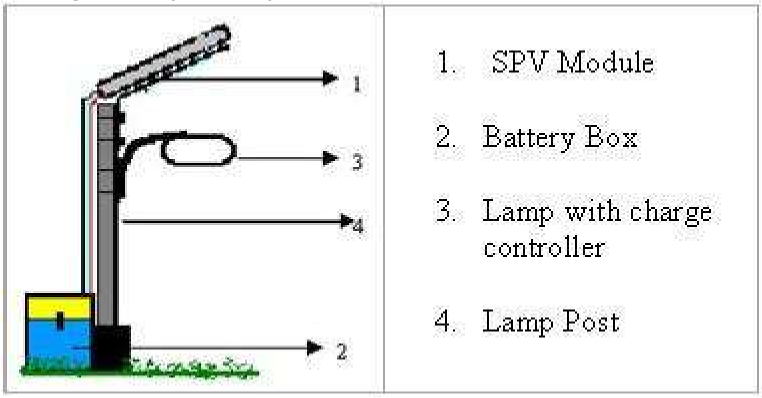
- Solar PV Module (Solar Cells)
- charge controller
- battery and
- lighting system (lamps & fans).

Operation Time

It depends on the capacity of the system. However, most systems are designed to give a daily working time of 3-4 hours with a fully charged battery. The system provides for buffer storage for 1-2 non-sunny /cloudy days

STREET LIGHT

Solar street lighting system uses the photovoltaic technology to convert the sunlight into DC electricity through solar cells. The generated electricity can either be used directly during the day or may be stored in the batteries for use during night hours.



Parts of a solar street lighting system

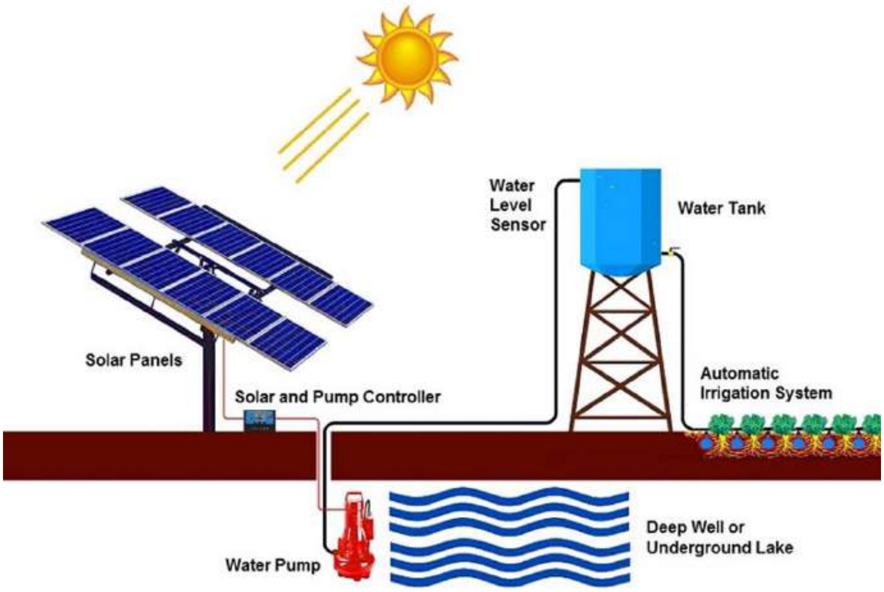
The solar street lighting system comprises of

- Solar photovoltaic module
- Battery box
- Lamp with charge controller
- Lamp post

In general, the specifications of the parts are

- 74 Watt Solar PV Module
- 12 V, 75 Ah Tubular battery with battery box
- Charge Controller cum inverter (20-35 kHz)
- 11 Watt CFL Lamp with fixtures
- 4 meter mild steel lamp post above ground level with weather proof paint and mounting hardware.

- **WATER PUMPING**
- The solar water pumping system uses solar energy to pump water.



<u>Parts of a solar water pumping system</u>

Solar PV panel

One of the following motor-pump sets compatible with the photovoltaic array:

- surface mounted centrifugal pump set
- submersible pump set
- floating pump set
- Submersible pump set, pipes

Working of a solar water pumping system
The system operates on power generated using solar PV (photovoltaic) system. The photovoltaic array converts the solar energy into electricity, which is used for running the motor pump set. The pumping system draws water from the open well, bore well, stream, pond, canal etc. The system requires a shadow-free area for installation of the Solar panel.
Advantages of a solar water pumping system

- No fuel cost - as it uses available free sun light
- No electricity required
- Long operating life
- Highly reliable and durable
- Easy to operate and maintain
- Eco-friendly

SOLAR COOKER

A solar cooker is a system which uses solar energy to cook food.
A variety of solar cookers have been developed, in four types of basic designs:
(i) box type solar cooker
(ii) dish type solar cooker
(iii) community solar cooker
(iv) advance solar cooker.

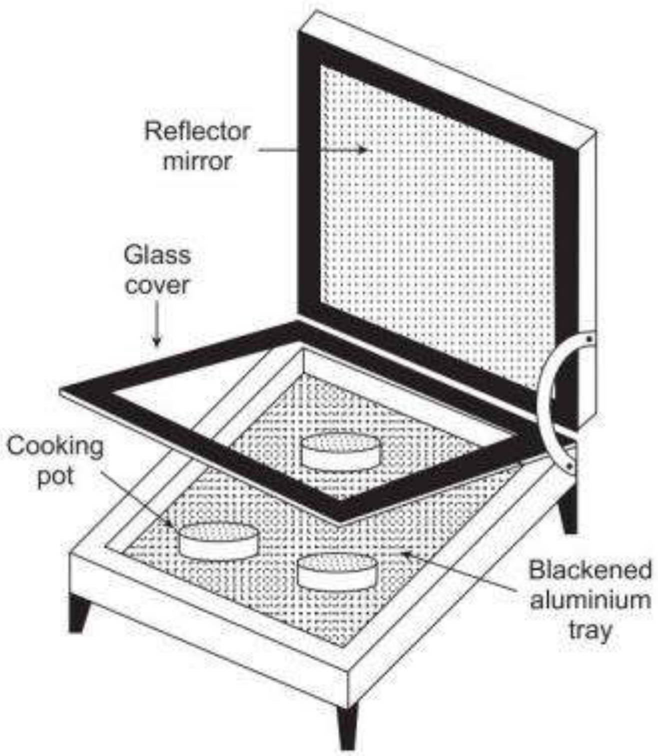


Figure 5.27 Box type solar cooker

SOLAR POND

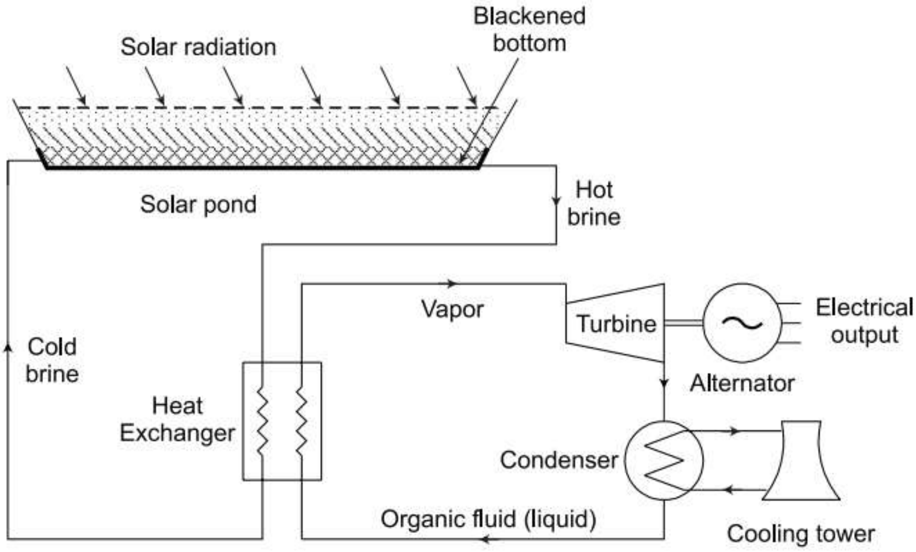


Figure 5.38 Solar pond electric power plant

When the sun's rays contact the bottom of a shallow pool, they heat the water adjacent to the bottom. When water at the bottom of the pool is heated, it becomes less dense than the cooler water above it, and convection begins. Solar ponds heat water by impeding this convection. Salt is added to the water until the lower layers of water become completely saturated. High-salinity water at the bottom of the pond does not mix readily with the low-salinity water above it, so when the bottom layer of water is heated, convection occurs separately in the bottom and top layers, with only mild mixing between the two. This greatly reduces heat loss, and allows for the high-salinity water to get up to 90 °C while maintaining 30 °C low-salinity water.[1] This hot, salty water can then be pumped away for use in electricity generation, through a turbine or as a source of thermal energy.

Wind Energy

7.1 INTRODUCTION

Wind is air in motion and it derives energy from solar radiation. About 2% of the total solar flux that reaches the earth's surface is transformed into wind energy due to uneven heating of the atmosphere. During daytime, the air over the land mass heats up faster than the air over the oceans. Hot air expands and rises while cool air from oceans rushes to fill the space, creating local winds. At night the process is reversed as the air cools more rapidly over land than water over off-shore land, causing breeze, as shown in Figure 7.1. On a global scale low pressure exists near the Equator due to greater heating, causing winds to blow from subtropical belts towards the Equator. Also, the axial rotation of the earth induces a centrifugal force which throws equatorial air masses to the upper atmosphere, causing deflection of winds.

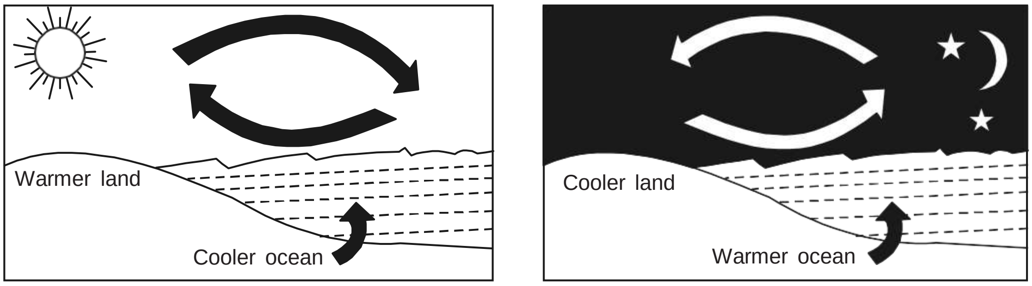


Figure 7.1 (a) Wind from ocean to land during daytime, and (b) wind from land to ocean during night.

7.2 CLASSIFICATION OF WIND TURBINES

Wind turbines are classified as horizontal-axis turbines or vertical-axis turbines depending upon the orientation of the axis of rotation of their rotors. A wind turbine operates by slowing down the wind and extracting a part of its energy in the process. For a horizontal-axis turbine, the rotor axis is kept horizontal and aligned parallel in the direction of the wind stream. In a vertical-axis turbine, the rotor axis is vertical and fixed, and remains perpendicular to the wind stream.

In general, wind turbines have blades, sails or buckets fixed to a central shaft. The extracted energy causes the shaft to rotate. This rotating shaft is used to drive a pump, to grind seeds or to generate electric power. Wind turbines are further classified into 'lift' and 'drag' type.

7.2.1 Lift Type and Drag Type Wind Turbines

Two important aerodynamic principles are used in wind turbine operations, i.e., lift and drag. Wind can rotate the rotor of a wind turbine either by lifting (lift) the blades or by simply passing against the blades (drag). Wind turbines can be identified based on their geometry and the manner in which the wind passes over the blade. Slow-speed turbines are mainly driven by the drag forces acting on the rotor. The torque at the rotor shaft is comparatively high which is of prime importance for mechanical applications such as water pumps. For slower turbines, a greater blade area is required, so the fabrication of blades is undertaken using curved plates.

High-speed turbines utilise lift forces to move the blades, which phenomenon is similar to what acts on the wings of an aeroplane. Faster turbines require aerofoil-type blades to minimize the adverse effect of the drag forces. The blades are fabricated from aerofoil sections with a high thickness-to-chord ratio in order to produce a high lift relative to drag.

For electric power generation, the shaft of the generator requires to be driven at a high speed. For the same swept area, the energy extracted by a wind turbine operating on lift forces is several times greater than the energy from the drag-type turbine. Thus, the lift-type turbines are more suitable compared to drag-type turbines for electric power generation.

7.3 TYPES OF ROTORS

Different types of rotors used in wind turbines are: (i) multiblade type, (ii) propeller type, (i) Savonious type, and (iv) Darrieus type. The first two are installed in horizontal-axis turbines, while the last two in vertical-axis turbines.

7.3.1 Multiblade Rotor

The multiblade rotor is fabricated from curved sheet metal blades. The width of blades increases outwards from the centre. Blades are fixed at their inner ends on a circular rim. They are also welded near their outer edge to another rim to provide a stable support. The number of blades used ranges from 12 to 18, as shown in Figure 7.2.

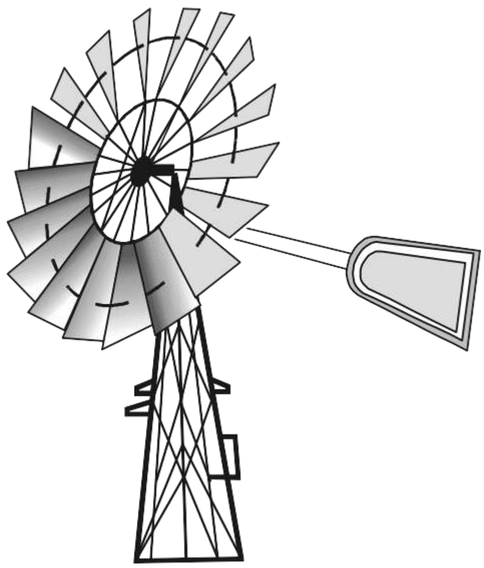


Figure 7.2 Multiblade rotor installed on a tower

7.1.1 Propeller Rotor

The propeller rotor comprises two or three aerodynamic blades made from strong but lightweight material such as fibre glass reinforced plastic. The diameter of the rotor ranges from 2 m to 25 m as detailed in Figure 7.3. The blade slope is designed by using the same aerodynamic theory as for aircraft.

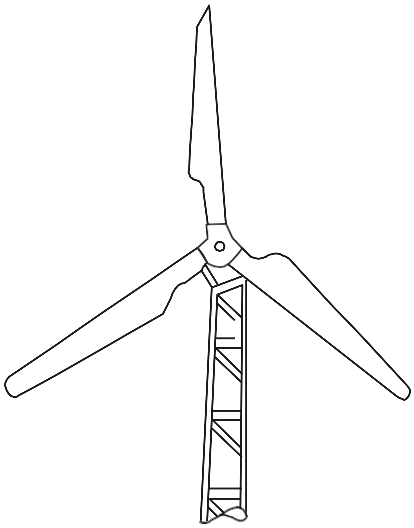
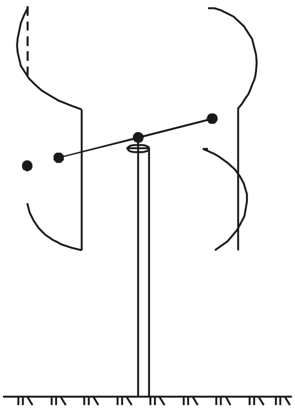


Figure 7.3 Propeller rotor installed on a tower.

7.1.2 Savonious Rotor

The Savonious rotor comprises two identical hollow semi-cylinders fixed to a vertical axis. The inner side of two half-cylinders face each other to have an S shaped cross section as detailed in Figure 7.4.

Figure 7.4 Savonious vertical-axis rotor



7.1.3 Darrieus Rotor

This rotor has two or three thin curved blades of flexible metal strips. It looks like an egg beater and operates with the wind coming from any direction. Both the ends of the blades are attached to a vertical shaft as shown in Figure 7.5. It has an advantage that it can be installed close to the ground eliminating the cost of the tower structure.

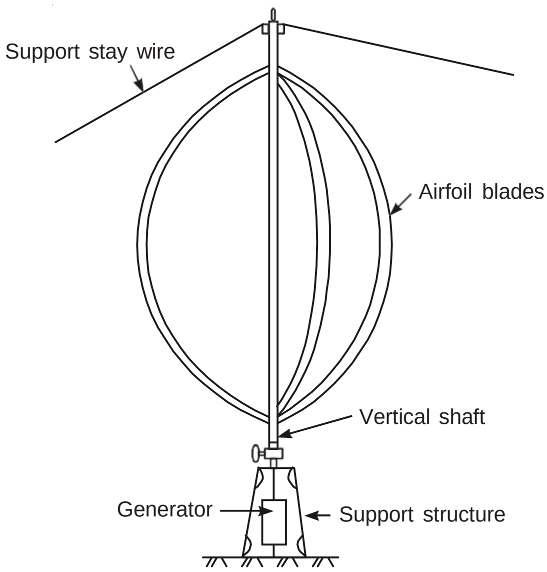


Figure 7.5 Darrieus rotor.

Lift is the driving force, creating maximum torque when the blade moves across the wind. This rotor was designed by a French engineer G.M. Darrieus in 1925. It is used for decentralized electricity generation.

7.2 TERMS USED IN WIND ENERGY

Airfoil (Aerofoil): A streamlined curved surface designed for air to flow around it in order to produce low drag and high lift forces.

Angle of attack: It is the angle between the relative air flow and the chord of the airfoil [Figure7.6(a)]

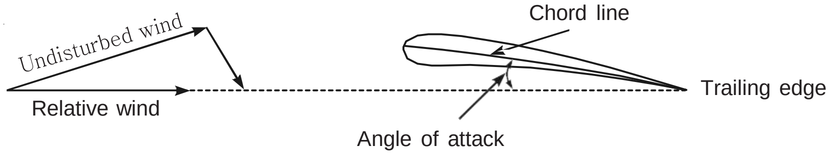


Figure 7.6(a) Angle of attack of a wind turbine airfoil.

Blade: An important part of a wind turbine that extracts wind energy.

Leading edge: It is the front edge of the blade that faces towards the direction of wind flow [Figure 7.6(b)].

Trailing edge: It is the rear edge of the blade that faces away from the direction of wind flow [Figure 7.6(b)].

Chord line: It is the line joining the leading edge and the trailing edge [Figure 7.6(b)].

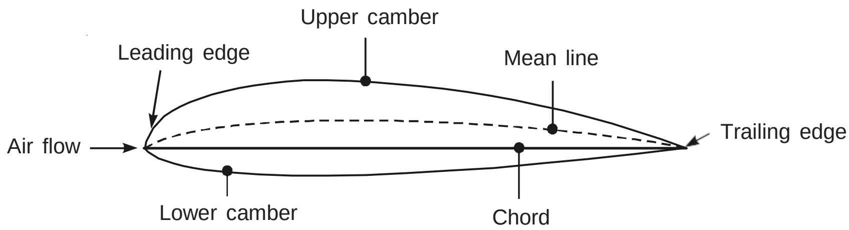

Upper camber
Leading edge
Mean line
Air flow
Trailing edge
Lower camber
Chord

Figure 7.6(b) Airfoil showing edges, camber and chord.

Mean line: A line that is equidistant from the upper and lower surfaces of the airfoil.

Camber: It is the maximum distance between the mean line and the chord line, which measures the curvature of the airfoil.

Rotor: It is the prime part of the wind turbine that extracts energy from the wind. It constitutes the blade-and-hub assembly.

Hub: Blades are fixed to a hub which is a central solid part of the turbine.

Propeller: It is the turbine shaft that rotates with the hub and blades and is called the propeller. Blades are twisted as per design. The outer profile of the blades conforms to aerodynamic performance while the inner profile meets the structural requirements.

Tip speed ratio: It is the ratio of the speed of the outer blade tip to the undisturbed natural wind speed.

Pitch angle: It is the angle made between the blade chord and the plane of the blade rotation.

Pitch control of blades: A system where the pitch angle of the blades changes according to the wind speed for efficient operation [Figure 7.6(c)].

Stall-regulated system: When the turbine blades are fixed at an optimum angle and the machine is stalled during high winds either by mechanical or hydraulic systems.

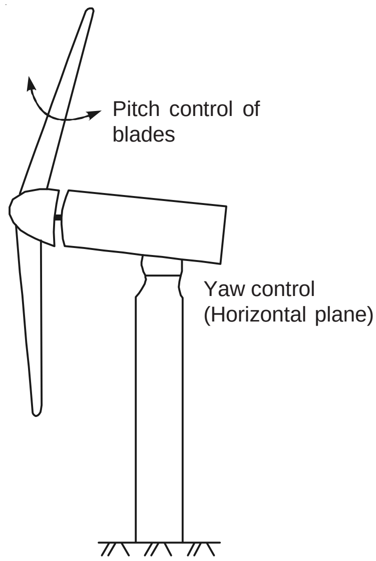


Figure 7.6(c) Pitch and yaw control of wind turbine.

Swept area: This is the area covered by the rotating rotor.

Solidity: It is the ratio of the blade area to the swept area.

Drag force: It is the force component which is in line with the velocity of wind.

Lift force: It is the force component perpendicular to drag force.

Nacelle: The nacelle houses the generator, the gear box, the hydraulic system and the yawing mechanism.

Yaw control: As the direction of the wind changes frequently, the yaw control is provided to steer the axis of the turbine in the direction of the wind. It keeps the turbine blades in the plane perpendicular to the wind, either in the upward wind direction or in the downward wind direction.

Cut-in speed: It is the wind speed at which a wind turbine starts to operate.

Rated wind speed: It is the wind speed at which the turbine attains its maximum output.

Cut-out speed: It is the wind speed at which a wind turbine is designed to be shut down to prevent damage from high winds. It is also called the *furling wind speed*.

Down wind: It is the opposite side of the direction from which the wind is blowing.

Up wind: It is the side of the direction from which the wind is blowing (in the path of the oncoming wind).

Wind rose: It is the pattern formed in a diagram illustrating vectors that represent wind velocities occurring from different directions.

Wind vane: A wind vane monitors the wind direction. It sends a signal to the controlling computer which activates the yaw mechanism to make the rotor face the wind direction.

7.3 AERODYNAMIC OPERATION OF WIND TURBINES

Aerodynamics deals with the movement of solid bodies through the air. In wind turbines, aerodynamics provides a method to explain the relative motion between airfoil and air. Airfoil is the cross-section of the wind turbine blade. When the wind passes over the surface of the rotor blade, it automatically passes over the longer or upper side of the blade, creating a low pressure area above the airfoil as shown in Figure 7.7(a).

The pressure difference between the top and the bottom surfaces results in a force called the aerodynamic lift that causes the airfoil to rise. As the blades can only move in a plane with the hub as their centre, the lift force causes rotation about the hub [Figure 7.7(b)]. The turbine thus extracts energy from the wind stream by converting the wind's linear kinetic energy into rotational motion. In addition to the lift force, a drag force perpendicular to the lift force also acts on the blade which impedes rotor rotation. The prime objective in wind turbine design is the desired lift-to-drag ratio of the blade (airfoil structure). The basic principles of lift and drag forces are dealt with in the next section.

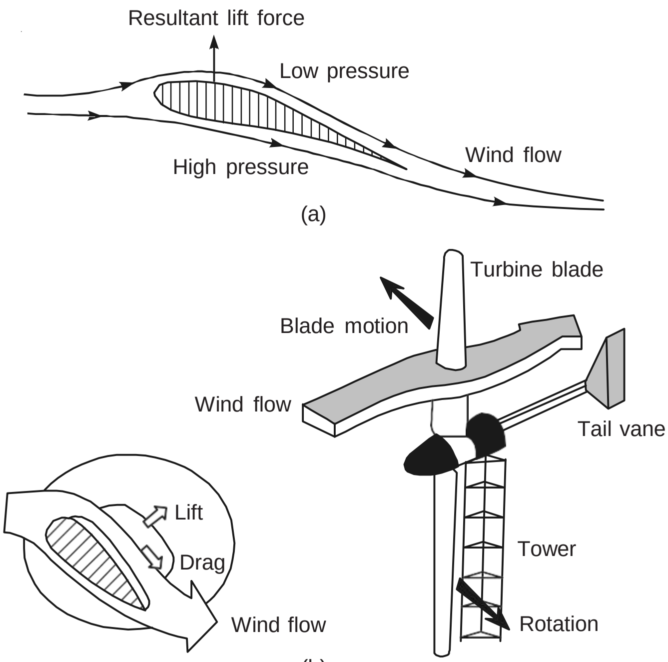


Figure 7.7 (a) Aerodynamic lift force on blade cross-section of wind turbine, and (b) the basic operating principle of wind turbine aerodynamic lift.

When air flows over solid bodies, several physical phenomena are noticed such as drag force acting on objects like trees and electric towers, the lift force developed by airplane wings, the lift force experienced by dust particles in a wind storm and the blade motion developed by a turbine. Either the fluid moves over a stationary body or a body moves through a standstill fluid; aerodynamically both activities are the same. The approach is to study the relative motion between the fluid and the body.

7.3.1 Drag

It is the resistance which a body experiences when a fluid moves over it. Flood water washes away animals, vehicles and buildings. Wind storm and hurricane knocks down transmission towers, trees, sweeps away catamaran and ships. These are a few undesirable examples of drag forces. The force that a flowing fluid exerts on a body in the direction of flow is called 'drag force'. Drag may bring an undesirable effect of friction, such as burning of space vehicles on entering into the earth's atmosphere. Reduction of drag is the basic engineering approach, associated with the reduction in fuel consumption in automobiles, aircraft and submarines. However, in certain engineering activities the drag produces a useful effect. A meteor from outer space burns due to friction with the earth's atmosphere, saving the inhabitants on earth from catastrophic impact.

Friction acts to help us as a 'life saver' in brakes of automobiles. Similarly, the drag force is useful in safe landing with a parachute.

7.3.2 Lift

When a body is immersed in a standstill fluid, only the normal pressure force is exerted on it. A flowing fluid in addition exerts tangential shear forces on the surface. Both these forces have two components, one is drag in the flow direction, the other is perpendicular to the fluid flow called 'lift'. It causes the body to move in the upward direction. The relative magnitudes of drag and lift forces depend completely on the shape of the object. Streamlined objects experience a smaller drag force than that experienced by blunt objects. Generation of lift always creates a certain amount of drag force.

Airfoils of a wind turbine are especially shaped to produce lift force on coming in contact with the moving air. It is achieved by fabricating the top surface of the airfoil as curved and the bottom surface nearly flat. Air flowing over the airfoil travels a longer distance to reach the tip-end of airfoil, in contrast to air flowing under the foil (Figure 7.8). It creates a pressure difference that generates an upward force which tends to lift the airfoil causing rotation of the wind turbine rotor. Good airfoils can have lift 30 times greater than drag.

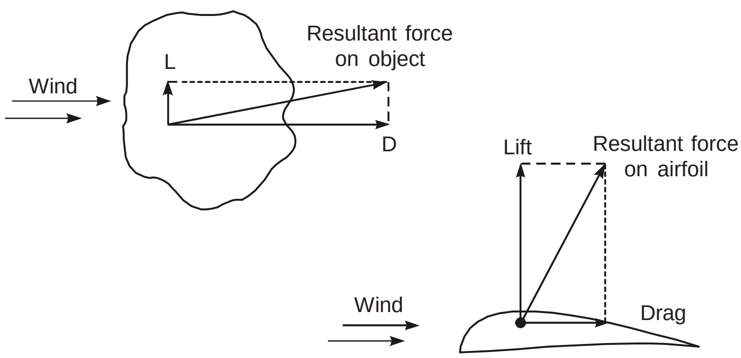


Figure 7.8 Relative magnitudes of lift and drag forces on a blunt object and a streamlined airfoil.

7.18 SUB-SYSTEMS OF A HORIZONTAL AXIS WIND TURBINE GENERATOR

Wind energy, extracted by blades, rotates the shaft which, by using the gear and coupling mechanism, operates the generator housed inside a nacelle. A roller assembly links the tower with the nacelle to permit its rotation about a vertical axis to keep the rotor in wind direction. Large wind turbine generators use pitch regulation and run at a fixed speed (50 cycles/second) to facilitate synchronization with the grid supply. A 225 kW WEG having a rotor diameter of 27 metres with swept area of 573 sq. m, installed on a tubular tower, is shown in Figure 7.23 with its various subsystems as follows:

Blades: Wind turbine blades need to be lightweight and possess adequate strength and hence require to be fabricated with aircraft industry techniques. The blades are made of glass fibre reinforced polyster with a suitable structural geometrical shape to create *lift* as the air flows over

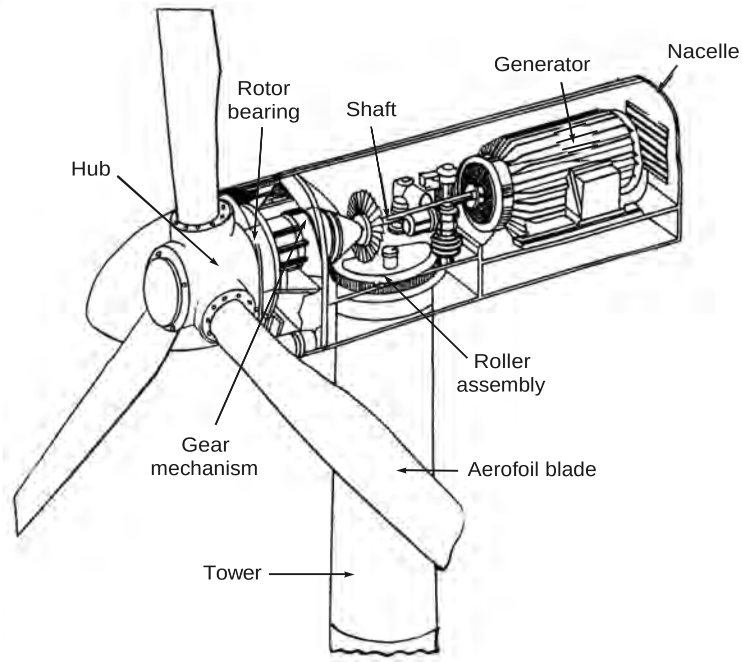


Figure 7.23 Subsystems of a horizontal axis wind turbine generator.

Nacelle: It houses the generator, the gear box hydraulic system and the yawing mechanism. Nacelle is placed at the top of the tower and is linked with the rotor.

Power transmission system: Mechanical power generated by rotor blades is transmitted to the generator through a two-stage gear box. From the gear box, the transmission shaft rotates the generator with a built-in friction clutch. The gear box is provided to increase the generator speed to 1500 rpm.

Generator: Generally the large WTGs, used with grid-connected systems, have induction generators. They use reactive power from grids and feed the generated power to boost the grid supply. Medium capacity WTGs use synchronous generators installed to electrify villages, and provide industrial power supply to remote places. Small capacity WTGs use permanent magnet dc generators which supply power to microwave stations and illuminating lighthouses.

Yaw control: Yawing is done by two yawing motors, which mesh with a big-toothed wheel mounted on top of the tower. Yaw control continuously tracks and keeps the rotor axis in the wind direction. During high speed wind, i.e., more than the cut-out speed, the machine is stopped by turning the rotor axis at right angles to the wind direction.

Brakes: Braking of WEGs is done by full feathering. An emergency STOP activates the hydraulic disc brakes fitted to the high-speed shaft of the gear box.

Controllers: WEGs are monitored and controlled by a microprocessor-based control unit. A controller monitors the parameters in the nacelle besides controlling the operation of the pitch system. Variations in the blade position are performed by a hydraulic system, which also delivers pressure to the brake system.

Tower: Modern wind turbine generators are installed on tubular towers. Large turbines use lattice towers designed to withstand gravity loads and wind loads. The height of the tower is decided for obtaining the designed value of wind speed and dimensions of the rotor (the higher the turbine capacity the larger the rotor).

7.18.1 Grid Connected Wind Turbine Generators

A common arrangement for connecting medium capacity WTGs (250 kW) to 'state grid' is shown in Figure 7.28.

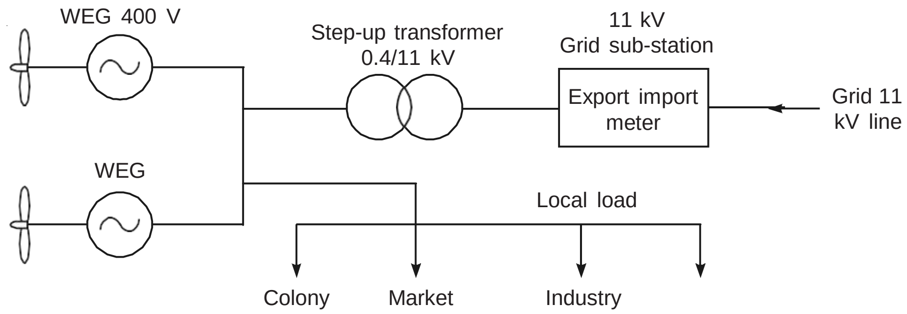


Figure 7.28 Grid-connected wind turbine generators.

WTGs generate electric power at 400 V; it is then stepped up to make this voltage compatible to the grid (11 kV). In India, grid-connected WEGs constitute wind farms where the generated power is distributed among the nearby consumers and the excess power is exported to the grid. Electrical energy is purchased (imported) from the grid during periods of no wind.

7.19 ADVANTAGES AND DISADVANTAGES OF WIND ENERGY SYSTEM

The advantages of WEC systems are:

1. Wind energy is a renewable source of energy and can be tapped, free of fuel cost.
2. The WTG produces electricity in an environmentally friendly way.
3. It can supply electric power to remote inaccessible areas like the Upper Himalayan range (Ladakh to Sikkim), Andaman and Nicobar islands, remote desert locations in Rajasthan, coastal areas of Kutch (Gujarat) and deep forest tribal settlements in Madhya Pradesh.

4. Public opinion is in favour of WTGs rather than fossil fuel and nuclear power generation. People do accept a wind turbine closer to their homes (2 km to 5 km). In contrast, the minimum acceptable distance to a nuclear power plant is 60 km.
5. Wind power generation is cost effective.
6. It is economically competitive with other modes of power generation.
7. Wind energy development is dynamic and an exciting addition to the landscape which increases public awareness of energy generation.
8. It is reliable and has been used for ages.

The disadvantages of WEC systems are:

1. Wind energy has low energy density and normally available at only selected geographical locations away from cities and load centres.
2. Wind speed being variable, wind energy is irregular, unsteady and erratic.
3. Wind turbine design is complex and needs more research and development work due to widely varying atmospheric conditions where these turbines are made to operate.
4. Large units have less capital cost per kWh, but require capital intensive technology. In contrast, small units are more reliable but have higher capital cost per kWh.
5. Wind energy systems require storage batteries which contribute to environmental pollution.
6. Wind farms are established in locations of favourable wind. These locations are in open areas away from load centres. Consequently, the connection to state grid is necessary.
7. Wind energy systems are capital intensive and need government support.

8.3 GRID INTERFACING OF A WIND FARM

Wind is not a steady source of energy, so it cannot on its own meet the needs of consumers at all times. Necessarily, it has to be integrated with the state grid to ensure a smooth supply of continuous power. Energy path from wind farm to the grid and then to energy users is illustrated in Figure 8.4.

WEGs generate at 400 V which is stepped up to 11 kV, then the overhead transmission lines connect to the substation for grid connection. Power evacuation may be on 11 kV or 22 kV or 33 kV lines depending on (a) the availability of distribution network, (b) the number of WEGs installed in the wind farm. A rule of thumb as given in Table 8.4 is adopted.

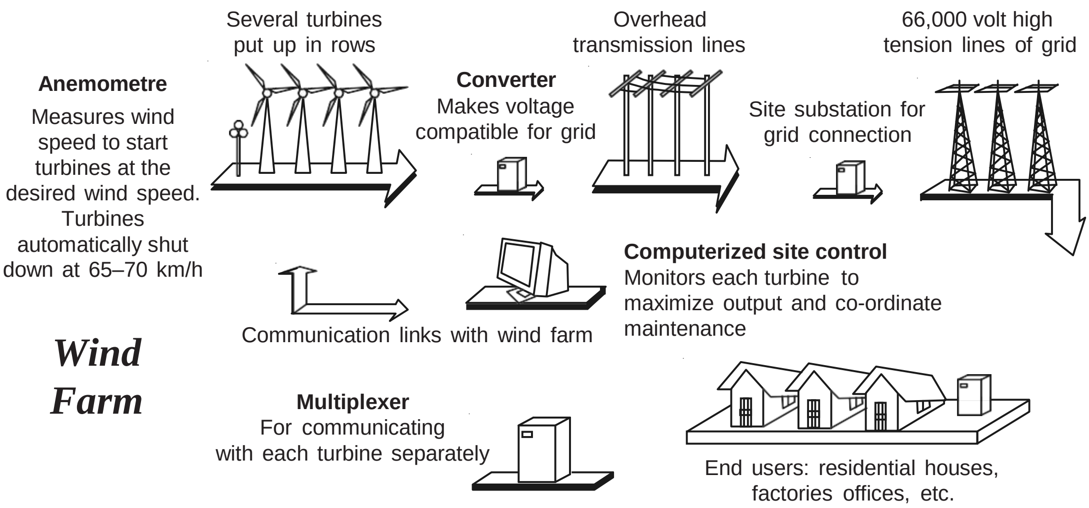


Figure 8.4 Energy path from wind farm to the user.

8.4 METHODS OF GRID CONNECTION

For a single-row layout of wind farm, one transformer connected to two WTGs is the most economical solution, whereas for a multi-array wind farm, one transformer is connected to four turbines, as shown in Figures 8.5(a) and (b).

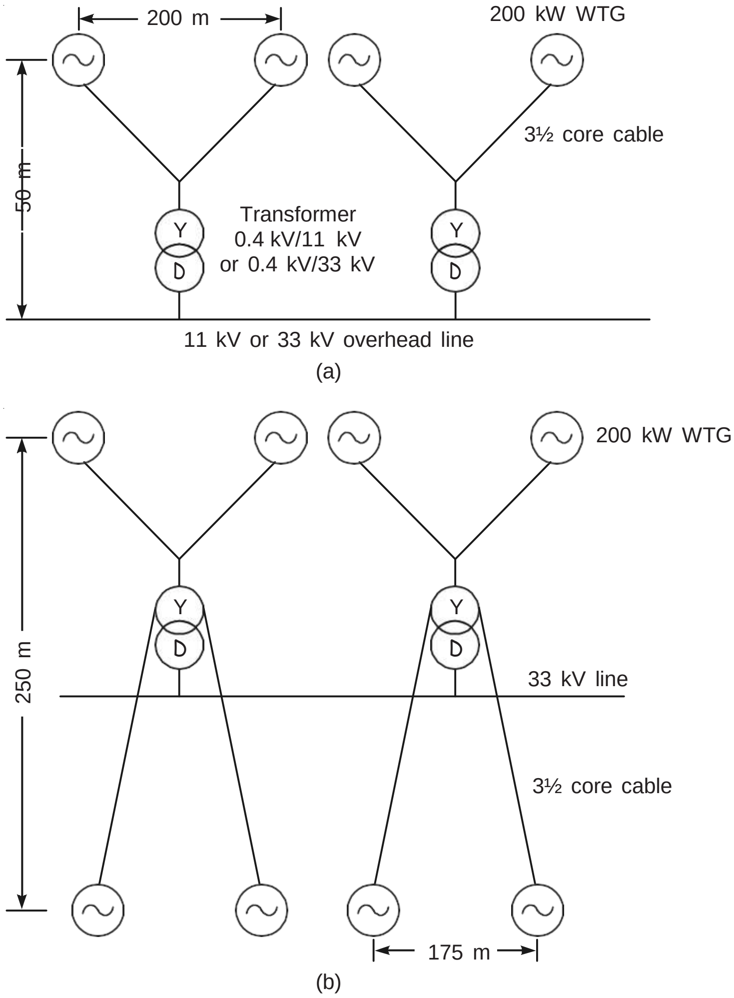
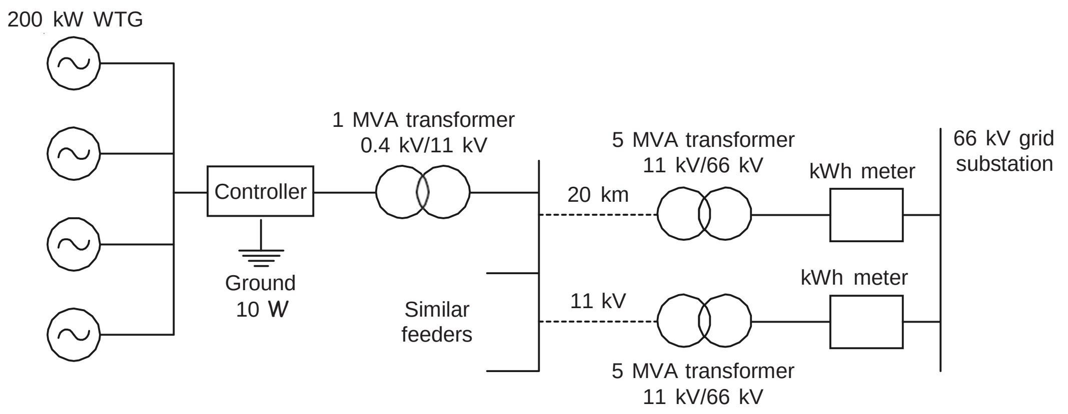


Figure 8.5 (a) Electrical system for a single-array wind farm, and (b) electrical system for amulti-array wind farm.

Generated power of wind farm, collected at 11 kV or 33 kV, is then further stepped up to the appropriate class of voltage while integrating with the state power grid, as shown in Figure 8.6.



It is assumed that the 66 kV grid/substation is located 20 km away from the wind farm which has an installed capacity of 10 MW.

Transformer capacity is determined by the number of turbines to be connected, keeping in mind the possibility of installing more turbines that would be connected at a later date.

A wind farm exports the generated energy to the grid but during the no-wind periods the local requirement of energy is met from the grid. Import-export kWh meters are installed in the grid substation.

Electrical system of generators with wind turbines

For interaction of wind turbines with the grid, there are two broad classifications as follows:

(a) Fixed speed turbine with generator directly connected to the grid (Figure 8.10).

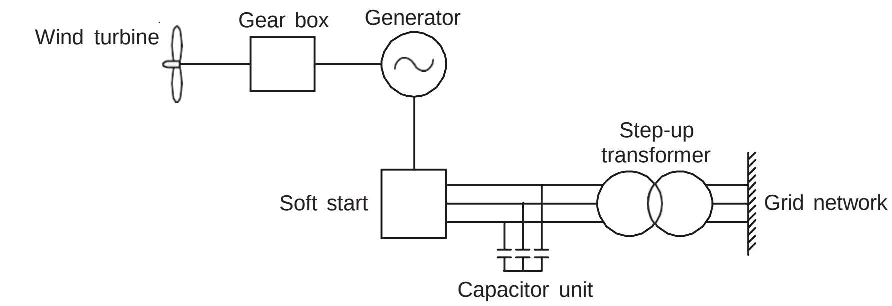


Figure 8.10 Schematic diagram of a fixed speed WEG.

The generators required in a direct grid connected system are:

(i) Squirrel cage/wound rotor induction machine

(ii) Wound rotor induction machine with rectifier control in the rotor

(b) Variable speed turbine generator, integrated through power electronic converters (Figure 8.11).

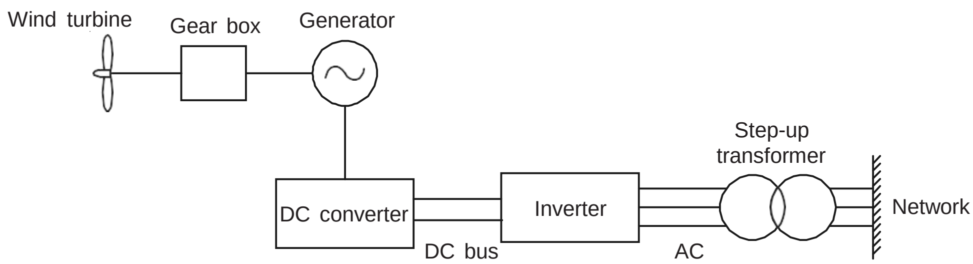


Figure 8.11 Schematic diagram of a variable speed WEG.

Under systems integrated through power electronic converters, the generators required are:

(i) Wound rotor induction machine with thyristor/IGBT bridge on the rotor for reduced converter size.

(ii) Permanent magnet synchronous machine with thyristor bridge and permanent magnet/wound rotor machine with IGBT bridge on the stator for full converter size.

Biomass Energy

12.1 INTRODUCTION

Biomass refers to solid carbonaceous material derived from plants and animals. These include residues of agriculture and forestry, animal waste and discarded material from food processing plants. Biomass being organic matter from terrestrial and marine vegetation, renews naturally in a short span of time, thus, classified as a renewable source of energy. It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from the atmosphere to form hexose (dextrose, glucose, etc.) expressed by the reaction

$$6CO_2 + H_2O \xrightarrow[\text{photosynthesis}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Biomass does not add CO_2 to the atmosphere as it absorbs the same amount of carbon in growing the plants as it releases when consumed as fuel. It is a superior fuel as the energy produced from biomass is 'carbon cycle neutral'.

Biomass fuel is used in over 90% of rural households and in about 15% urban dwellings. Agriculture products rich in starch and sugar like wheat, maize, sugarcane can be fermented to produce ethanol (C_2H_5OH). Methanol (CH_3OH) is also produced by distillation of biomass that contains cellulose like wood and bagasse. Both these alcohols can be used to fuel vehicles and can be mixed with diesel to make biodiesel.

12.2 BIOMASS RESOURCES

Biomass resources for energy production are widely available in forest areas, rural farms, urban refuse and organic waste from agro-industries. Biomass classification is illustrated in Figure 12.1.

India produces over 550 million tonnes of agricultural and agro-industrial residues every year. Similarly, 290 million cattle population produces about 438 million tonnes of dung annually. Prime biomass sources are discussed below:

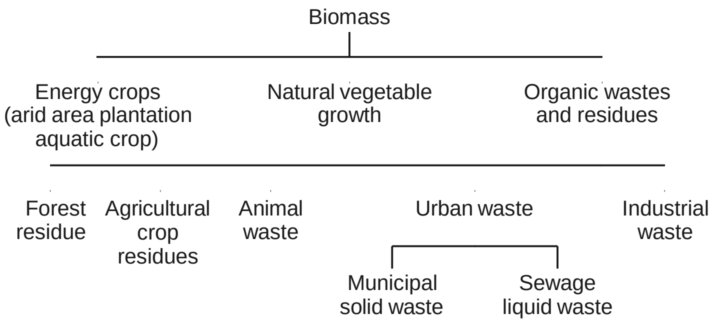


Figure 12.1 Biomass classification.

Forests, natural or cultivated are a rich source of timber, fuel wood, charcoal and raw material for paper mills and other industries. Fast growing trees like Eucalyptus, Neem, Kikar and Gulmohar are grown along canals, railway tracks and on lands of marginal quality. Wood, saw dust, and bark residue are generated in sawmills. Forests also provide foliage and logging residues. An important characteristic of forest residue is its calorific value, which is 4399 to 4977 kcal/kg for softwood foliage and 3888 to 5219 kcal/kg for hard wood species.

Agricultural crop residues

Crop residues are available in abundance as natural resource, easily collected and stored. These are, rice husk, wheat straw, corn cobs, cotton sticks, sugarcane bagasse, groundnut and coconut shells. These are converted into briquettes or pellets for use as clean fuel. These are called 'biofuels' which are high efficiency solid fuels.

Energy crops

Energy farming refers to the cultivation of fast growing plants which supply fuel wood, biomass that can be converted into gaseous and liquid fuels like biogas, vegetable oil and alcohol. To harvest biomass for power generation, energy plantation is done on degraded or wastelands which are saline, wind eroded lands in arid areas and water-logged lands.

Energy farming is promoted by MNRE in nine different agro-climate regions, namely, Garhwal (U.P.), Gwalpahar (Haryana), Udaipur (Rajasthan) and Shantiniketan (West Bengal). The other four centres are Madurai (Tamil Nadu), Calicut (Kerala), Raipur (Chhattisgarh), Bhubaneswar (Orissa). These centres produce quality seedlings of about 35 tree species through clonal propagation. These fast growing fuel wood species produce 20–25 tonnes of biomass per hectare per year. The Biomass Research Centre Lucknow found the 'Kubabul' tree that grows well on saline and rocky soils, provides wood of high calorific value (4500 kcal/kg).

Vegetable oil crops

Oil can be extracted from fertile area crops such as, sunflower, cotton seed, groundnut, rapeseed, palm and coconut. These oils after purification can be blended with diesel oil suitable as engine fuel.

There is an arid area shrub 'Jajoba', its seeds provide oil which is an important renewable source of energy. It is cultivated in Rajasthan, Gujarat and Orissa under hot-arid conditions. It is an ideal plant for areas of scanty rain with low fertility soil and produces up to 2000 kg of dry seed per hectare annually. Jajoba oil having good insulating property can be used as transformer oil. Its products are high quality lubricants and waxes, suitable for industry and transport sector. It is a good raw material for paints and varnishes.

Aquatic crop

Aquatic crop constitutes three water plants, namely algae, water hyacinth and sea weed. These plants grow abundantly in water bodies and provide organic matter for biogas plants.

Energy plantation programme is directed to bring sub-standard soil under cultivation. It restores the fertility of land, halts desertification, prevents soil erosion, reduces flooding and improves microclimate.

Animal waste

Animal waste, an organic material with combustible property, is a rich source of fuel. Dung cakes prepared with animal waste are used for cooking in rural and semi-urban areas. It is also a raw material for biogas plants.

Urban waste

Urban waste is of two types: (i) Municipal Solid Waste (MSW) which includes human excreta, household garbage and commercial waste. (ii) Liquid Waste from domestic sewage and effluents from institutional activities. As per MNRE estimate about 42 million tonnes of solid waste (1.15 lakh tonnes per day) and 6000 million cubic metres of liquid waste are generated every year in urban areas. At present MSW is dumped in sanitary landfills, where fuel gas is produced which is a valuable source of renewable energy. Sewage is suitably processed to produce biogas.

Industrial waste

Energy recovery from industrial waste was taken up in 1994. Projects are implemented with technical assistance of national laboratories. Projects developed under this programme are:

Pulp and Paper Industry Effluent, Starch and Glucose Industry Waste, Palm Oil Industry, Distillary Waste and Tanneries Waste. Each project is aimed to treat its waste for the production of bio-energy which can be used for power generation.

12.3 BIOFUELS

Biomass is an organic carbon-based matter obtained from plants. Biomass is a source of energy and 40% of the total energy consumed in India comes from wood, crop residues, cow dung, etc. for cooking and various domestic uses. Dry biomass gives heat energy by direct combustion.

Direct burning of firewood in traditional chulhas utilises only 10% heat. Besides inefficient burning, smoke discharge in kitchens is a health hazard. To harness fuel value, technologies are required to convert biomass into a high quality usable solid, liquid and gaseous fuels called 'biofuels'. Such fuels are discussed below.

Charcoal

Charcoal is a smokeless dry solid fuel with high energy density. Modern charcoal retorts (furnaces) operate at about 600°C to produce charcoal from 25–35% of dry biomass feed. It contains 75–80% carbon and is useful as a compact fuel. It can be burnt to provide heat for domestic, commercial and industrial applications.

Briquetting

Biomass briquetting is densification of loose biomass into a high density solid fuel. Biomass of any form such as cotton sticks, rice husk, coconut shells, saw dust and wood chips can be converted into briquetts. It reduces the volume-to-weight ratio, thus making transportation easy for efficient commercial and industrial use. The calorific value is about 3500 kcal / kg. Biomass briquettes can replace 'C' grade coal used in industrial boilers.

Vegetable oil

Vegetable oils such as rapeseed, palm, coconut and cotton seed oil can substitute diesel as engine fuel. Jajoba trees cultivated in marginal lands produce oil seeds. Jajoba oil is considered liquid gold like crude oil as it can be processed into a wide range of products like motor oil, lubricants, mono-unsaturated alcohols and oil of cosmetic value. Euphorbia species produce latex which after water removal give light hydrocarbon oil.

12.4 BIOGAS

Biogas can be produced by digestion of animal, plant and human waste. Digestion is a biological process that takes place in a digester with anaerobic organism in absence of oxygen at a temperature between 35°C and 70°C. In rural areas, household biogas plants operate from cow and buffalo dung which provide gas for cooking and lighting. Biogas is a mixture of CH_4 (55% to 65%), CO_2 (30% to 40%), H_2, H_2S and N_2 (< 10%) having a calorific value between 5000 and 5500 kcal/kg.

12.5 PRODUCER GAS

Producer gas is obtained by partial combustion of wood or any cellulose organic material of plant origin. It is a mixture of a few gases and its constituents are CO_2 (19%), CH_4 (1%), H_2 (18%), CO_2 (11%) and N_2 (45–60%). Hydrogen and methane keep heating value between 4.5 MJ/m^3 and 6 MJ/m^3 depending upon the volume of its constituents. Producer gas can be burnt in a boiler to generate steam. It is used as fuel in IC engines used for irrigation pumps, in spark ignition engines and gas turbines for power generation.

12.6 LIQUID FUEL (ETHANOL)

Ethanol (C_2H_5OH) is a flammable colourless biofuel. It can be produced by fermentation of any feedstock which contains sugar or starch and even cellulose material. Biomass containing sugar are: sugar-beets, sugarcane, sweet sorghum; starch crop covers corn, wheat, cassava and potato. Cellulose is found in all plant tissues, is available in wood, solid waste and agriculture residues. Ethanol is suitably used as a fuel additive to cut down a vehicle's carbon monoxide and other smog-causing emissions. In nine sugar producing Indian states, petrol blended with 5% ethanol is supplied.

12.7 BIOMASS CONVERSION TECHNOLOGIES

Biomass material from a variety of sources can be utilised optimally by adopting efficient and state-of-the-art conversion technologies such as:

Combustion

Direct combustion is the main process adopted for utilising biomass energy. It is burnt to produce heat utilised for cooking, space heating, industrial processes and for electricity generation. This utilisation method is very inefficient with heat transfer losses of 30–90% of the original energy contained in the biomass. The problem is addressed through the use of more efficient cook-stove for burning solid fuels.

Fermentation

Fermentation is a metabolic process that produces chemical changes in organic substrates through the action of enzymes. In biochemistry, it is narrowly defined as the extraction of energy from carbohydrates in the absence of oxygen. In food production, it may more broadly refer to any process in which the activity of microorganisms brings about a desirable change to a foodstuff or beverage.[1] The science of fermentation is known as zymology.

Thermo-chemical conversion

Thermo-chemical conversion is a process to decompose biomass with various combinations of temperatures and pressures. It includes 'pyrolysis' and 'gasification'.

Pyrolysis

Biomass is heated in absence of oxygen, or partially combusted in a limited oxygen supply, to produce a hydrocarbon, rich in gas mixture (H_2, CO_2, CO CH_4 and lower hydrocarbons), an oil like liquid and a carbon rich solid residue (charcoal).

The pyrolitic or 'bio-oil' produced can easily be transported and refined into a series of products similar to refining crude oil. There is no waste product, the conversion efficiency is high (82%) depending upon the feedstock used, the process temperature in reactor and the fuel/ air ratio during combustion.

Gasification

Gasification is conversion of a solid biomass, at a high temperature with controlled air, into a gaseous fuel. The output gas is known as producer gas, a mixture of H_2 (15–20%), CO (10–20%), CH_4 (1–5%), CO_2 (9–12%) and N_2 (45–55%). The gas is more versatile than the solid biomass, it can be burnt to produce process heat and steam, or used in internal combustion engines or gas turbines to generate electricity. The gasification process renders the use of biomass which is relatively clean and acceptable in environmental terms.

Liquefaction

Liquefaction of biomass can be processed through 'fast' or 'flash' pyrolysis, called 'pyrolytic oil' which is a dark brown liquid of low viscosity and a mixture of hydrocarbons. Pyrolysis liquid is a good substitute for heating oil.

Another liquefaction method is through methanol synthesis. Gasification of biomass produces synthetic gas containing a mixture of H_2 and CO. The gas is purified by adjusting the hydrogen and carbon monoxide composition. Finally, the purified gas is subjected to liquefaction process, converted to methanol over a zinc chromium calatyst. Methanol can be used as liquid fuel.

12.8 BIOCHEMICAL CONVERSION

There are two forms of biochemical conversions:

1. Anaerobic digestion
2. Ethanol fermentation

12.8.1 Anaerobic Digestion (Anaerobic Fermentation)

This process converts the cattle dung, human wastes and other organic waste with high moisture content into biogas (gobar gas) through anaerobic fermentation in absence of air. Fermentation occures in two stages by two different metabolic groups of bacteria. Initially the organic material is hydrolyzed into fatty acids, alcohol, sugars, H_2 and CO_2. Methane forming bacteria then converts the products of the first stage to CH_4 and CO_2, in the temperature range 30–55°C. Biogas produced can be used for heating, or for operating engine driven generators to produce electricity. Fermentation occurs in a sealed tank called 'digester' where the sludge left behind is used as enriched fertilizer.

12.8.2 Ethanol Fermentation

Ethanol can be produced by decomposition of biomass containing sugar like sugarcane, cassava sweet sorghum, beet, potato, corn, grape, etc. into sugar molecules such as glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$).

Ethanol fermentation involves biological conversion of sugar into ethanol and CO_2.

12.9 BIOMASS GASIFICATION

Biomass gasification is thermo-chemical conversion of solid biomass into a combustible gas fuel through partial combustion with no solid carbonaceous residue. Gasifiers use wood waste and agriculture residue.

12.9.1 Gasifiers

Gasifiers (fixed bed type) can be of 'updraft' or 'downdraft' type depeding upon the direction of the air flow. The working of biomass gasification can be explained by considering a typical downdraft gasifier (Figure 12.2) where fuel and air move in a co-current manner. In the updraft gasifier, fuel and air move in a countercurrent manner. However, the basic reaction zones remain the same.

Fuel is loaded in the reactor from the top. As the fuel moves down it is subjected to drying (120°C) and then pyrolysis (200–600°C) where solid char, acetic acid, methanol and water vapour are produced. Descending volatiles and char reach the oxidation zone where air is injected to complete the combustion. It is the reaction zone and the temperature rises to 1100°C. This helps in breaking down the heavier hydrocarbons and tars.

As these products move downwards, they enter the 'reduction zone' (900–600°C, reaction being endothermic) where producer gas is formed by the action of CO_2 and water vapour on red hot charcoal as detailed below:

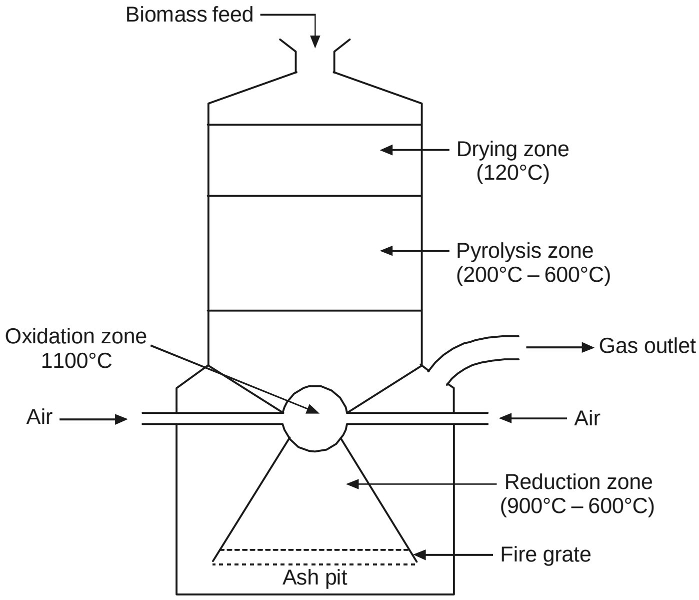


Figure 12.2 Downdraft gasifier.

Producer gas formed in the reduction zone contains combustible products like CO, H_2 and CH_4. Hot gas flowing out is usually polluted with soot, tar and vapour. For purifying, it is passed through coolers, tar is removed by condensation, whereas soot and ash are removed by centrifugal separation.

Clean producer gas provides the process heat to operate stoves (for cooking), boilers, driers, ovens and furnaces. The major application is in area of electric power generation either through dual-fuel IC engines (where diesel oil is replaced to an extent of 60%–80%), or through 100% gas-fired spark ignition engines.

A biomass gasifier-based electricity generation system costs from ` 4.0 crores to 4.5 crores/MW and the power generation cost is between ` 2.50 and ` 3.50 per kWh.

Fixed bed gasifiers can attain efficiency up to 75% for conversion of solid biomass to gaseous fuel. However, the performance depends on fuel size and moisture content, volatiles and ash content.

12.9.2 Fluidized Bed Gasifier

Fluidized Bed Combustion (FBC) is a better option to use than the problematic biomass of farm residues like rice husk (high ash content), bagasse, industrial waste such as saw dust and pulping effluents, sewage sludge etc. FBC constitutes a hot bed of inert solid particles of sand or crushed refractory support on a fine mesh or grid. The bed material is fluidized by an upward current of air as shown in Figure 12.3.

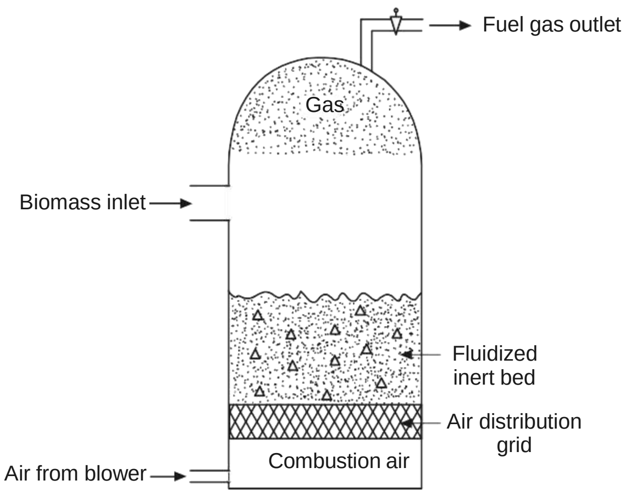


Figure 12.3 Fluidized bed gasifier.

Pressurized air starts bubbling through the bed and the particles attain a state of high turbulence, and the bed exhibits fluid like properties. A uniform temperature within the range of 850 –1050°C is maintained. Large surface area is created in the fluidized bed and the constantly changing area per unit volume provides a higher conversion efficiency at low operating temperatures compared to the fixed beds. High heating capacity of sand and the uniform temperature of fluidized bed makes possible to gasify low-grade fuels of even non-uniform size and high moisture content.

When the gasifier is put in use, the bed material is heated to ignition temperature of the fuel, biomass is then injected causing rapid oxidation and gasification. Fuel gas so produced contains impurities, dust, char particles and tar. It needs conditioning and cleaning for utilization as an engine fuel.

12.10 BIOGAS

Biogas is a renewable energy derived from organic wastes such as cattle dung, human waste, etc. It is a safe fuel for cooking and lighting. Left-over digested slurry is used as enriched manure in agriculture lands.

12.10.1 Biogas Technology

Biogas is produced from wet biomass through a biological conversion process that involves bacterial breakdown of organic matter by micro-organisms to produce CH_4, CO_2 and H_2O. The process is known as 'anaerobic digestion' which proceeds in three steps.

1. Hydrolysis
2. Acid formation
3. Methane formation

Hydrolysis

Organic waste of animal and plants contains carbohydrates in the form of cellulose, hemicellulose and lignin. A group of anaerobic micro-organisms (celluolytic bacteria / hydrobytic bacteria) breaks down complex organic material into simple and soluble organic components, primarily acetates. The rate of hydrolysis depends on bacterial concentration, quality of substrate, pH (between 6 and 7) and temperature (30°C – 40°C) of digester contents.

Acid formation

Decomposed simple organic material is acted upon by acetogenic bacteria and converted into simple acetic acid.

Methane formation

Acetic acid so formed becomes the substrate strictly for anaerobic methanogeric bacteria, which ferment acetic acid to methane and CO_2. Gas production is stable for pH between 6.6 and 7.6.

Biogas consists of CH_4, CO_2 and traces of other gases such as H_2, CO, N_2, O_2 and H_2S. Gas mixture is saturated with water vapour. The methane content of biogas is about 60% which provides a high calorific value to find use in cooking, lighting and power generation.

12.11 BIOGAS PLANTS

The biogas plant is a device that converts cattle dung and other organic matter into inflammable gas called biogas and into a good quality organic manure under anaerobic conditions. There are two popular designs of biogas plants: (i) Floating drum (constant pressure) type and (ii) Fixed dome (constant volume) type.

12.11.1 Floating Drum Type Biogas Plant

A popular model developed by Khadi Village Industries Commission (KVIC) was standardized in 1961. It comprises an underground cylindrical masonary digester having an inlet pipe for feeding animal dung slurry and an outlet pipe for sludge. There is a steel dome for gas collection which floats over the slurry. It moves up and down depending upon accumulation and discharge of gas guided by the dome guide shaft (Figure 12.4).

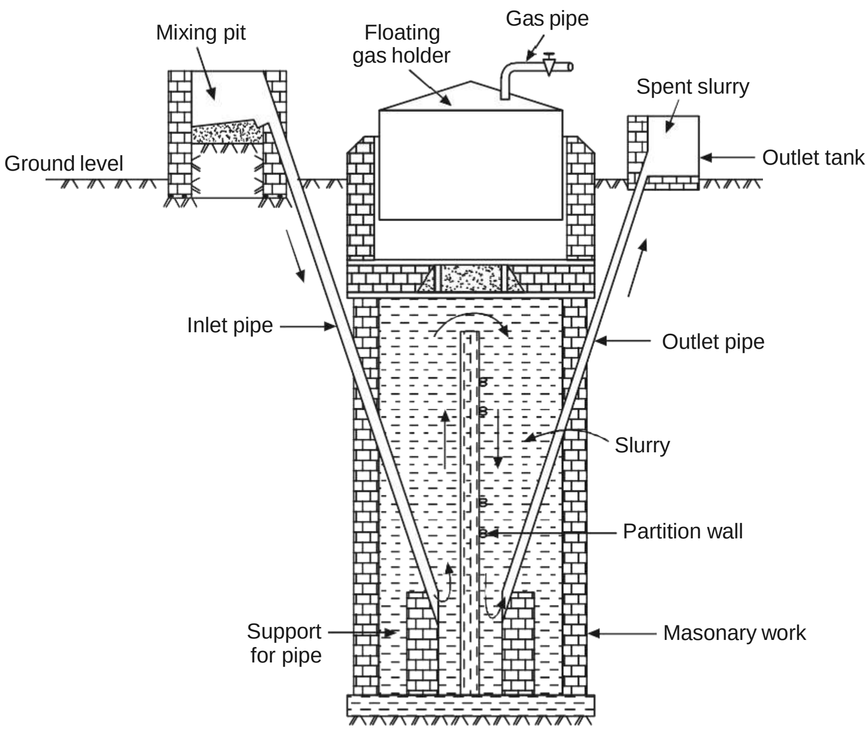


Figure 12.4 Floating drum biogas plant (KVIC model).

A partition wall is provided in the digester to improve circulation, necessary for fermentation. The floating gas holder builds gas pressure of about 10 cm of water column, sufficient to supply gas up to 100 metre. Gas pressure also forces out the spent slurry through a sludge pipe.

12.11.2 Fixed Dome Type Biogas Plant

It is an economical design where the digester is combined with a dome-shaped gas holder (Figure 12.5). It is known as Janata model; the composite unit is made of brick and cement masonary having no moving parts, thus ensuring no wear and tear and longer working life. When gas is produced, the pressure in the dome changes from 0 to 100 cm of water column. It regulates gas distribution and outflow of spent slurry.

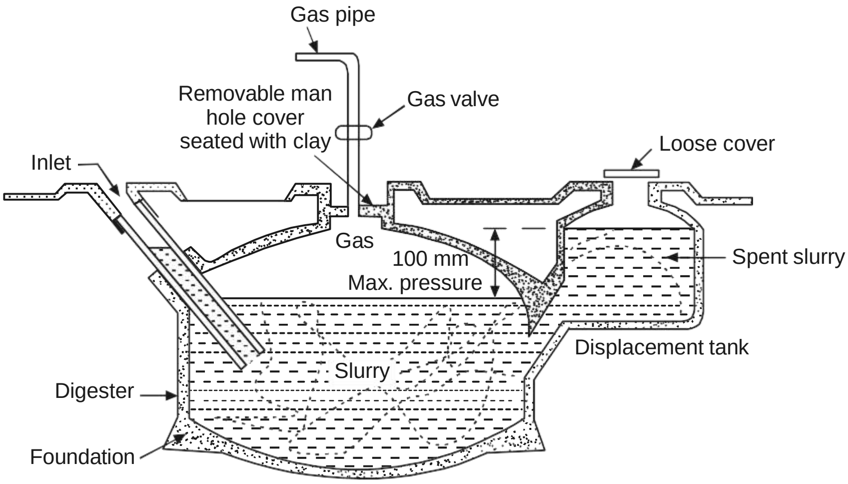


Figure 12.5 Fixed dome biogas plant (Janata model).

12.11.3 Deenbandhu Biogas Plant (DBP)

This plant developed by AFPRO (Action For Food Production) with the objective to extend the biogas technology to places where the availability of bricks is a limiting factor and bamboo is easily available. Its cost is reduced as the surface area is minimized by joining segments of two different diameter spheres at their bases as given in Figure 12.6. This plant requires less space being mainly undergound. It is 30% economical compared to the Janata biogas plant. After intensive trial and testing it has been approved by MNRE for family size installation.

12.11.4 Community Night-soil Based Biogas Plant

Community night-soil based biogas plants have been developed to facilitate sanitary treatment of human waste at community and institutional level (Figure 12.7). This installation constitutes

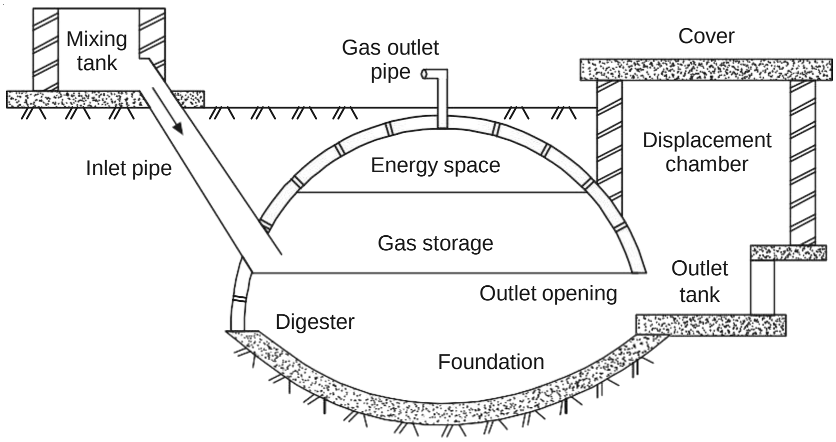


Figure 12.6 Deenbandhu biogas plant.

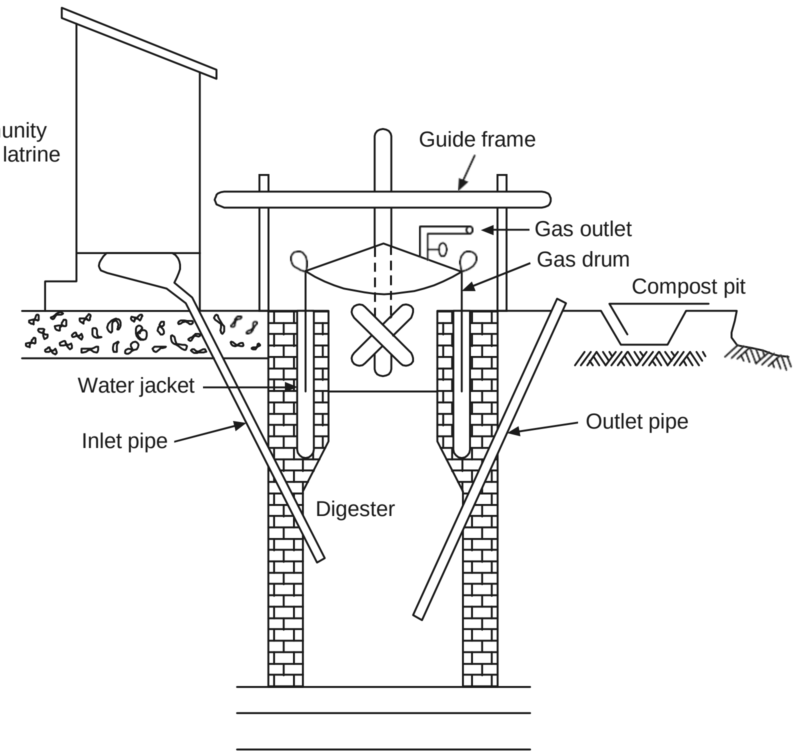


Figure 12.7 Community night-soil based biogas plant.

a floating metal drum with a water jacket. It is linked with community toilets and serves a population of about 1000 persons to provide fuel for cooking, operate dual-fuel engines for water supply and generate electric power.

12.12 BIODIESEL

Biodiesel is a liquid fuel produced from non-edible oil seeds such as Jatropha, Pongamia pinnata (Karanja), etc. which can be grown on wasteland. However, the oil extracted from these seeds has high viscosity (20 times that of diesel) which causes serious lubrication, oil contimination and injector choking problems. These problems are solved through trans-esterification, a process where the raw vegetables oils are treated with alcohol (methanol or ethanol with a catalyst) to form methyl or ethyl esters. The monoesters produced by trans-esterifying vegetable oil are called 'biodiesel' having low fuel viscosity with high octane number and heating value. Endurance tests show that biodiesel can be adopted as an alternative fuel for existing diesel engines without modifications.

In EU and USA, edible vegetable oil like sunflower, groundnut, soyabean and cotton seed, etc. are used to produce biodiesel. India is endowed with a number of non-edible vegetable oil producing trees which thrives in inhospitable conditions of heat, low water, rocky and sandy soils, a renewable resource of economic significance (Jojoba in Rajasthan).

Biodiesel is the name of diesel fuel made from vegetable oil or animal fats. The concept dates back to 1885, when Dr. Rudolf Diesel developed the first diesel engine to run on vegetable oil. In recent past the use of bio oil as an alternative renewable fuel to compete with petroleum was proposed during 1980.

The advantages of biodiesel as engine fuel are: (i) biodegradable and produces 80% less CO_2 and 100% less SO_2 emissions, (ii) renewable, (iii) higher octane number, (iv) can be used as neat fuel (100% biodiesel) or mixed in any ratio with petro-diesel, and (iv) has a higher flash point making it safe to transport. Selected fuel properties of biodiesel and petrodiesel are given in Table 12.5.

Table 12.5 Properties of biodiesel and petrodiesel

Properties	*Petrodiesel*	*Biodiesel*
Boiling point, °C	188–343	182–338
Viscosity at 40°C	1.3–4.1	1.9–6.0
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, wt%	0	11
Sulphur, wt%	0.05 max	0.0–0.0024
Heating value, kcal/litre	7278	6491

12.12.1 Production of Biodiesel from Jatropha

Jatropha curcas drought resistant perennial shrub with 4–5 metre height is ideally suited to green up the wastelands in arid areas. Commercial seed production commences from the 6th year onwards with yield of 6000 kg/ha under rain-fed conditions and 12000 kg/ha in irrigated areas. The average oil production is 0.25 kg oil/kg seed. The oil cake is used as organic fertilizer.

Scientists of Central Salt & Marine Chemical Research Insitute (CSMCRI) Bhavnagar (Gujarat) have confirmed the use of Jatropha curcas and Jojoba seed oil as promising substitutes for diesel. The yield of Jojoba seed is 0.5 kg per plant after 10 years of plantation, Jojoba seed costs ` 200/kg, so presently it is uneconomical as feedstock for engine oil.

The characteristics of four biodiesels obtained from vegetable oils of peanut, soyabean, sunflower Jatropha and diesel are given in Table 12.6

Table 12.6 Characteristics of four biodiesels

Name	*Flash point* (°C)	*Density at* 20/40°C	*Viscosity*	*Octane number*	*Heating value* (MJ/litre)
Diesel	32	0.82–0.86	2.0–7.5	42	34.5–36.0
Biodiesel (Jatropha)	161	0.878	4.54	65	33.7

Biodiesel (Sunflower)	183	0.880	4.60	49	33.5
Biodiesel Soyabean	178	0.885	4.50	45	33.5
Biodiesel Peanut	176	0.883	4.90	54	33.6

The heat of combustion for biodiesel is up to 95% by volume of conventional diesel, but biodiesel being oxygenated provides the same fuel value as the diesel. The parameters in Table 12.5 justify Jatropha seed (cost ` 5.0/kg) as an economically favourable feedstock to produce biodiesel.

Oil is extracted from Jatropha seeds in an oil press. It is treated with methanol (CH_3OH) to produce three methyl ester molecules and one glycerol molecule. Alkalis like NaOH or KOH are used to catalyze the reaction having the following constituents: 1000 litre Jatropha oil + 400 litre

(CH_3OH) + 10 litre catalyst. The reaction process is completed rapidly, glycerol is separated and methyl ester is obtained as biodiesel.

The Ministry of Petroleum and Natural Gas has opened a biofuel centre in Delhi to build awareness of importance of Jatropha curcas cultivation and manufacture of biodiesel. The Indian Oil Corporation (IOC) has already established a biodiesel plant at Faridabad and another one being established in Panipat refinery to prepare 30,000 litres of biodiesel daily by crushing 100,000 kg Jatropha seeds. Biodiesel shall be blended with diesel to the extent of 5% in different Indian climatic conditions. Approximately, 40 million tonnes of HSD is consumed annually in India, thus, only 5% replacement of petroleum fuel by biodiesel would save the country approximately ` 4000 crores in foreign exchange yearly.

12.13 BIOFUEL PETROL

Shell oil company started selling petrol containing 10% cellulosic ethanol in Ottawa. Biofuel is produced from wheat straw. Logen's process converts biomass into cellulostic ethanol using a combination of thermal, chemical and biochemical techniques. Yield of cellulosic ethanol is 340 litres per tonne of fibre. Lignin is the plant fibre is used to drive the process by generating stream and electricity, thus, eliminating the need of coal or natural gas. Cellulosic ethanol is identical to ethanol, but produces up to 90% less CO_2 than petrol.

UNIT V - OTHER ENERGY SOURCES

Tidal Energy: Energy from the tides, Barrage and Non Barrage Tidal power systems. Wave Energy: Energy from waves, wave power devices. Ocean Thermal Energy Conversion (OTEC)- Hydrogen Production and Storage- Fuel cell: Principle of working- various types - construction and applications. Energy Storage System- Hybrid Energy Systems.

Introduction

Tidal power or tidal energy is the form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity. The barrage method of extracting tidal energy involves building a barrage across a bay or river that is subject to tidal flow. Turbines installed in the barrage wall generate power as water flows in and out of the estuary basin, bay, or river. Wave energy (or wave power) is the transport and capture of energy by ocean surface waves. The energy captured is then used for all different kinds of useful work, including electricity generation, water desalination, and pumping of water. Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface waters. A fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode. At the anode site, the hydrogen molecules are split into electrons and protons. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

Tidal Energy: Energy from the tides

Tidal power, also called tidal energy is any form of renewable energy in which tidal action in the oceans is converted to electric power. There are three main types of energy that can be captured from the oceans: wave, tidal stream, and tidal range.

Using the power of the tides, energy is produced from the gravitational pull from both the moon and the sun, which pulls water upwards, while the Earth’s rotational and gravitational power pulls water down, thus creating high and low tides. This movement of water from the changing tides is a natural form of kinetic energy. The tidal stream devices which utilise these currents are broadly similar to submerged wind turbines and are used to exploit the kinetic energy in tidal currents. Due to the higher density of water the blades can be smaller and turn more slowly, but they still deliver a significant amount of power. To increase the flow and power output from the turbine, concentrators (or shrouds) may be used around the blades to streamline and concentrate the flow towards the rotors.

It can only be installed along coastlines. Coastlines often experience two high tides and two low tides on a daily basis. The difference in water levels must be at least 5 meters high to produce electricity. The various components include, steam generator, tidal turbine or the more innovative dynamic tidal power (DTP) technology to turn kinetic energy into electricity.

The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern

Barrage and Non Barrage Tidal power systems

Tidal electricity can be created from several technologies, the main ones being tidal barrages, tidal turbines and tidal lagoons.

Tidal Barrages

The Tidal Barrage uses long walls, dams, sluice gates or tidal locks to capture and store the potential energy of the ocean. A Tidal Barrage is a type of tidal power generation scheme that involves the construction of a fairly low walled dam, known as a “tidal barrage”. It spans across the entrance of a tidal inlet, basin or estuary creating a single enclosed tidal reservoir, similar in many respects to a hydroelectric impoundment reservoir. The bottom of this barrage dam is located on the sea floor with the top of the tidal barrage being just above the highest level that the water can get too at the highest annual tide. The barrage has a number of underwater tunnels cut into its width allowing the sea water to flow through them in a controlled way by using “sluice gates” on their entrance and exit points. Fixed within these tunnels are huge tidal turbine generators that spin as the sea water rushes past them either to fill or empty the tidal reservoir thereby generating electricity.

The water which flows into and out of these underwater tunnels carries enormous amounts of kinetic energy and the job of the tidal barrage is to extract as much of this energy as possible which it uses to produce electricity. Tidal barrage generation using the tides is very similar to hydroelectric generation, except that the water flows in two directions rather than in just one. On incoming high tides, the water flows in one direction and fills up the tidal reservoir with sea water. On outgoing ebbing tides, the sea water flows in the opposite direction emptying it. As a tide is the vertical movement of water, the tidal barrage generator exploits this natural rise and fall of tidal waters caused by the gravitational pull of the sun and the moon.

The tidal energy extracted from tides is a potential energy as the tide moves in a vertical up-down direction between a low and a high tide and back to a low creating a height or head differential. A tidal barrage generation scheme exploits this head differential to generate electricity by creating a difference in the water levels at the side of a dam and then passing this water difference through the turbines. The three main tidal energy barrage schemes that use this water differential to their advantage are:

1. **Flood Generation:** The tidal power is generated as the water enters a tidal reservoir on the incoming Flood tide.
2. **Ebb Generation:** The tidal power is generated as the water leaves a tidal reservoir on the Ebb flow tide.
3. **Two-way Generation:** The tidal power is generated as the water flows in both directions in and out of the reservoir during both the Flood and the Ebb tides.

Tidal Barrage Flood Generation

A Tidal Barrage Flood Generation uses the energy of an incoming rising tide as it moves towards the land. The tidal basin is emptied through sluice gates or lock gates located along the section of the barrage and at low tide the basin is affectively empty. As the tide turns and starts to comes in, the sluice gates are closed and the barrage holds back the rising sea level, creating a difference in height between the levels of water on either side of the barrage dam.

The sluice gates at the entrances to the dam tunnels can either be closed as the sea water rises to allow for a sufficient head of water to develop between the sea level and the basin level before being opened, generating more kinetic energy as the water rushes through, turning the turbines as it passes. Or may remain fully open, filling up the basin more slowly and maintaining the same water level inside the basin as out in the sea.

The tidal reservoir is therefore filled up through the turbine tunnels which spin the turbines generating tidal electricity on the flood tide and is then emptied through the opened sluice or lock gates on the ebb tide. Then a flood tidal barrage scheme is a one-way tidal generation scheme on the incoming tide with tidal generation restricted to about 6 hours per tidal cycle as the basin fills up.

The movement of the water through the tunnels as the tidal basin fills up can be a slow process, so low speed turbines are used to generate the electrical power. This slow filling cycle allows fish or other sea life to enter the enclosed basin without danger from the fast rotating turbine blades. Once the tidal basin is full of water at high tide, all the sluice gates are opened allowing all the trapped water behind the dam to return back to the ocean or sea as it ebbs away.

Flood generator tidal power generates electricity on incoming or flood tide, but this form of tidal energy generation is generally much less efficient than generating electricity as the tidal basin empties, called “Ebb Generation”. This is because the amount of kinetic energy contained in the lower half of the basin in which flood generation operates is much less the kinetic energy present in the upper half of the basin in which ebb generation operates due to the effects of gravity and the secondary filling of the basin from inland rivers and streams connected to it via the land.

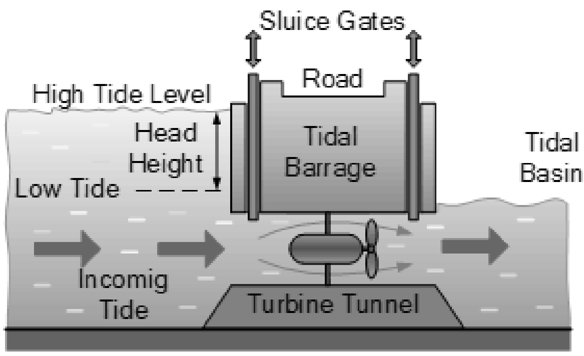


Fig. 1. Tidal Barrage Flood Generation

Tidal Barrage Ebb Generation

A Tidal Barrage Ebb Generation uses the energy of an outgoing or falling tide, referred to as the "ebb tide", as it returns back to the sea making it the opposite of the previous flood tidal barrage scheme. At low tide, all the sluice and lock gates along the barrage are fully opened allowing the tidal basin to fill up slowly at a rate determined by the incoming flood tide. When the ocean or sea level feeding the basin reaches its highest point at high tide, all the sluices and lock gates are then closed entrapping the water inside the tidal basin (reservoir). This reservoir of water may continue to fill-up due to inland rivers and streams connected to it from the land.

As the level of the ocean outside the reservoir drops on the outgoing tide towards its low tide mark, a difference between the higher level of the entrapped water inside the tidal reservoir and the actual sea level outside now exists. This difference in vertical height between the high level mark and the low mark is known as the "head height".

At some time after the beginning of the ebb tide, the difference in the head height across the tidal barrage between the water inside the tidal reservoir and the falling tide level outside becomes sufficiently large enough to start the electrical generation process and the sluice gates connected to the turbine tunnels are opened allowing the water to flow.

When the closed sluice gates are opened, the trapped potential energy of the water inside flows back out to the sea under the enormous force of both the gravity and the weight of the water in the reservoir basin behind it. This rapid exit of the water through the tunnels on the outgoing tide causes the turbines to spin at a fast speed generating electrical power.

The turbines continue to generate this renewable tidal electricity until the head height between the external sea level and the internal basin is too low to drive the turbines at which point the turbines are disconnected and the sluice gates are closed again to prevent the tidal basin from over draining and affecting local wildlife. At some point the incoming flood tide level will again be at a sufficient level to open all the lock gates filling-up the basin and repeating the whole generation cycle over again as shown.

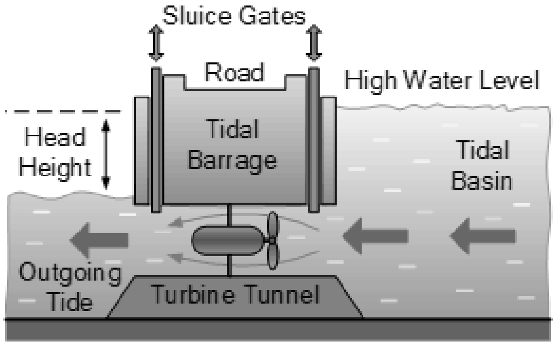


Fig. 2. Tidal Barrage Ebb Generation

According to the estimates of the Indian government, the country has a potential of 8,000 MW of tidal energy. This includes about 7,000 MW in the Gulf of Cambay in Gujarat, 1,200 MW in the Gulf of Kutch and 100 MW in the Gangetic delta in the Sunderbans region of West Bengal.

Two-way Tidal Barrage Generation Scheme

Both Flood Tidal Barrage and Ebb Tidal Barrage installations are "one-way" tidal generation schemes, but in order to increase the power generation time and therefore improve efficiency, we can use special double effect turbines that generate power in both directions. A Two-way Tidal Barrage Scheme uses the energy over parts of both the rising tide and the falling tide to generate electricity.

Two-way electrical generation requires a more accurate control of the sluice gates, keeping them closed until the differential head height sufficient in either direction before being opened. As the tide ebbs and flows, sea water flows in or out of the tidal reservoir through the same gate system. This flow of tidal water back and forth causes the turbine generators located within the tunnel to rotate in both directions producing electricity.

However, this two-way generation is in general less efficient than one-way flood or ebb generation as the required head height is much smaller which reduces the period over which normal one-way generation might have otherwise occurred. Also, bi-directional tidal turbine generators designed to operate in both directions are generally more expensive and less efficient than dedicated uni-directional tidal generators.

Non Barrage Tidal power systems

Tidal turbines

Tidal stream generators are underwater tidal turbines which produce mechanical power by converting the kinetic energy from water currents (the kinetic power component), in a similar way to wind turbines which draw energy from air currents. A tidal stream is a fast-flowing body of water created by tides. A turbine is a machine that takes energy from a flow of fluid. That fluid can be air (wind) or liquid (water). Because water is much more dense than air, tidal energy is more powerful than wind energy. Unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity.

Placing turbines in tidal streams is complex, because the machines are large and disrupt the tide they are trying to harness. The environmental impact could be severe, depending on the size of the turbine and the site of the tidal stream. Turbines are most effective in shallow water. This produces more energy and allows ships to navigate around the turbines. A tidal generator's turbine blades also turn slowly, which helps marine life avoid getting caught in the system.

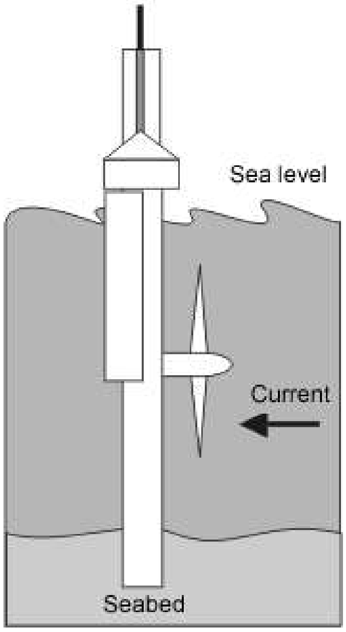


Fig. 3. Tidal turbine

The Bay of Fundy in Canada has the highest tidal ranges in the world, where the height difference between low and high tide water levels can reach 16.3 meters, taller than a three storey building, and therefore brimming with potential for tidal energy production.

Tidal lagoon

A tidal lagoon is a power station that generates electricity from the natural rise and fall of the tides. Tidal lagoons work in a similar way to tidal barrages by capturing a large volume of water behind a man-made structure which is then released to drive turbines and generate electricity. Unlike a barrage, where the structure spans an entire river estuary in a straight line, a tidal lagoon encloses an area of coastline with a high tidal range behind a breakwater, with a footprint carefully designed for the local environment.

As the tide comes in (floods) the water is held back by the turbine wicket gates, which are used to control the flow through the turbine and can be completely closed to stop the water from entering the lagoon. This creates a difference in water level height (head) between the inside of the lagoon and the sea. Once the difference between water levels is optimised, the wicket gates are opened and water rushes into the lagoon through the bulb turbines mounted inside concrete turbine housings in a section of the breakwater wall. As the water turns the turbines, electricity is generated.

The water in the lagoon then returns to closely match the same level as the sea outside. This process also happens in reverse as the tide flows out (ebbs) because the turbines are ‘bi-directional’ and so electricity can be generated from the incoming and outgoing tides. We can hold the tide within the lagoon for approximately 2.5 hours as the sea outside ebbs and the head builds.

The height and time of the tides can be predicted years in advance to a high degree of accuracy, allowing the precise operation of the lagoon on each tidal cycle to be optimised well in advance.

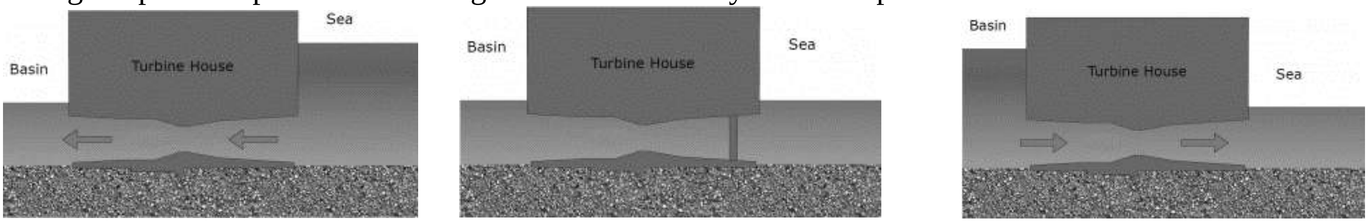


Fig. 4. a. Generating on the flood tide b. Holding period at high or low water c. Generating on the ebb tide

Advantages of Tidal Energy

- **Renewable:** Compared to fossil fuels or nuclear reserves, the gravitational fields from the sun and the moon, as well as the earth's rotation around its axis won't cease to exist any time soon.
- **Green:** Tidal power is an environmentally friendly energy source. In addition to being a renewable energy, it does not emit any climate gases and does not take up a lot of space.
- **Predictable:** Tidal currents are highly predictable. High and low tide develop with well-known cycles, making it easier to construct the system with right dimensions, since we already know what kind of powers the equipment will be exposed to.
- **Effective at Low Speeds:** Water has 1000 times higher density than air, which makes it possible to generate electricity at low speeds. Calculations show that power can be generated even at 1m/s (equivalent to a little over 3ft/s).
- **Long Lifespans:** We have no reason to believe that tidal power plants are not long lived. This ultimately reduces the cost these power plants can sell their electricity, making tidal energy more cost-competitive.

Disadvantages of Tidal Energy

- **Environmental Effects:** Tidal barrages relies on manipulation on ocean levels and therefore potentially have the environmental effects on the environment similar to those of hydroelectric dams.
- **Close to Land:** Tidal power plants needs to be constructed close to land.
- **Expensive:** It is important to realize that the methods for generating electricity from tidal energy is a relatively new technology.

The IEA believes tidal energy could start playing a significant part in the global energy mix by 2030. Tidal energy may produce up to 748 GW of power by 2050, according to Ocean Energy Systems. Although, compared to solar, the predictions are conservative. (Solar power could hit 4,600 GW by

Wave Energy: Energy from waves

Waves form as wind blows over the surface of open water in oceans and lakes. Ocean waves contain tremendous energy. Wave power is produced by the up and down motion of floating devices placed on the surface of the ocean. As the waves travel across the ocean, high-tech devices capture the natural movements of ocean currents and the flow of swells to generate power.

Wave energy or wave power is essentially the power drawn from waves. When wind blows across the sea surface, it transfers the energy to the waves. They are powerful source of energy and the energy output is measured by wave speed, wave height, wavelength and water density. The more strong the waves, the more capable it is to produce power. The captured energy can then be used for electricity generation, powering plants or pumping of water. For example when you look out at a beach and see waves crashing against the shore, you are witnessing wave energy. Wave energy is often mixed with tidal power, which is quite different. When wind blows across the surface of the water strongly enough, it creates waves. This occurs most often and most powerfully on the ocean because of the lack of land to resist the power of the wind. The kinds of waves that are formed, depend on from where they are being influenced.

Long, steady waves that flow endlessly against the beach are likely formed from storms and extreme weather conditions far away. The power of storms and their influence on the surface of the water is so powerful that it can cause waves on the shores of another hemisphere. When you see high, choppy waves that rise and fall very quickly, you are likely seeing waves that were created by a nearby weather system. These waves are usually newly formed occurrences. The power from these waves can then be harnessed through wave energy converter (WEC).

Wave power devices

As an ocean wave passes a stationary position, the surface of the sea changes in height, water near the surface moves as it losses its kinetic and potential energy, which affects the pressure under the surface. The periodic or oscillatory nature of ocean waves means that we can use a variety of different Wave Energy Devices to harness the energy produced by the oceans waves.

The problem lies is that the oscillatory frequency of an ocean wave is relatively slow and is much less than the hundreds of revolutions per minute required for electric power generation. Then a great variety of wave energy devices and designs are available to convert these slow-acting, reversing wave forces into the high speed, unidirectional rotation of a generator shaft.

There are three fundamental but very different wave energy devices used in converting wave power into electric power, and these are:

1. **Wave Profile Devices:** These are wave energy devices which turn the oscillating height of the oceans surface into mechanical energy.
2. **Oscillating Water Columns:** These are wave energy devices which convert the energy of the waves into air pressure.
3. **Wave Capture Devices:** These are wave energy devices which convert the energy of the waves into potential energy.

Tidal turbines are more expensive to build and maintain than wind turbines, but produce more energy. They also produce energy more consistently as the tide is continuous while the wind doesn't always

Wave Profile Devices

Wave profile devices are a class of wave energy device which floats on or near to the sea surface and moves in response to the shape of the incident wave or, for submersible devices, it moves up and down under the influence of the variations in underwater pressure as a wave moves by. Most types of wave profile devices float on the surface absorbing the wave energy in all directions by following the movements of waves at or near the sea surface, just like a float.

If the physical size of the wave profile device is very small compared to the periodic length of the wave, this type of wave energy device is called a “point absorber”. If the size of the device is larger or longer than the typical periodic wavelength, it is called a “linear absorber”, but more commonly they are collectively known as “wave attenuators”. The main difference between the two wave energy devices is how the oscillating system converts the wave energy between the absorber and a reaction point. This energy absorption can be achieved either by a floating body, an oscillating solid member or oscillating water within a buoys structure itself.

The waves energy is absorbed using vertical motion (heave), horizontal motion in the direction of wave travel (surge), angular motion about a central axis parallel to the wave crests (pitch) or angular motion about a vertical axis (yaw) or a combination of all four with the energy being generated by reacting these different movements against some kind of fixed resistance called a reaction point.

To make efficient use of the force generated by the wave, we need some kind of force reaction. In other words, we want the waves force on the float to react against another rigid or semi-rigid body. Reaction points can be inertial masses such as heavy suspended ballast plates, sea-floor anchors or a fixed dead-weight or pile as shown. The pitching and heaving of the waves causes a relative motion between an absorber and reaction point.

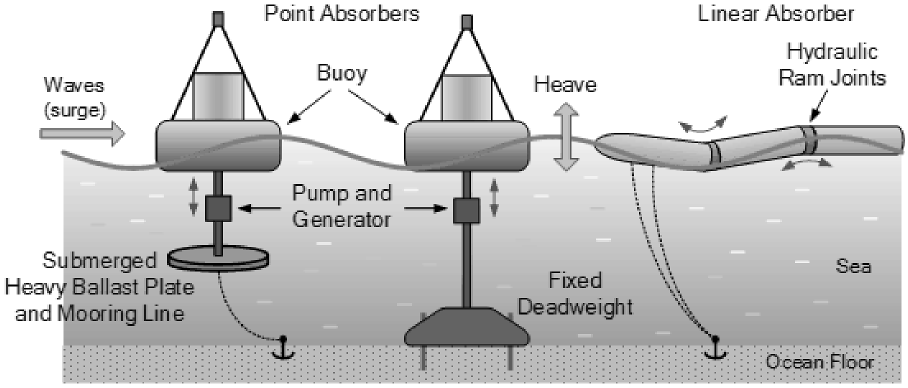


Fig. 5. Wave Profile Devices

The left hand wave energy device above, uses a heavy ballast plate suspended below the floating buoy. The buoy is prevented from floating away by a mooring line attached to a sea-floor anchor. This mooring line allows the point absorber to operate offshore in deeper waters. As the buoy bobs up-and-down in the waves, a oscillatory mutual force reaction is generated between the freely moving absorber and the heavy plate causing a hydraulic pump in between to rotate a generator producing electricity.

The middle wave energy device operates in a similar manner to the previous floating buoy device. The difference this time is that the freely heaving buoy reacts against a fixed reaction point such as a fixed dead-weight on the ocean floor. As this type of point absorber is bottom mounted, it is operated in shallower near shore locations.

The third device is an example of a linear absorber (wave attenuator) which floats on the surface of the water. It to is tethered to the ocean floor so that it can swing perpendicularly towards the incoming waves. As the waves pass along the length of this snake like wave energy device, they cause the long cylindrical body to sag downwards into the troughs of the waves and arch upwards when the waves crest is passing.

Oscillating Water Column

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 waters 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.

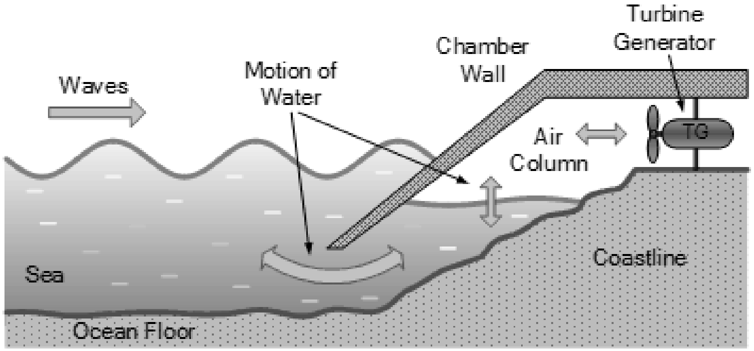


Fig. 6. Oscillating Water Column

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.

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. The advantage of this shoreline scheme is that the main moving part, the turbine can be easily removed for repair or maintenance because it is on land. The disadvantage though is that, as with the previous wave energy devices, the oscillating wave columns output is dependent on the level of wave energy, which varies day by day according to the season.

Wave Capture Device

A Wave Capture Device also known as a Overtopping Wave Power Device, is a shoreline to near shore wave energy device that captures the movements of the tides and waves and converts it into potential energy. Wave energy is converted into potential energy by lifting the water up onto a higher level. The wave capture device, or more commonly an overtopping device, elevates ocean waves to a holding reservoir above sea level.

The overtopping wave energy converter works in much the same way as an impoundment type hydroelectric dam works. Sea water is captured and impounded at a height above sea level creating a low head situation which is then drained out through a reaction turbine, usually a Kaplan Turbine generating electricity as shown.

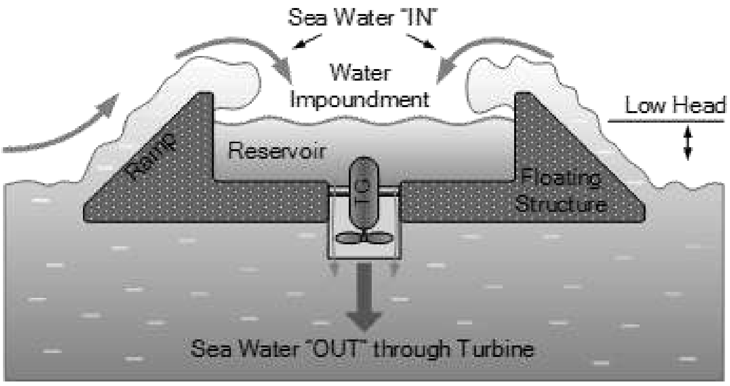


Fig. 7. Wave Capture Device

The basic impoundment structure can be either fixed or a floating structure tethered to the sea bed. The wave overtopping device uses a ramp design on the device to elevate part of the incoming waves above their natural height. As the waves hit the structure they flow up a ramp and over the top (hence the name "overtopping"), into a raised water impoundment reservoir on the device in order to fill it. Once captured, the potential energy of the trapped water in the reservoir is extracted using gravity as the water returns to the sea via a low-head Kaplan turbine generator located at the bottom of the wave capture device.

Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy also called as Ocean Thermal Energy Conversion (OTEC) refers to a method of using the temperature difference between the deep parts of the sea which are cold and the shallow parts of the sea which are cold to run a heat engine and produce useful work. Basically, Ocean thermal energy conversion is an electricity generation system. The deeper parts of the ocean are cooler due to the fact that the heat of sunlight cannot penetrate very deep into the water. Here the efficiency of the system depends on the temperature difference. Greater the temperature difference, greater the efficiency. The temperature difference in the oceans between the deep and shallow parts is maximum in the tropics, 20 to 25^{o} C. Tropics receive a lot of sunlight which warms the surface of the oceans, increasing the temperature gradient.

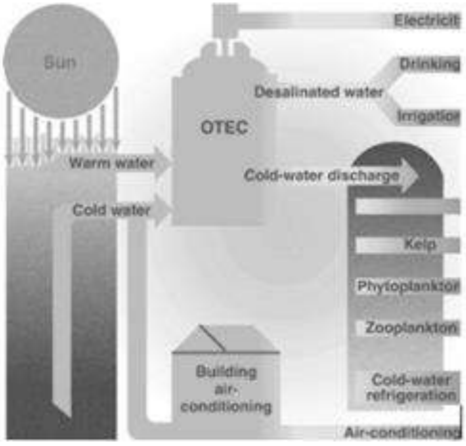


Fig. 8. Ocean Thermal Energy Conversion

The energy source of OTEC is abundantly available, free and will be so, for as long as the sun shines and ocean currents exist. Estimates suggest that ocean thermal energy could contain more than twice the world's electricity demand. This makes it necessary for us to give it a closer look.

Types of Ocean Thermal Energy Conversion Systems

The two types of Ocean Thermal Energy Conversion Systems are closed cycle and open cycle.

Closed Cycle: Closed cycle Ocean Thermal Energy Conversion systems use a working fluid with a low boiling point, Ammonia for example, and use it to power a turbine to generate electricity. Warm seawater is taken in from the surface of the oceans and cold water from the deep at 5^{o} . The warm seawater vaporizes the fluid in the heat exchanger which then turns the turbines of the generator. The fluid now in the vapour state is brought in contact with cold water which turns it back into a liquid. The fluid is recycled in the system so it is called a closed system.

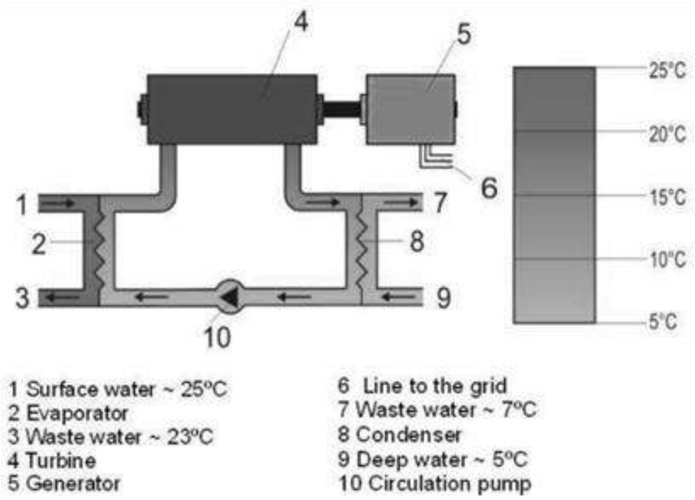


Fig. 9. Closed cycle Ocean Thermal Energy Conversion Systems

Open Cycle: Open cycle OTEC directly uses the warm water from the surface to make electricity. The warm seawater is first pumped in a low-pressure chamber where due to the drop in pressure, it undergoes a drop in boiling point as well. This causes the water to boil. This steam drives a low-pressure turbine which is attached to an electrical generator. The advantage of this system over a closed system is that, in open cycle, desalinated water in the form of steam is obtained. Since it is steam, it is free from all impurities. This water can be used for domestic, industrial or agricultural purposes.

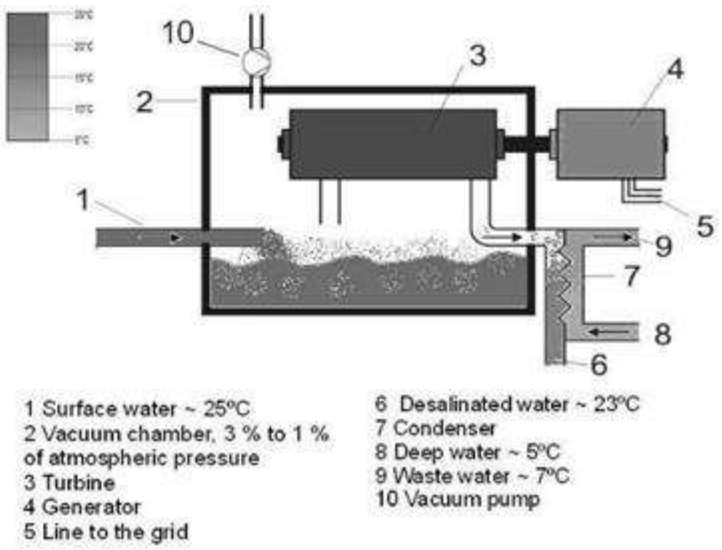


Fig. 10. Open cycle Ocean Thermal Energy Conversion Systems

Land- and sea-based OTEC

Open- and closed-cycle OTEC can operate either on the shore (land-based) or out at sea (sometimes known as floating or grazing). Land-based OTEC plants are constructed on the shoreline with four large hot and cold pipelines dipping down into the sea: a hot water input, a hot water output, a cold-water input, and a cold-water output. Unfortunately, shoreline construction makes them more susceptible to problems like coastal erosion and damage from hurricanes and other storms.

Sea-based OTEC plants are essentially the same but have to be constructed on some sort of tethered, floating platform, not unlike a floating oil platform, with the four pipes running down into the sea; early prototypes were run from converted oil tankers and barges. They also need a cable running back to land to send the electrical power they generate ashore. Hybrid forms of OTEC are also possible.

Advantages:

- Power from OTEC is continuous, renewable and pollution free.
- Unlike other forms of solar energy, output of OTEC shows very little daily or seasonal variation.
- Drawing of warm and cold sea water and returning of the sea water, close to the thermocline, could be accomplished with minimum environment impact.
- Electric power generated by OTEC could be used to produce hydrogen.

Disadvantages:

- Capital investment is very high.
- Due to small temperature difference in between the surface water and deep water, conversion efficiency is very low about 3-4%.
- Low efficiency of these plants coupled with high capital cost and maintenance cost makes them uneconomical for small plants.

Hydrogen Production and Storage - Fuel cell

Although abundant on earth as an element, hydrogen is almost always found as part of another compound, such as water (H_2O), and must be separated from the compounds that contain it before it can be used in vehicles. Once separated, hydrogen can be used along with oxygen from the air in a fuel cell to create electricity through an electrochemical process.

Production

Hydrogen can be produced from diverse, domestic resources including fossil fuels, biomass and water electrolysis with electricity. The environmental impact and energy efficiency of hydrogen depends on how it is produced. Several projects are under way to decrease costs associated with hydrogen production. The current most notable production pathways are the following:

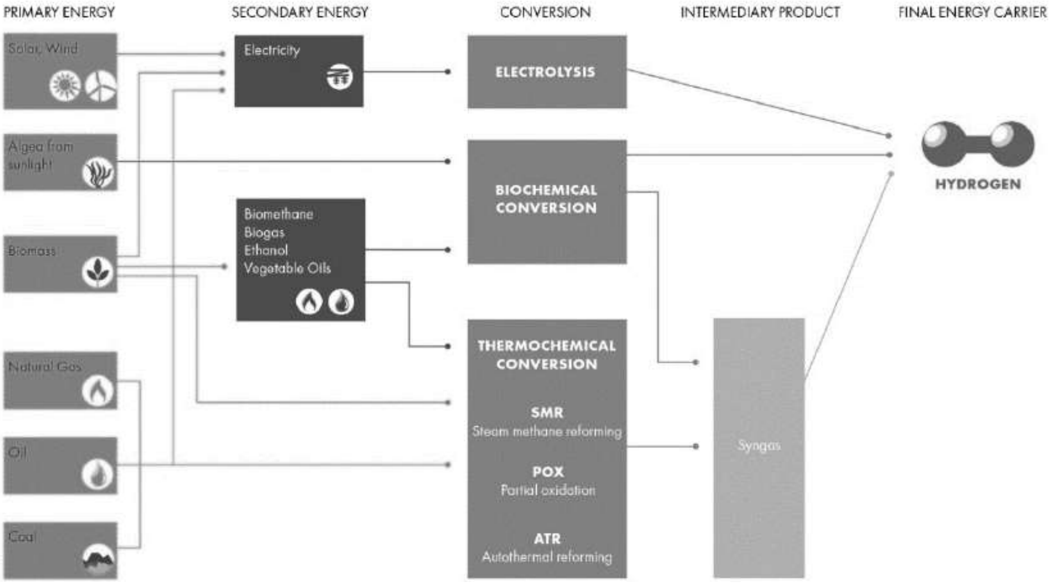


Fig. 11. Methods of producing hydrogen

Electrolysis

Method: Electrolysis

In short: Process where water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) gas with energy input and heat in the case of high temperature Electrolysis.

In Practice: An electric current splits water into its constituent parts. If renewable energy is used, the gas has a zero-carbon footprint, and is known as green hydrogen.

An electric current splits water into hydrogen and oxygen. If the electricity is produced by renewable sources, such as solar or wind, the resulting hydrogen will be considered renewable as well and has numerous emissions benefits. This reaction takes place in a unit called an electrolyzer. Electrolyzers can range in size from small, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.

A DC electrical power source is connected to two electrodes, or two plates (typically made from some inert metal such as platinum or iridium) which are placed in the water. Hydrogen will appear at the cathode (where electrons enter the water), and oxygen will appear at the anode.

At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas. Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$

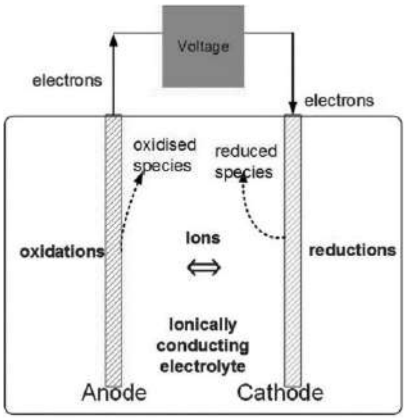


Fig. 12. Electrolysis

Steam Methane Reforming

Method: Reforming - most notably Reforming of natural gas but also biogas

In short: The primary ways in which natural gas, mostly methane, is converted to hydrogen involve reaction with either steam (steam reforming or steam methane reforming SMR when methane is used), oxygen (partial oxidation), or both in sequence (autothermal reforming)

In practice: Steam reforming: Pure water vapour is used as the oxidant. The reaction requires the introduction of heat ("endothermic").
Partial oxidation: Oxygen or air is used in this method. The process releases heat ("exothermic").

Most of the hydrogen produced today, is being produced through the CO_2 intensive process called Steam Methane Reforming.

High-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic, that is, heat must be supplied to the process for the reaction to proceed.

Subsequently, in "water-gas shift reaction," the carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen. Steam reforming can also be used to produce hydrogen from other fuels, such as ethanol, propane, or even gasoline.

Steam-methane reforming reaction: $CH_4 + H_2O$ (+ heat) → $CO + 3H_2$
Water-gas shift reaction: $CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

Partial Oxidation

In partial oxidation, the methane and other hydrocarbons in natural gas react with a limited amount of oxygen (typically from air) that is not enough to completely oxidize the hydrocarbons to carbon dioxide and water. With less than the stoichiometric amount of oxygen available, the reaction products contain primarily hydrogen and carbon monoxide (and nitrogen, if the reaction is carried out with air rather than pure oxygen), and a relatively small amount of carbon dioxide and other compounds. Subsequently, in a water-gas shift reaction, the carbon monoxide reacts with water to form carbon dioxide and more hydrogen.

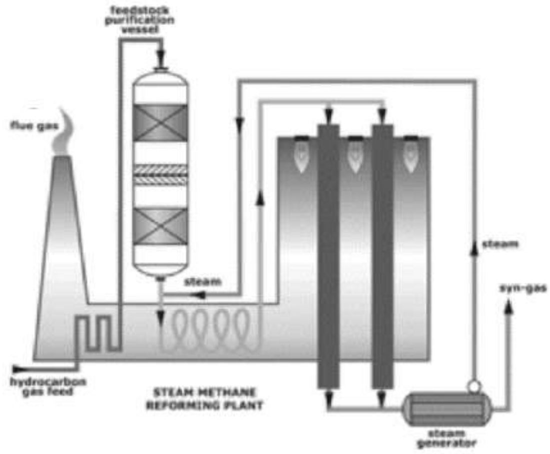


Fig. 13. Steam-methane reforming

Autothermal reforming: This process is a combination of steam reforming and partial oxidation and operates with a mixture of air and water vapour. The ratio of the two oxidants is adjusted so that no heat needs to be introduced or discharged ("isothermal").

Hydrogen as a By-Product or Industrial Residual Hydrogen
Method: Hydrogen from other industrial processes that create hydrogen as a by-product
In Short: Electrochemical processes, such as the industrial production of caustic soda and chlorine produce hydrogen as a waste product.
In Practice: Producing chlorine and caustic soda comes down to passing an electric current through brine (a solution of salt – sodium chloride – in water). The brine dissociates and recombines through exchange of electrons (delivered by the current) into gaseous chlorine, dissolved caustic soda1 and hydrogen. By the nature of the chemical reaction, chlorine, caustic soda and hydrogen are always manufactured in a fixed ratio: 1.1 tonne of caustic and 0.03 tonne of hydrogen per tonne of chlorine.

If the production of hydrogen can be the first objective of the separation process, it can also be that the separation process aims first at producing another molecule and produces hydrogen as a by-product.

Producing chlorine and caustic soda comes down to passing an electric current through brine (a solution of salt – sodium chloride – in water). The brine dissociates and recombines through exchange of electrons (delivered by the current) into gaseous chlorine, dissolved caustic soda and hydrogen. By the nature of the chemical reaction, chlorine, caustic soda and hydrogen are always manufactured in a fixed ratio: 1.1 ton of caustic and 0.03 ton of hydrogen per ton of chlorine. Hydrogen produced by this process can be made available for other applications, such as fuel cell electric vehicles.

Although the technology required to harness tidal energy is well established, tidal power is expensive, and there is only one major tidal generating station in operation. This is a 240 megawatt station at the mouth of the La Rance river estuary in France.

Fermentation

Biomass is converted into sugar-rich feedstocks that can be fermented to produce hydrogen. In fermentation-based systems, microorganisms, such as bacteria, break down organic matter to produce hydrogen. The organic matter can be refined sugars, raw biomass sources such as corn stover and even wastewater. Because no light is required, these methods are sometimes called "dark fermentation" methods.

In direct hydrogen fermentation, the microbes produce the hydrogen themselves. These microbes can break down complex molecules through many different pathways, and the byproducts of some of the pathways can be combined by enzymes to produce hydrogen. Researchers are studying how to make fermentation systems produce hydrogen faster (improving the rate) and produce more hydrogen from the same amount of organic matter (increasing the yield).

Microbial electrolysis cells (MECs) are devices that harness the energy and protons produced by microbes breaking down organic matter, combined with an additional small electric current, to produce hydrogen. This technology is very new, and researchers are working on improving many aspects of the system, from finding lower-cost materials to identifying the most effective type of microbes to use.

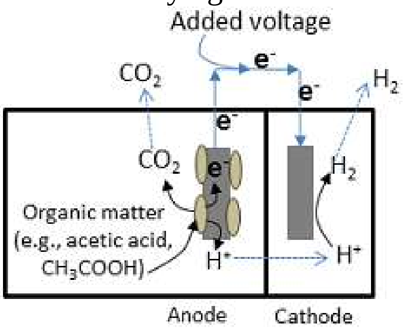


Fig. 14. Fermentation

Hydrogen storage

A major advantage of hydrogen is that it can be produced from (surplus) renewable energies, and unlike electricity it can also be stored in large amounts for extended periods of time. For that reason, hydrogen produced on an industrial scale could play an important part in the energy transition.

The most important hydrogen storage methods, which have been tried and tested over lengthy periods of time, include physical storage methods based on either compression or cooling or a combination of the two (hybrid storage). In addition, a large number of other new hydrogen storage technologies are being pursued or investigated. These technologies can be grouped together under the name materials-based storage technologies. These can include solids, liquids or surfaces.

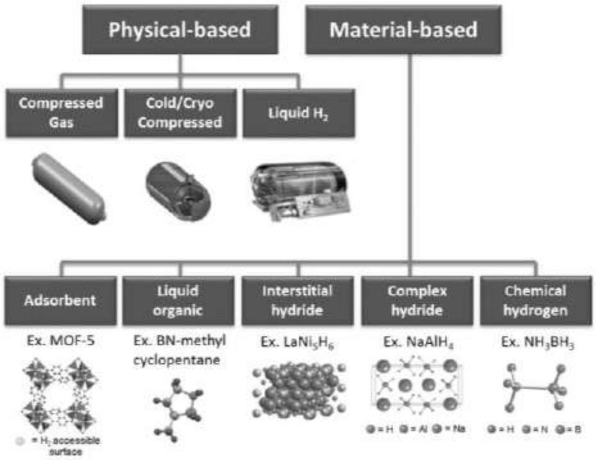


Fig. 15. Methods of hydrogen storage

Liquefied Hydrogen

Apart from the traditional methods of storing gaseous hydrogen under pressure, it is also possible to store cryo-genic hydrogen in the liquid state. Liquid hydrogen (LH_2) is in demand today in applications requiring high levels of purity, such as in the chip industry for example. As an energy carrier, LH_2 has a higher energy density than gaseous hydrogen, but it requires liquefaction at –253°C, which involves a complex technical plant and an extra economic cost. When storing liquid hydrogen, the tanks and storage facilities have to be insulated in order to keep in check the evaporation that occurs if heat is carried over into the stored content, due to conduction, radiation or convection. Tanks for LH_2 are used today primarily in space travel.

Cold- and cryo-compressed Hydrogen

In addition to separate compression or cooling, the two storage methods can be combined. The cooled hydrogen is then compressed, which results in a further development of hydrogen storage for mobility purposes. The first field installations are already in operation. The advantage of cold or cryogenic compression is a higher energy density in comparison to compressed hydrogen. However, cooling requires an additional energy input.

Currently it takes in the region of 9 to 12 % of the final energy made available in the form of H_2 to compress hydrogen from 1 to 350 or 700 bar. By contrast, the energy input for liquefaction (cooling) is much higher, currently around 30%. The energy input is subject to large spreads, depending on the method, quantity and external conditions. Work is currently in progress to find more economic methods with a significantly lower energy input.

Materials-Based H_2 Storage

An alternative to physical storage methods is provided by hydrogen storage in solids and liquids and on surfaces. Most of these storage methods are still in development. Moreover, the storage densities that have been achieved are still not adequate, the cost and time involved in charging and discharging hydrogen are too high, and/or the process costs are too expensive. Material-based hydrogen storage media can be divided into three classes: first, hydride storage systems; second, liquid hydrogen carriers; and third, surface storage systems, which take up hydrogen by adsorption, i.e. attachment to the surface.

Hydride storage systems

In metal hydride storage systems the hydrogen forms interstitial compounds with metals. Here molecular hydrogen is first adsorbed on the metal surface and then incorporated in elemental form (H) into the metallic lattice with heat output and released again with heat input. Metal hydrides are based on elemental metals such as palladium, magnesium and lanthanum, intermetallic compounds, light metals such as aluminium, or certain alloys. Palla-dium, for example, can absorb a hydrogen gas volume up to 900 times its own volume.

Liquid organic hydrogen carriers

Liquid organic hydrogen carriers represent another option for binding hydrogen chemically. They are chemical compounds with high hydrogen absorption capacities. They currently include, in particular, the carbazole derivative N-ethylcarbazole, but also toluene.

Surface storage systems (sorbents)

Finally, hydrogen can be stored as a sorbate by attachment (adsorption) on materials with high specific surface areas. Such sorption materials include, among others, microporous organometallic framework compounds (metal-organic frameworks) microporous crystalline aluminosilicates (zeolites) or microscopically small carbon nanotubes. Adsorption materials in powder form can achieve high volumetric storage densities.

Underground Storage

When it comes to the industrial storage of hydrogen, salt caverns, exhausted oil and gas fields or aquifers can be used as underground stores. Although being more expensive, cavern storage facilities are most suitable for hydrogen storage. Underground stores have been used for many years for natural gas and crude oil/oil products, which are stored in bulk to balance seasonal supply/demand fluctuations or for crisis preparedness.

Gas Grid

Another possibility for storing surplus renewable energy in the form of hydrogen is to feed it into the public natural gas network (Hydrogen Enriched Natural Gas or HENG). Infrastructure elements that were installed at the time, such as pipelines, gas installations, seals, gas appliances etc., were designed for the hydrogen-rich gas and were later modified with the switch to natural gas.

The National Hydrogen Energy Road Map (NHERM) is a program in India initiated by the National Hydrogen Energy Board (NHEB) in 2003 and approved in 2006 for bridging the technological gaps in different areas of hydrogen energy

Fuel cell

A fuel cell can be defined as an electrochemical cell that generates electrical energy from fuel via an electrochemical reaction. These cells require a continuous input of fuel and an oxidizing agent (generally oxygen) in order to sustain the reactions that generate the electricity. Therefore, these cells can constantly generate electricity until the supply of fuel and oxygen is cut off.

Despite being invented in the year 1838, fuel cells began commercial use only a century later when they were used by NASA to power space capsules and satellites. Today, these devices are used as the primary or secondary source of power for many facilities including industries, commercial buildings, and residential buildings.

Construction

A fuel cell is similar to electrochemical cells, which consists of a cathode, an anode, and an electrolyte. In these cells, the electrolyte enables the movement of the protons.

The basic construction of a hydrogen fuel cell consists of two electrodes, an electrolyte, a fuel (hydrogen) and a power supply. An electrolyte that separates the two electrodes is an ion conducting material which facilitates the free passage of ions. In a fuel cell, an oxidizing agent (or oxygen) is made to flow through a fuel (hydrogen). Hydrogen and oxygen combine to form water and generate heat. At the anode, hydrogen is stripped of its electron and its proton is made to pass through the electrolyte. The electron is made to pass through an external DC (direct current) circuit to power devices.

Principle of working

The reaction between hydrogen and oxygen can be used to generate electricity via a fuel cell. Such a cell was used in the Apollo space programme and it served two different purposes – It was used as a fuel source as well as a source of drinking water (the water vapour produced from the cell, when condensed, was fit for human consumption).

The working of this fuel cell involved the passing of hydrogen and oxygen into a concentrated solution of sodium hydroxide via carbon electrodes. The cell reaction can be written as follows:

Cathode Reaction : $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
Anode Reaction : $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$
Net Cell Reaction : $2H_2 + O_2 \rightarrow 2H_2O$

However, the reaction rate of this electrochemical reaction is quite low. This issue is overcome with the help of a catalyst such as platinum or palladium. In order to increase the effective surface area, the catalyst is finely divided before being incorporated into the electrodes.

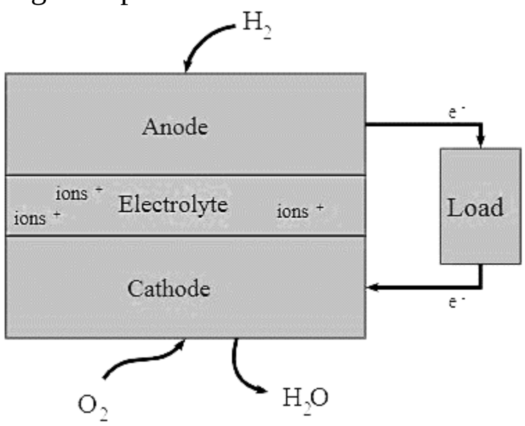


Fig. 16. Operation of fuel cell

The efficiency of the fuel cell described above in the generation of electricity generally approximates to 70% whereas thermal power plants have an efficiency of 40%. This substantial difference in efficiency is because the generation of electric current in a thermal power plant involves the conversion of water into steam and the usage of this steam to rotate a turbine. Fuel cells, however, offer a platform for the direct conversion of chemical energy into electrical energy.

Types of fuel cells

Despite working in a similar manner, there exist many varieties of fuel cells. Some of these types of fuel cells are discussed here.

The Polymer Electrolyte Membrane (PEM) Fuel Cell

- These cells are also known as proton exchange membrane fuel cells (or PEMFCs).
- The temperature range that these cells operate in is between 50^o C to 100^o C
- The electrolyte used in PEMFCs is a polymer which has the ability to conduct protons.
- A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.
- Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.

Phosphoric Acid Fuel Cell

- These fuel cells involve the use of phosphoric acid as an electrolyte in order to channel the H+
- The working temperatures of these cells lie in the range of 150^o C – 200^o C
- Electrons are forced to travel to the cathode via an external circuit because of the non-conductive nature of phosphoric acid.
- Due to the acidic nature of the electrolyte, the components of these cells tend to corrode or oxidize over time.

Solid Acid Fuel Cell

- A solid acid material is used as the electrolyte in these fuel cells.
- The molecular structures of these solid acids are ordered at low temperatures.
- At higher temperatures, a phase transition can occur which leads to a huge increase in conductivity.
- Examples of solid acids include $CsHSO_4$ and $CsH2PO_4$ (cesium hydrogen sulphate and cesium dihydrogen phosphate respectively)

Alkaline Fuel Cell

- This was the fuel cell which was used as the primary source of electricity in the Apollo space program.
- In these cells, an aqueous alkaline solution is used to saturate a porous matrix, which is in turn used to separate the electrodes.
- The operating temperatures of these cells are quite low (approximately 90° C).
- These cells are highly efficient. They also produce heat and water along with electricity.

Solid Oxide Fuel Cell

- These cells involve the use of a solid oxide or a ceramic electrolyte (such as yttria-stabilized zirconia).
- These fuel cells are highly efficient and have a relatively low cost (theoretical efficiency can even approach 85%).
- The operating temperatures of these cells are very high (lower limit of 600° C, standard operating temperatures lie between 800 and 1000° C).
- Solid oxide fuel cells are limited to stationary applications due to their high operating temperatures.

Molten Carbonate Fuel Cell

- The electrolyte used in these cells is lithium potassium carbonate salt. This salt becomes liquid at high temperatures, enabling the movement of carbonate ions.
- Similar to SOFCs, these fuel cells also have a relatively high operating temperature of 650° .
- The anode and the cathode of this cell are vulnerable to corrosion due to the high operating temperature and the presence of the carbonate electrolyte.
- These cells can be powered by carbon-based fuels such as natural gas and biogas.

More than 10 million metric tons of hydrogen are produced annually in the United States. Most of the hydrogen produced in the United States comes from a process called steam methane reforming.

Applications of fuel cell

Fuel cell technology has a wide range of applications. Currently, heavy research is being conducted in order to manufacture a cost-efficient automobile which is powered by a fuel cell. A few applications of this technology are listed below.

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Appolo space program.
- Generally, the byproducts produced from these cells are heat and water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

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. Therefore, an energy storage system can be an important component to improve the reliability of the power network. There are various types of energy storages, such as electric double layer capacitor (EDLC), BESS, superconducting magnetic energy storage (SMES), flywheel (FW), plug in electric vehicle (PEV), etc.

Rechargeable batteries were invented in 1836 by an English chemist. This battery was designed with lead-acid technology and is still the type used for car batteries.

Electric double layer capacitor

Electric double-layer capacitors are based on the operating principle of the electric double-layer that is formed at the interface between activated charcoal and an electrolyte.

The activated charcoal is used as an electrode and activated charcoal is used in its solid form, and the electrolytic fluid is liquid. When these materials come in contact with each other, the positive and negative poles are distributed relative to each other over an extremely short distance. Such a phenomenon is known as an electric double-layer. When an external electric field is applied, the electric double-layer that is formed in the vicinity of the activated charcoal's surface within the electrolytic fluid is used as the fundamental capacitor structure.

EDLC is also known as super capacitor or ultra capacitor. The EDLC enables large power effects per weight having a goal up to 10 kW/kg but a storage capacity around 10 Wh/kg only. The storage time is short or typically up to 30–60s.

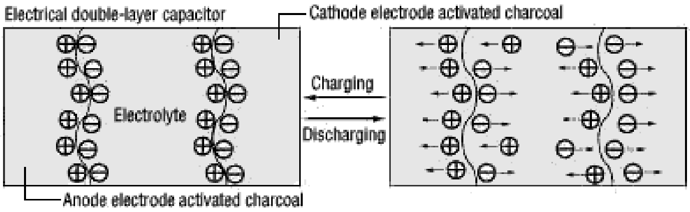


Fig. 17. Electric double-layer capacitors

Battery energy storage system

Batteries are the most common power source for basic handheld devices to large scale industrial applications. A battery can be defined as; it is a combination of one or more electrochemical cells that are capable of converting stored chemical energy into electrical energy. Types of batteries are primary and secondary batteries. Secondary batteries are rechargeable and are used in renewable energy systems. The types of rechargeable batteries are SMF, Lead Acid, Li and Nicd.

SMF Battery

SMF is a Sealed Maintenance Free battery, designed to offer reliable, consistent and low maintenance power for UPS applications. These batteries can be subject to deep cycle applications and minimum maintenance in rural and power deficit areas. These batteries are available from 12V.

Fig. 18. SMF Battery

Lithium (Li) Battery:

The lithium battery has been one of the greatest achievements in portable power in the last decade; with use of lithium batteries we have been able to shift from black and white mobile to color mobiles with additional features like GPS, email alerts etc. These are the high energy density potential devices for higher capacities. And relatively low self-discharge batteries. Also Special cells can provide very high current to applications such as power tools.

Fig. 19. Lithium (Li) Battery

Nickel Cadmium (Nicd) Battery

The Nickel Cadmium batteries have the advantage of being recharged many times and possess a relatively constant potential during discharge and have more electrical and physical withstanding capacity. This battery uses nickel oxide for cathode, a cadmium compound for anode and potassium hydroxide solution as its electrolyte.

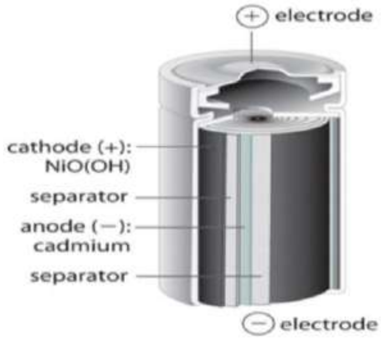


Fig. 20. Nickel Cadmium (Nicd) Battery

Lead Acid Battery

Lead Acid batteries are widely used in automobiles, inverters, backup power systems etc. Unlike tubular and maintenance free batteries, Lead Acid batteries require proper care and maintenance to prolong its life. The Lead Acid battery consists of a series of plates kept immersed in sulphuric acid solution. The plates have grids on which the active material is attached. The plates are divided into positive and negative plates. The positive plates hold pure lead as the active material while lead oxide is attached on the negative plates.

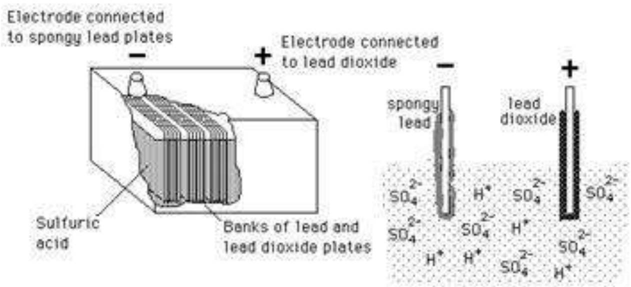


Fig. 21. Lead Acid Battery

Lithium – Ion Battery

Lithium –Ion batteries are now popular in majority of electronic portable devices like Mobile phone, Laptop, Digital Camera, etc due to their long lasting power efficiency. These are the most popular rechargeable batteries with advantages like best energy density, negligible charge loss and no memory effect. Li-Ion battery uses Lithium ions as the charge carriers which move from the negative electrode to the positive electrode during discharge and back when charging.

Fig. 22. Lithium – Ion Battery

Lithium Ion Polymer (Li-ion polymer)

The Lithium Ion Polymer battery offers similar elements to the Li-ion battery in an ultra-slim and simplified packaging form. It is of lithium-ion technology in a pouch format. This makes them lighter, but less rigid. The Li-polymer is different from other batteries in the type of electrolyte used, a dry solid polymer electrolyte. Rather than conducting electricity, this electrolyte allows an exchange of ions (electrically charged atoms or groups of atoms).

Fig.23. Lithium Ion Polymer

Lithium ion batteries and are not toxic and are smaller and charge faster than NiCd batteries. They are commonly used in tablets, gaming systems, and cell phones.

Superconducting magnetic energy storage

The SMES system is a relatively recent technology. Its operation is based on storing energy in a magnetic field, which is created by a DC current through a large superconducting coil at a cryogenic temperature. The energy stored is calculated as the product of the self-inductance of the coil and the square of the current flowing through it. The response time is very short. The SMES technology has been demonstrated but the price is still very high.

Flywheel

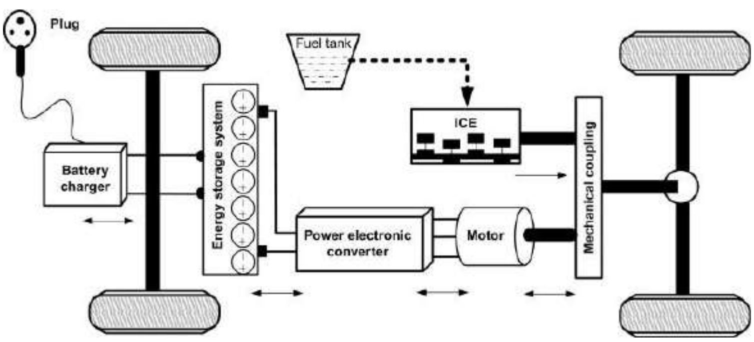
In an FW the storage capacity is based on the kinetic energy of a rotating disc which depends on the square of the rotational speed. A mass rotates on two magnetic bearings in order to decrease friction at high speed, coupled with an electric machine. Energy is transferred to the FW when the machine operates as a motor (the FW accelerates), charging the energy storage device. The FW energy storage system (FESS) is discharged when the electric machine regenerates through the drive (slowing the FW). FESSs have long lifetimes, high energy density, and a large maximum output power. The energy efficiency of an FESS can be as high as 90%. Typical capacities range from 3–133 kWh.

Plug in electric vehicle

Recent PEVs have been increased extensively and usually include a BESS. PEVs may play an important part in balancing the energy on the grid by serving as distributed sources of stored energy, a concept called “vehicle-to-grid”. By drawing on a large number of batteries plugged into the Smart grid (SG) throughout its service region, a utility can potentially inject extra power into the grid during critical peak times, avoiding brownouts and rolling blackouts. Therefore, they can play a vital role to improve the power system reliability and the power quality of the SG.

PEVs can drastically lessen the dependence on oil, and they emit nothing about air pollutants when running in all-electric modes. However, they do rely on power plants to charge their batteries, and conventional fossil-fueled power plants release pollution. To run a PEV as cleanly as possible, it needs to be charged in the hours of the morning when power demand is at its lowest and when wind power is typically at its peak. The SG technologies will help to meet this goal by interacting with the PEV to charge it at the most optimal time.

PHEV is hybrid electric vehicle that contains at least (i) a battery storage system of 4 kWh or more, used to power the motion of the vehicle; (ii) a means of recharging that battery system from an external source of electricity; and (iii) an ability to drive at least 10 mi in all-electric mode, and consume no gasoline”. Conceptually, a PHEV is a HEV with large battery pack that can be recharged from the external source (utility grid or renewable source of energy) to extend the all-electric range (AER) of the vehicles



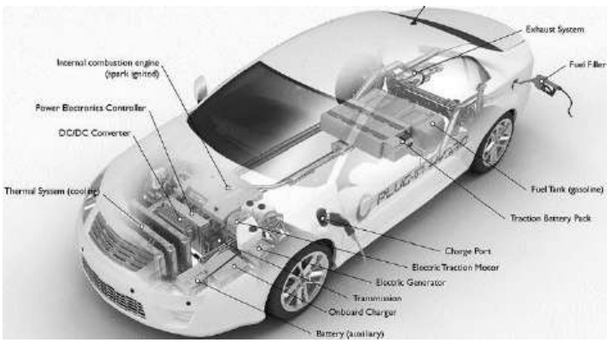


Fig. 24. Plug in electric vehicle

Hybrid Energy Systems

A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply A hybrid system can combine wind, solar with an additional resource of generation or storage. They may range in size from relatively large island grids of many megawatts to individual household power supplies on the order of one kilowatt.

Hybrid power systems that deliver alternating current of fixed frequency are an emerging technology for supplying electric power in remote locations. They can take advantage of the ease of transforming the AC power to higher voltages to minimize power loss in transferring the power over relatively long distances.

Larger systems, nominally above 100 kW, typically consist of AC-connected diesel generators, renewable sources, loads, and occasionally include energy storage subsystems. Below 100 kW, combinations of both AC and DC-connected components are common as is use of energy storage. The DC components could include diesel generators, renewable sources, and storage. Small hybrid systems serving only DC loads, typically less than 5 kW, have been used commercially for many years at remote sites for telecommunications repeater stations and other low power applications.

In general, a hybrid system might contain AC diesel generators, DC diesel generators, an AC distribution system, a DC distribution system, loads, renewable power sources (wind turbines, or photovoltaic power sources), energy storage, power converters, rotary converters, coupled diesel systems, dump loads, load management options, or a supervisory control system. Hybrid systems might also include biomass or hydroelectric generators. A schematic of the possibilities for hybrid systems is illustrated in the following figure.

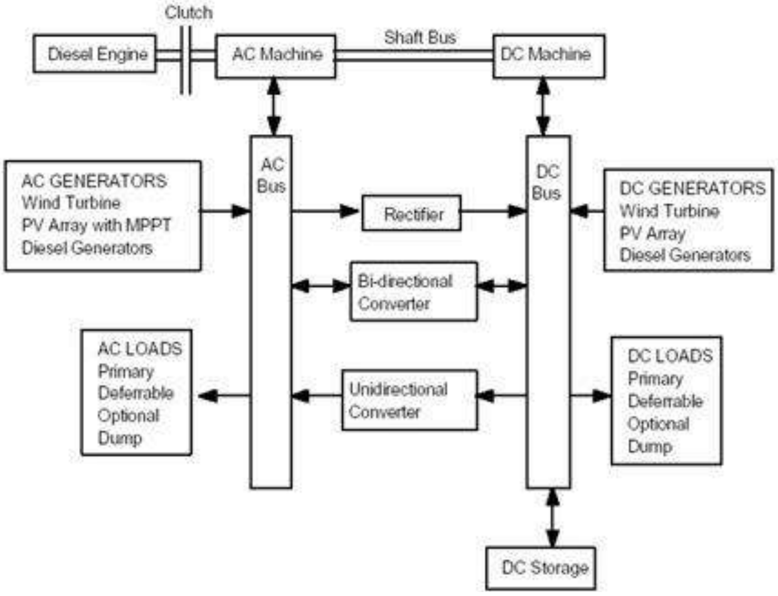


Fig. 25. Hybrid energy storage system

Examples of hybrid systems

Wind-solar hybrid system

As the wind does not blow all the time nor does the sun shine all the time, solar and wind power alone are poor power sources. Hybridizing solar and wind power (min wind speed 4-6m/s) sources together with storage batteries to cover the periods of time without sun or wind provides a realistic form of power generation. The system creates a stand-alone energy source that is both dependable and consistent which is called the solar-wind hybrid system. Generally, these solar wind hybrid systems are capable of small capabilities. The typical power generation capacities of solar wind hybrid systems are in the range from 1 kW to 10 kW.

Major components of solar-wind hybrid power plant are Solar PV modules, Wind turbine Regulation and conversion units, Inverters and electronic controllers, Battery Bank Generator (if required).

Working

- The hybrid solar wind turbine generator uses solar panels that collect light and convert it to energy along with wind turbines that collect energy from the wind.
- Solar wind composite power inverter has inputs for both sources, instead of having to use two inverters and it contains the required AC to DC transformer to supply charge to batteries from AC generators.
- Hence the power from the solar panels and wind turbine is filtered and stored in the battery bank.
- For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional fuels, such as diesel.
- If the batteries run low, the engine generator can provide power and recharge the batteries.
- Adding an engine generator makes the system more complex, but modern electronic controllers can operate these systems automatically.
- An engine generator can also reduce the size of the other components needed for the system.
- Keep in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods

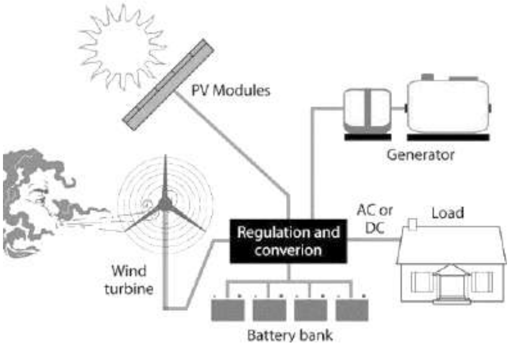


Fig. 26. Wind-solar hybrid system

Wind–hydro hybrid system

Hydropower generation is to convert potential energy in water into electrical energy by means of hydropower generators. As a renewable and clean energy source, hydropower accounts for the dominant portion of electricity generated from all renewable sources. In many locations of the world, hydropower is complementary with wind power, while the seasonal wind power distribution is higher in winter and spring but lower in summer and fall, hydropower is lower in the dry seasons (winter and spring) but higher in the wet seasons (summer and fall). Thus, the integration of wind and hydropower systems can provide significant technical, economic, and systematic benefits for both systems. Taking a reservoir as a means of energy regulation, "green" electricity can be produced with wind–hydro hybrid systems.

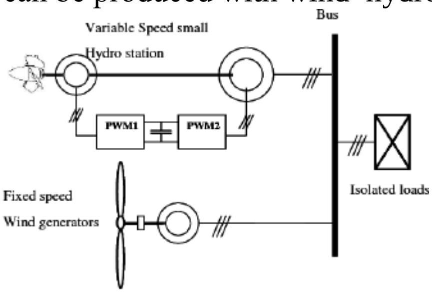


Fig. 27. Wind–hydro hybrid system

Wind–hydrogen system

Hydrogen is an energy carrier and can be produced from a variety of resources such as water, fossil fuels, and biomass. As a fuel with a high energy density, hydrogen can be stored, transported and then converted into electricity by means of fuel cells at end users. It is widely recognized that wind power, solar power and other renewable energy power generation systems can be integrated with the electrolysis hydrogen production system to produce hydrogen fuel. The largest wind to- hydrogen power system in the UK has been applied to a building that is fuelled solely by wind and "green" hydrogen power with the developed hydrogen mini grid system technology. In this system, electricity generated from a wind turbine is mainly used to provide to the building and excess electricity is used to produce hydrogen using a state-of-the-art high-pressure alkaline electrolyser.

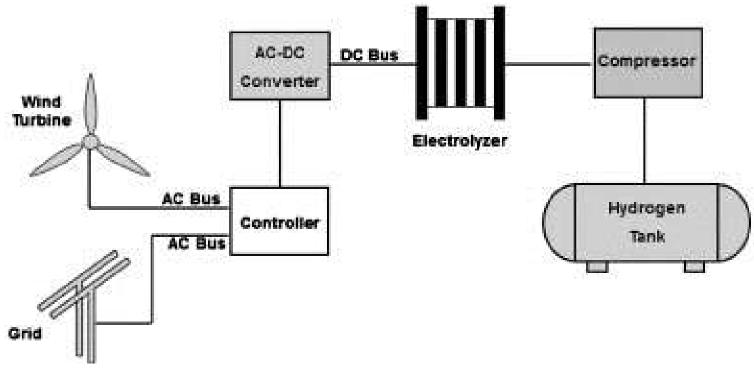


Fig. 28. Wind–hydrogen system

Wind–diesel power generation system

Wind power can be combined with power produced by diesel engine-generator systems to provide a stable supply of electricity. In response to the variations in wind power generation and electricity consumption, diesel generator sets may operate intermittently to reduce the consumption of the fuel. It was reported that a viable wind–diesel stand-alone system can operate with an estimated 50–80% fuel saving compared to power supply from diesel generation alone. Till now, many new techniques have been developed and a large number of wind– diesel power generation systems have been installed all over the world. According to the proportion of wind use in the system, three different types of wind–diesel systems can be distinguished: low, medium, and high penetration wind–diesel systems. Presently, low penetration systems are used at the commercial level, whereas solutions for high penetration wind–diesel systems are at the demonstration level. The technology trends include the development of robust and proven control strategies

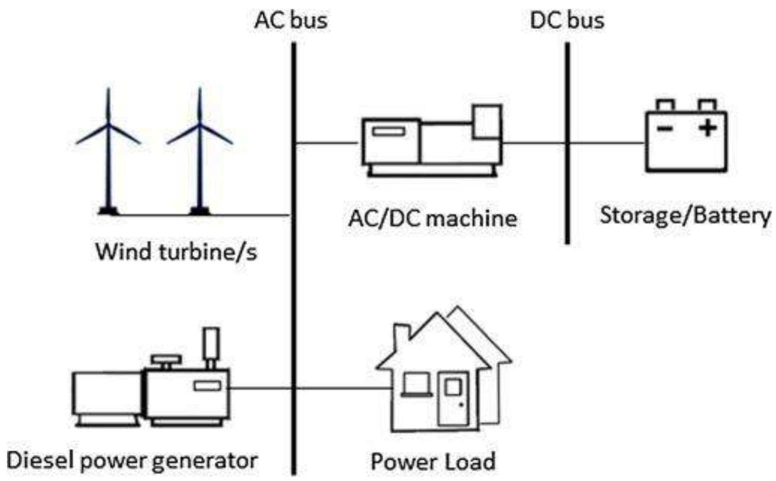


Fig. 29. Wind–diesel power generation system