LECTURE NOTES
ON
RENEWABLE ENERGY

6TH SEMESTER ,
BRANCH-ELECTRICAL ENGINEERING

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1. INTRODUCTION TO RENEWABLE ENERGY

Renewable energy sources occur in nature which are regenerative or inexhaustible like solar energy, wind energy, hydropower, geothermal, biomass, tidal and wave energy. Most of these alternative sources are the manifestation of solar energy . India is implementing one of the world's largest programmes in renewable energy. The country ranks second in the world in biogas utilization and fifth in wind power and photovoltaic production.

Small hydropower is under renewable source. Large hydropower is also renewable in nature, but has been utilized all over the world for many decades and hence not included in the term 'alternate or renewable'. Municipal and industrial waste is also a useful source of energy, but are different forms of biomass.

The Ministry of New and Renewable Energy (MNRE) have made efforts during the past few decades to develop and utilize various renewable energy resources in the country. Consequently, wind electric generators, solar water heaters, solar lanterns, street lights, biogas plants, biomass gasifiers and small hydro-electric generators have become commercially available. Wind farms, solar arrays, hydro and biomass power generation are all environmentally benign unlike fossil fuel and nuclear plants. It is planned to cover electrification of all those remote villages which are not approachable by grid power supply.

ENVIRONMENTAL CONSEQUENCES OF FOSSIL FUEL USE

Energy conversion and environment are interrelated. With the increase in electric power generation, environmental degradation has become a serious problem. To meet the bulk electric energy demand in industrial and agricultural sectors, India has to move forward and build many large thermal, hydro and nuclear power projects. All of these projects have environmental ramifications. We all live in an environment, which constitutes air, water, land and other biological organisms present in the biosphere. Air, water and the surrounding environment are all polluted by emissions from energy conversion plants and industries. Clean air in the atmosphere, natural pure water and good growth of trees are the basic requirements for human survival. Nature has created self-cleaning processes like photosynthesis, water cycle, carbon and nitrogen cycles, winds and four important seasons in a year. However, the large-scale fossil fuel combustion causes atmospheric pollution, effluent discharge in water, particulate matter and fly ash—that all adversely affect the environment and it then becomes beyond the nature's capacity to clean and create ecological balance. It causes irreversible damages to water bodies, i.e., lakes and rivers; produces acid rain that damages agriculture and forests and creates ozone layer holes and global warming. Emphasis is now being laid on alleviation of the situation for sustainable development, with appropriate technology.

1. ATMOSPHERIC POLLUTION

Due considerations have been given to treat the pollution caused by thermal plants that burn coal. India's energy security is largely based on fossil fuel generating plants, supported by hydro and nuclear plants which are also responsible for environmental hazards. The major pollutants which are released from coal-based generating plants are: SO2, nitrogen oxides (NOx), CO and CO2, hydrocarbons, fly ash and suspended particulates. Indian coal carries 0.6% to 1% sulphur and its ash content varies from 30% to 50%. Various pollutants are dealt below with their possible impact and related issues.

2. Oxides of Sulphur (SO_2)

Coal containing sulphur, on burning in the combustion chamber, produces SO_2 which is released through chimney. It causes respiratory ailments in concentrations of 20 mg/m3 and constitutes danger to life in amounts of 400 mg/m3 . In atmosphere, SO_2 is further oxidized to H_2SO_4 and falls down on the earth as acid rain. It is injurious to plants and causes damage to buildings and marble structures (e.g. the marble monument like Taj Mahal). Sulphur emissions can be removed from the coal by gasification or floatation processes. Use of chemical reaction is recommended to remove sulphur oxides from flue gas. Installing limestone scrubbers in the power plants also reduces the sulphur emission.

3. Oxides of Nitrogen (NO_x)

Oxides of nitrogen that pollute the air include NO, NO_2 and N_2O. Of these, nitrogen oxide (NO_2) is a major pollutant. It is highly injurious; if inhaled in concentration of 150–200 ppm NO_2 can damage
respiratory tissues and may cause even pneumonia. Emission of NO_x can be reduced by: ∑ Installing advanced technology burners in the boiler to ensure complete combustion and reduction of these oxides. ∑ Providing tall stacks for wider dispersion of air pollutants that can lower pollution level in the ambient air (100 mg/m3).

4. Oxides of Carbon (CO, CO_2)

CO is a toxic gas and affects human metabolism. If released to the atmosphere, it gets converted to CO_2. The concentration of CO_2 reduces in the air through the natural process of photosynthesis to generate oxygen and organic matter. High concentration of CO_2 is also a major cause of global warming. To control CO_2 emissions, the combustion efficiency of boilers should be improved which also results in reducing coal consumption.

5. HYDROCARBONS

In the boiler combustion chamber, during the process of oxidation, a few specific hydrocarbons are formed. These compounds contribute to photochemical reaction, which causes damage to atmospheric ozone layer.

6. PARTICULATES (FLY ASH)

Particulates comprise fine particles of carbon, ash and other inert material with size greater than 1 mm. It gets emitted from chimney in the form of fly ash. Particulates suspended in air with pollution level 300 mg/m3 cause poor visibility, lungs inflammation and bronchitis.

IMPORTANCE OF RENEWABLE SOURCES OF ENERGY

India, being a developing county, has witnessed a rapidly growing energy need owing to the fast industrialization and increasing demographic profile. Modern society cannot normally exist without electric energy. Starting from the base of merely 1700 MW in 1950 the installed generating capacity has now risen to 80,000 MW approximately. Around 85% of villages are enjoying the benefit of electricity. Despite the progress achieved, the consumption is increasing at an annual growth rate of 4 to 5% and at the other side the conventional energy sources are exhausting.The Renewable energy source is only solution for future energy crises, which is cheap and clean as compare to non-renewable energy sources. The economy of the nation can be improved by utilizing such easily managed energy sources. The main sources are solar thermal, solar PV, wind, geothermal, ocean thermal, ocean , wave, ocean tide, mini hydro, biomass, chemical, waste fuel etc. India has planned the following by new and Renewable Sources of Energy (NRSE) Schemes under ministry of Non-conventional Energy by ninth plan (1998- 2003) given as:

Small hydro	320 MW
™ Biomass	250 MW
™ Agriculture waste	250 MW
™ Solar & PV Thermal	100 MW
™ Wind farms	2000 MW

SUSTAINABLE DESIGN AND DEVELOPMENT.

The most significant component of sustainable building design is having a renewable energy source. Simply being able to create electricity from a renewable source is not only more energy efficient, but can save money over time. Plus, renewable energy sources are environmentally friendly and do not leave a big carbon footprint, if any at all. Below we will examine some of the more popular renewable energy sources.

The basic aim of energy security for a nation is to reduce its dependency on the imported energy sources for its economic growth. India will continue to experience an energy supply shortfall throughout the forecast period. This gap has widened since 1985, when the country became a net importer of coal. India has been unable to raise its oil production substantially in the 1990s. Rising oil demand of close to 10 percent per year has led to sizable oil import bills. In addition, the government subsidizes refined oil product prices, thus compounding the overall monetary loss to the government. Imports of oil and coal have been increasing at rates of 7% and 16% per annum respectively during the period 1991-99. The dependence on energy imports is projected to increase in the future. Estimates indicate that oil imports will meet 75% of total oil consumption requirements and coal imports will meet 22% of total coal consumption As per requirements in 2006. The imports of gas and LNG (liquefied natural gas) are likely to increase in the coming years.

This energy import dependence implies vulnerability to external price shocks and supply fluctuations, which threaten the energy security of the country. Increasing dependence on oil imports means reliance on imports from the Middle East, a region susceptible to disturbances and consequent disruptions of oil supplies. This calls for diversification of sources of oil imports. The need to deal with oil price fluctuations also necessitates measures to be taken to reduce the oil dependence of the economy, possibly through fiscal measures to reduce demand, and by developing alternatives to oil, such as natural gas and renewable energy. Some of the strategies that can be used to meet future challenges to their energy security are

- Building stockpiles
- Diversification of energy supply sources
- Increased capacity of fuel switching
- Demand restraint,
- Development of renewable energy sources.
- Energy efficiency

- Sustainable development

Although all these options are feasible, their implementation will take time. Also, for countries like India, reliance on stockpiles would tend to be slow because of resource constraints. Besides, the market is not sophisticated enough or the monitoring agencies experienced enough to predict the supply situation in time to take necessary action. Insufficient storage capacity is another cause for worry and needs to be a augmented, if India has to increase its energy stock pile. However, out of all these options, the simplest and the most easily attainable is reducing demand through persistent energy conservation efforts.

TYPES OF RE SOURCES

Natural resources (also called land or raw materials) occur naturally within environments that exist relatively undisturbed by mankind, in a natural form. Natural resources are derived from the environment. Many of them are essential for our survival while others are used for satisfying our wants. Natural resources may be further classified in different ways. On the basis of origin, resources may be divided into: - biotic resources – obtained from the biosphere (forests and their products, animals, birds and their products, fish and other marine organisms; mineral fuels (coal, oil/petroleum) are also included in this category because they were formed from decayed organic matter; - abiotic resources – non-living things (land, water, air, ores). With respect to renewability, natural resources may be divided into: - non-renewable resources – are formed over long geological periods (minerals and fossil fuels). Their rate of formation is extremely slow, so they cannot be replenished once they get depleted. Metallic minerals can be reused by recycling them. But coal, oil/petroleum and natural gas cannot be recycled. - renewable resources – can be replenished or reproduced easily, at a rate comparable or faster than its rate of consumption by humans. Some of them (sunlight, air, wind, tides, hydroelectricity) are continuously available and their quantity is not affected by human consumption. They have also been named perpetual resources. Many renewable resources can be depleted by human use, but may also be replenished. Natural resources such as land, water, soil, plants and animals must be carefully managed, with a particular focus on how management affects the quality of life for both present and future generations. Renewable resources are seldom perfectly renewable. If their levels are heavily decreased, they may not be able to completely replenish themselves. Urban sprawl, cultivation, irrigation, grazing, deforestation, fishing, hunting, and habitat destruction can all be causes of the destruction of an otherwise renewable resource. There have been numerous efforts to prevent the mistakes that lead to the depletion of renewable resources. Despite this, destruction of renewable resources often proves to be profitable, and happens as a result. As we have become more environment-oriented in the last decade, we may hope for more reason in renewable resource management.

Kinds of renewable

resources 1.Solar energy

Solar energy is the energy derived directly from the sun and it is an extremely clean and renewable form of energy. The sun is the most abundant source of energy on Earth. The main uses of solar energy are: water heating (solar thermal collectors convert the sun's rays into heat), production of electricity (the photovoltaic cell converts sunlight directly into electricity), heating buildings (solar thermal collectors convert the sun's rays into hot air) and desalination of seawater. Solar panels convert solar energy into DC (district current) electricity which enters an inverter. The inverter turns DC electricity into AC (alternating current) electricity needed by home appliances or lights. When more solar energy is produced than the amount needed, it can be stored in a battery as DC electricity. One major advantage of solar energy is that it is available to everyone and can be harnessed by individuals everywhere, thus making power distribution across large areas unnecessary.

2. Wind

Wind power is the conversion of wind energy into more useful forms. Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electrical current by means of an electrical generator. In windmills (a much older technology) wind energy is used to turn mechanical machinery to do physical work, like crushing grain or pumping water.

Interest in wind came about because it is a very clean form of energy. The oil shocks of the 1970s furthered interest in wind and other alternative energy sources. Despite research and development cuts, there is considerable wind research and usage today. Many countries have deployed wind technology and use wind equipment to gain energy. Often, power is gained through wind farms - large groups of wind turbines. Wind power is used in large scale wind farms for national electrical grids as well as in small individual turbines for providing electricity to rural residences or grid- isolated locations. A few people have objected to wind energy, as they work against the greenhouse effect if used to replace the use of fossil-fuel. Nevertheless, some say the wind farms are too noisy and cause traffic congestion nearby. Others complain that windmills kill birds.

3. Hydropower

Hydropower is power derived from the energy of falling water, running water or ocean energy (power of waves), which may be harnessed for useful purposes. It is a very common resource which can be used to generate electricity or to do useful work. Hydroelectric power plants capture the energy of falling water to generate electricity. A dam usually raises the water level of the river to create falling water and it also makes it possible to control the flow of water. The reservoir that is formed is, in effect, stored energy. The force of falling water pushing against the turbine's blades causes the turbine to spin. The turbine converts the kinetic energy of falling water into mechanical energy. A generator is connected to the turbine, so when the turbine spins it causes the generator to spin also. It converts the mechanical energy from the turbine into electric energy. The amount of electricity a hydropower plant produces depends on two factors: how far the water flows and the amount of water. Transmission lines conduct electricity from the hydropower plant to homes and business.

4. Geothermal power

Geothermal power is power extracted from heat stored in the Earth. This geothermal energy originates from the original formation of the planet, from radioactive decay of minerals, and from solar energy absorbed at the surface. A part of direct geothermal heating capacity is installed for district heating, spas, industrial processes, desalination and agricultural applications. Geothermal power is cost effective, reliable, sustainable, and environmentally friendly. The Earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, but only a very small fraction may be profitably exploited. Drilling and exploration for deep resources is very expensive. Geothermal electric plants were traditionally built exclusively on the edges of tectonic plates where high temperature geothermal resources are available near the surface. The improvements in drilling and extraction technology enable building geothermal systems over a much greater geographical range. The thermal efficiency of geothermal electric plants is low, around 10- 23%, because geothermal fluids do not reach the high temperatures of steam. Exhaust heat is wasted, unless it can be used directly and locally, for example in greenhouses, timber mills, fisheries

and district heating. Direct heating is far more efficient than electricity generation as it can use heat resources with lower temperatures. Where natural hot springs are available, the heated water can be piped directly into radiators. There is a certain environmental risk connected with the use of geothermal heat, namely, hot water from geothermal sources holds dissolved gases and sometimes small amounts of toxic chemicals like mercury, arsenic. Geothermal power requires no fuel (except for pumps), and is therefore immune to fuel cost fluctuations, but capital costs are significant.
Drilling accounts for over half the costs, and exploration of deep resources entails significant risks.

5. Biomass

Biomass is biological material derived from living or recently living organisms. We as humans create a huge amount of by-products including human waste, general waste, animal waste, and much more. Biomass conversion technologies now take advantage of these and by burning by-products, they may release the energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid bio fuel or combustible biogas, instead of 4 further polluting the atmosphere. Many waste treatment facilities and landfill sites are moving to biomass energy to create power and to make their towns and cities cleaner. Categories of biomass materials; there are five basic categories of material:

- Virgin wood, from forestry or from wood processing
- Energy crops: high yield crops grown specifically for energy applications
- Agricultural residues: residues from agriculture harvesting or processing
- Food waste, from food and drink manufacture, preparation and processing, and postconsumer waste
- Industrial waste and co-products from manufacturing and industrial processes

As there is wide diversity in the characteristics and properties of these different classes of material and their various sub-groups, there is also a wide range of conversion technologies, which include both thermal (combustion, gasification, pyrolysis) and chemical conversion technologies (anaerobic digestion, fermentation, composting). Biomass power plant size is often driven by biomass availability in close proximity as transport costs of the (bulky) fuel play a key factor in the plant's economics.

6. Fresh water

Water can be considered a renewable material in conditions of carefully controlled usage, treatment, and release. If not, it would become a non-renewable resource at that location. For example, groundwater could be removed from an aquifer at a rate greater than the sustainable recharge. Removal of water from the pore spaces may cause permanent compaction that cannot be renewed.

7. Forests

Forests are naturally renewable if removal of the trees is controlled. We are witnessing the process of deforestation (destroying or removing a forest ecosystem) in many areas today. Trees are cut for fuel, for the profit, for acquiring land to plant crops or grow animals. Sometimes deforestation is natural (large fires). Species may become extinct (the loss of their habitat), erosion and flooding can occur as well as desertification and decreased land productivity. The general climate of an area can also change. Many countries have developed programmes aimed at reducing deforestation.

8. Agricultural products

Sustainable agriculture stands for the use of techniques which allow for minimal and controlled environmental damage. Products from this type of agriculture are renewable and sustainable when processing and logistics related to these products also have sustainable characteristics.

LIMITATIONS OF RE SOURCES.

The main limitations of renewable energy sources include their higher initial cost, that can be excessive and a deterrent for users, as well as the cost of storing systems, which is also quite high. Also, renewable energy depends on weather conditions, and unpredictable weather conditions for a long time period could lead to energy deficiency. In addition to that, large land areas are required in order to install the necessary renewable energy technology. According to Brook and Bradshaw renewable energy sources could provide around 50% of the total energy required in the United States, but more than 17% of the land would have to be used .

PRESENT INDIA AND INTERNATIONAL ENERGY SCENARIO OF CONVENTIONAL AND RE SOURCES.

ENERGY

SCENARIO

INTRODUCTION

Any physical activity in this world, whether carried out by human beings or by nature, is cause due to
flow of energy in one form or the other. The word 'energy' itself is derived from the Greek word 'en-ergon', which means 'in-work' or 'work content'. The work output depends on the energy input. Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them. Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy
- Conventional and Non-conventional energy

- **Primary and Secondary energy**

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. The major primary and secondary energy sources. Primary energy sources are costly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non energy uses, for example coal or natural gas can be used as a feedstock in fertilizer plants.

- **Commercial and Non commercial energy**

Commercial Energy

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

Non-Commercial Energy

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

- **Renewable and Non-Renewable energy**

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

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas which are likely to deplete with time.

- **Conventional and Non-conventional**

energy Conventional Energy

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

Non-conventional energy

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

Indian Energy Scenario

Coal dominates the energy mix in India, contributing to 55% of the total primary energy production. Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10% in 1994 to 13% in 1999. There has been a decline in the share of oil in primary energy production from 20% to 17% during the same period. Energy Supply Coal Supply India has huge coal reserves, at least 84,396 million tones of proven recoverable reserves (at the end of 2003). These amounts to almost 8.6% of the world reserves and it may last for about 230 years at the current Reserve to Production (R/P) ratio. In contrast, the world's proven coal reserves are expected to last only for 192 years at the current R/P ratio. Reserves/Production (R/P) ratio- If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that the remaining reserves would last if production were to continue at that level. India is the fourth largest producer of coal and lignite in the world. Coal production is concentrated in these states (Andhra Pradesh, Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra, Orissa, Jharkhand, and West Bengal).

Oil Supply

Oil accounts for about 36 % of India's total energy consumption. India today is one of the top ten oil-guzzling nations in the world and will soon overtake Korea as the third largest consumer of oil in Asia after China and Japan. The country's annual crude oil production is peaked at about 32 million tonne as against the current oil consumption by end of 2007 is expected to reach 136 million tonne(MT), of which domestic production will be only 34 MT. India will have to pay an oil bill of roughly $50 billion, assuming a weighted average price of $50 per barrel of crude. In 2003-04, against total export of $64 billion, oil imports accounted for $21 billion. India imports 70% of its crude needs mainly from gulf nations. The majority of India's roughly 5.4 billion barrels in oil reserves are located in the Bombay High, upper Assam, Cambay, Krishna-Godavari. In terms of sector wise petroleum product consumption, transport accounts for 42% followed by domestic and industry with 24% and 24% respectively. India spent more than Rs.1,10,000 crore on oil imports at the end of 2004.

Natural Gas Supply

Natural gas accounts for about 8.9 per cent of energy consumption in the country. The current demand for natural gas is about 96 million cubic metres per day (mcmd) as against availability of 67 mcmd. By 2007, the demand is expected to be around 200 mcmd. Natural gas reserves are estimated at 660 billion cubic meters.

Electrical Energy Supply

The all India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004, consisting of 28,860 MW- hydro, 77,931 MW- thermal and 2,720 MW- nuclear and 1,869 MW- wind (Ministry of Power).

Nuclear Power Supply

Nuclear Power contributes to about 2.4 per cent of electricity generated in India. India has ten nuclear power reactors at five nuclear power stations producing electricity. More nuclear reactors have also been approved for construction.

Hydro Power Supply

India is endowed with a vast and viable hydro potential for power generation of which only 15% has been harnessed so far. The share of hydropower in the country's total generated units has steadily decreased and it presently stands at 25% as on 31st May 2004. It is assessed that exploitable potential at 60% load factor is 84,000 MW.

Final Energy Consumption

Final energy consumption is the actual energy demand at the user end. This is the difference between primary energy consumption and the losses that takes place in transport, transmission & distribution and refinement. The actual final energy consumption (past and projected) is given below.

TABLE DEMAND FOR COMMERCIAL ENERGY FOR FINAL CONSUMPTION (BAU SCENARIO)

Source	Units	1994-95	2001-02	2006-07	2011-12
Electricity	Billion Units	289.36	480.08	712.67	1067.88
Coal	Million Tonnes	76.67	109.01	134.99	173.47
Lignite	Million Tonnes	4.85	11.69	16.02	19.70
Natural Gas	Million Cubic	9880	15730	18291	20853
Oil	Million Tonnes	63.55	99.89	139.95	196.47

Source: Planning Commission BAU:_Business As Usual

Long Term Energy Scenario for

India Coal:
Coal is the predominant energy source for power production in India, generating approximately 70% of total domestic electricity. Energy demand in India is expected to increase over the next 10- 15 years; although new oil and gas plants are planned, coal is expected to remain the dominant fuel for power generation. Despite significant increases in total installed capacity during the last decade, the gap between electricity supply and demand continues to increase. The resulting shortfall has had a negative impact on industrial output and economic growth. However, to meet expected future demand, indigenous coal production will have to be greatly expanded. Production currently stands at around 290 Million tonnes per year, but coal demand is expected to more than double by 2010.
Indian coal is typically of poor quality and as such requires to be beneficiated to improve the quality; Coal imports will also need to increase dramatically to satisfy industrial and power generation requirements.

Oil
India's demand for petroleum products is likely to rise from 97.7 million tonnes in 2001-02 to around
139.95 million tonnes in 2006-07, according to projections of the Tenth Five-Year Plan. The plan document puts compound annual growth rate (CAGR) at 3.6 % during the plan period. Domestic crude oil production is likely to rise marginally from 32.03 million tonnes in2001-02 to 33.97 million tonnes by the end of the 10th plan period (2006-07). India's self sufficiency in oil has consistently declined from 60% in the 50s to 30% currently. Same is expected to go down to 8% by 2020. As shown in the figure 1.8, around 92% of India's total oil demand by 2020 has to be met by imports.

Natural Gas

India's natural gas production is likely to rise from 86.56 million cmpd in 2002-03 to 103.08 million cmpd in 2006-07. It is mainly based on the strength of a more than doubling of production by private operators to 38.25 mm cmpd .

Electricity

India currently has a peak demand shortage of around 14% and an energy deficit of 8.4%. Keeping this in view and to maintain a GDP (gross domestic product) growth of 8% to 10%, the Government of India has very prudently set a target of 215,804 MW power generation capacity by March 2012 from the level of 100,010 MW as on March 2001, that is a capacity addition of 115,794 MW in the next 11 years. In the area of nuclear power the objective is to achieve 20,000 MW of nuclear generation capacity by the year 2020.

2. SOLAR ENERGY

Introduction:

Solar energy is an important, clean, cheap and abundantly available renewable energy. It is received on Earth in cyclic, intermittent and dilute form with very low power density 0 to 1 kW/m2.Solar energy received on the ground level is affected by atmospheric clarity, degree of latitude, etc. For design purpose, the variation of available solar power, the optimum tilt angle of solar flat plate collectors, the location and orientation of the heliostats should be calculated.

Units of solar power and solar energy:

In SI units, energy is expressed in Joule. Other units are angley and

Calorie where 1 angley = 1 Cal/cm2.day
1 Cal = 4.186 J

For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of kJ/m2/day or kJ/m2/hour. Solar power is expressed in terms of W/m2 or kW/m2.

SOLAR PHOTOVOLTAIC SYSTEM-OPERATING PRINCIPLE

Solar cell: Solar cell is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect .

Materials for Solar cell

Solar cells are composed of various semiconducting materials
1. Crystalline silicon
2. Cadmium telluride
3. Copper indium diselenide
4. Gallium arsenide
5. Indium phosphide
6. Zinc sulphide

. Over 95% of all the solar cells produced worldwide are composed of the semiconductor material Silicon (Si). As the second most abundant element in earth`s crust, silicon has the advantage, of being available in sufficient quantities.

. To produce a solar cell , the semiconductor is contaminated or "doped".

.Doping is the intentional introduction of chemical elements into the semiconductor.

.By doing this , depending upon the type of dopant ,one can obtain a surplus of either positive charge carriers (called p-conducting semiconductor layer) or negative charge carriers (called n-conducting semiconductor layer).

. If two differently contaminated semiconductor layers are combined, then a so-called p-n- junction results on the boundary of the layers .

. By doping trivalent element, we get p-type semiconductor.(with excess amount of hole)

. By doping pentavalent element, we get n-typesemiconductor (with excess amount of electron)

Photovoltaic effect

Definition: The generation of voltage across the PN junction in a semiconductor due to the absorption of light radiation is called photovoltaic effect. The Devices based on this effect is called photovoltaic device.

Electron-hole formation
. Photovoltaic energy conversion relies on the number of photons strikes on the earth. (photon is a flux of light particles)
. On a clear day, about 4.4 x 1017 photons strike a square centimeter of the Earth's surface every second.
. Only some of these photons - those with energy in excess of the band gap - can be converted into electricity by the solar cell.
. When such photon enters the semiconductor, it may be absorbed and promote an electron from the valence band to the conduction band.
. Therefore, a vacant is created in the valence band and it is called hole.
. Now, the electron in the conduction band and hole in valence band combine together and forms electron-hole pairs.

When a solar cell (p-n junction) is illuminated, electron–hole pairs are generated and the electric current obtained I is the difference between the solar light generated current IL and the diode dark current Ij , i.e.

$$I = IL - Ij$$

$$I = IL - I0 [\exp (eV/kT) -1]$$

This phenomenon is known as the photovoltaic effect

Principle:

The solar cells are based on the principles of photovoltaic effect. The photovoltaic effect is the photogeneration of charge carriers in a light absorbing materials as a result of absorption of light radiation .

PHOTOVOLTAIC CELL CONCEPTS

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.

Solar cells are fabricated from semiconductor materials prepared in three physical states– single multicrystal, many small crystals (polycrystalline) and amorphous (non crystalline).

Single Crystal Silicon

Silicon solar cells are commonly used for both terrestrial and space applications. The basic raw material is sand (SiO2) from which silica (Si) is extracted and purified repeatedly to obtain the metallurgical grade silicon. It contains about 1% impurities and further processed to convert it to a purer semiconductor grade silicon. It is then finally converted into a single crystal ingot.

Polycrystalline Silicon Cells

The production cost of a single crystal silicon cell is quite high compared to the polycrystalline silicon cell. Polysilicon can be obtained in thin ribbons drawn from molten silicon bath and cooled very slowly to obtain large size crystallites. Cells are made with care so that the grain boundaries cause no major interference with the flow of electrons and grains are larger in size than the thickness of the cell. The polycrystalline silicon solar cell can be fabricated in three designs, namely p-n junction cells, Metal Insulator Semiconductor (MIS) cells, and conducting oxide-insulator semiconductor cells. For a p-n junction solar cell, a polycrystalline silicon film is deposited by chemical vapour deposition on substrates like glass, graphite, metallurgical grade silicon and metal. An MIS cell can be developed by inserting a thin insulting layer of SiO2 between the metal and the semiconductor. A nicely developed cell with chromium metal base with SiO2 insulation over it, the p-type crystalline silicon can give efficiency up to 12% at AM-1 condition with cell dimension of 0.2 cm .

Amorphous Silicon Cells

Amorphous silicon is pure silicon with no crystal properties. It is highly light absorbent and requires only 1 mm to 2 mm of material to absorb photons of the incident light. Thin amorphous layers can be deposited on cheap substrates like steel, glass and plastic. Hydrogenated amorphous silicon (a-Si :
H) is a suitable material for thin film solar cells, mainly due to its high photo-conductivity, high optical absorption of visible light with optical band gap of 1.55 eV. Thin films of nearly 0.7 mm can produce solar cells comparatively at low cost. Amorphous silicon cells can be fabricated in four structures: (i) metal, insulator–semiconductor (MIS), (ii) p-i-n devices, (iii) hetrojunction, and (iv) Schottky barriers. The p-i-n junction, a-Si solar cells are beneficial for commercial production due to their good performance. A common type of p-i-n junction, a-Si solar cell, consists of a deposited layer of boron doped a-Si : H(200 Å) and above it, is a deposited layer of n-doped a-Si : H (80 Å). Then, a 70 Å thick layer of Indium Tin Oxide (ITO) is deposited over the n-type layer which serves in two ways, i.e., conducting electrode and anti reflective coating. In a single junction (a-Si : H) solar cell, a part of solar radiation with less energy than band gap remains unutilized and wasted as heat, causing low cell efficiency. This drawback is solved by adopting a ‘tandem structure’ that involves stacked junctions where semiconductors having different energy gaps are erected on top of each other with decreasing band gap in the direction of light path.

cell

A PV Cell or Solar Cell or Photovoltaic Cell is the smallest and basic building block of a Photovoltaic System (Solar Module and a Solar Panel). These cells vary in size ranging from about 0.5 inches to 4 inches. These are made up of solar photovoltaic material that converts solar radiation into direct current (DC) electricity. Materials used for photovoltaic include mono crystalline silicon, polycrystalline silicon, microcrystalline silicon, cadmium telluride, and copper indium selenide
/sulfide.

Different Types of PV Cells

Many new styles of PV cells are being developed today but mainly two distinct material:

1. Crystalline Silicon PV Cells (Mono crystalline)
   These Solar Cells are manufactured from crystalline silicon. Many of you must be knowing that silicon is the second most common material on Earth and is abundantly found in sand. To make solar cells out of silicon, manufactured silicon crystals are sliced to about 300 micrometers thick and coated to work as a semiconductor to capture solar energy.

2. Thin-film or Polycrystalline PV Cells Thin-film PV cells use amorphous silicon or an alternative to silicon as a semiconductor. These solar cells are relatively flexible and can be directly installed with building materials. They work great even during clouds when there is low sun light. Here, the disadvantage is that thin-film PV Cells comparatively generate less electricity than crystalline silicon cells.

Solar PV Module

A bare single cell cannot be used for outdoor energy generation by itself. It is because (i) the output of a single cell is very small and (ii) it requires protection (encapsulation) against dust, moisture, mechanical shocks and outdoor harsh conditions. Workable voltage and reasonable power is obtained by interconnecting an appropriate number of cells. Cells from same batch are used to make PV module. This is done to ensure that mismatch losses are minimal in the module. The electrically connected cells are encapsulated, typically by using two sheets of ethylene vinyl acetate (EVA) at either side. EVA is a good electrical insulator, transparent material and has very low water absorption. The encapsulant cannot provide rigidity to the module, for which glass is provided at the front side of the module. At the rear side of the module a hard polymer material, typically, polyvinyl fluoride (PVF, also known as tedlar) is used. Theses layers are arranged as shown in Fig. 6.29 and hermetically sealed to make it suitable for outside applications for 20-30 years without environmental degradation. This assembly is known as solar module a basic building block of a PV system. Most common commercial modules have a series connection of 32 or 36 silicon cells to make it capable of charging a 12 V storage battery. However, larger and smaller capacity modules are also available in international market.

Solar Photovoltaic Panels

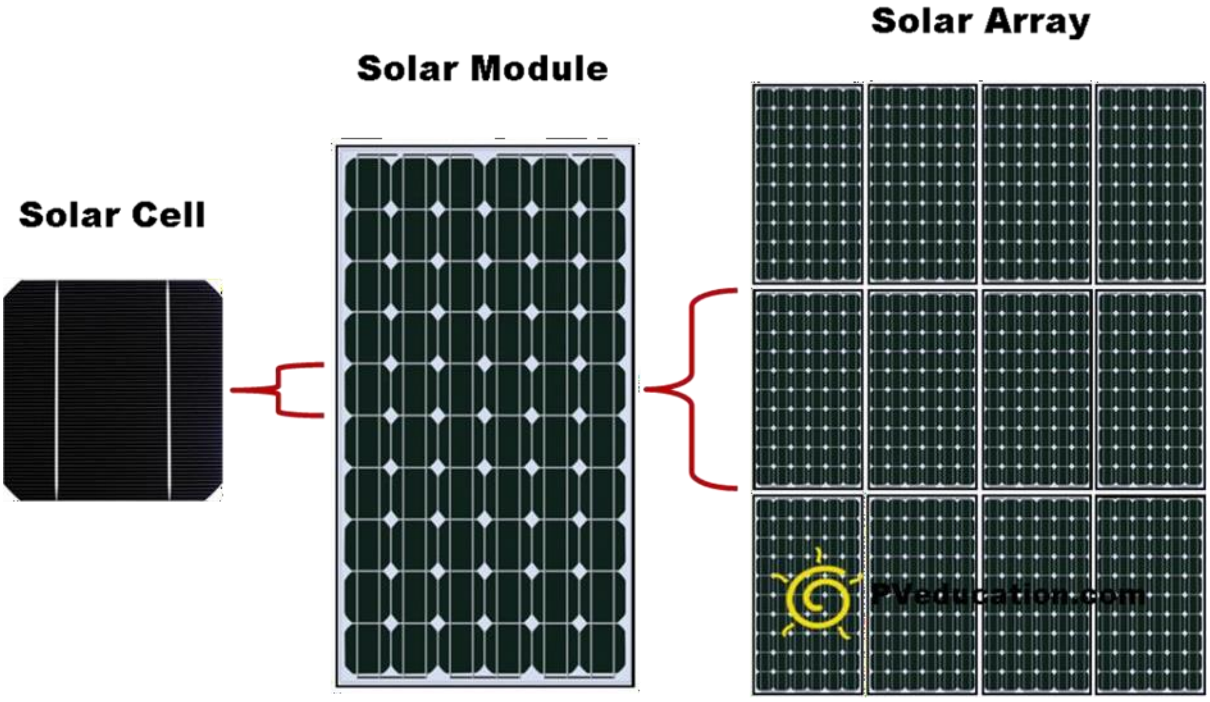
An array or Solar PV Cells are electrically connected together to form a PV Module and an Array of such Modules are again electrically connected together to form a Solar Panel. This connection is done by soldering using flux cored solder wire and PV Ribbon

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. Thus while interconnecting the modules; the installer should have this information available for each module. Solar panel is a group of several Solar Photovoltaic Systems modules connected in series-parallel combination in a frame that can be mounted on a structure

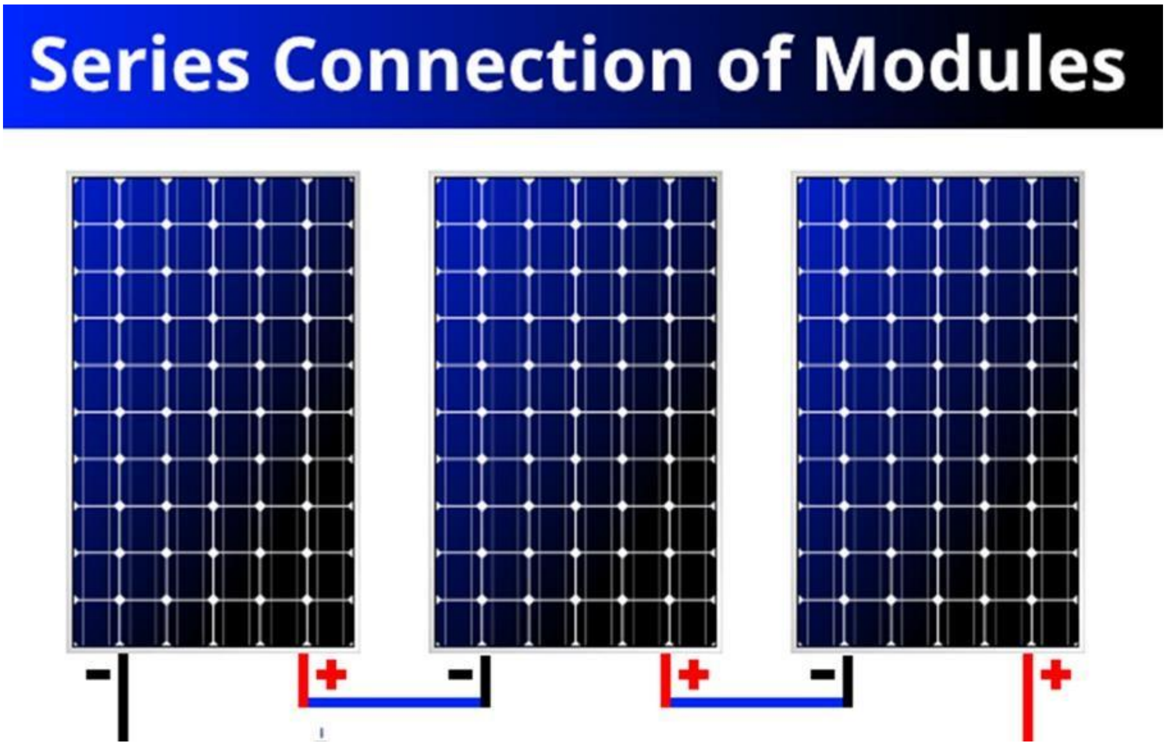
Solar PV Array

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.



Series Connection of Modules

Sometimes the system voltage required for a power plant is much higher than what a single PV module can produce. In such cases, N-number of PV modules is connected in series to deliver the required voltage level. This series connection of the PV modules is similar to that of the connections of N-number of cells in a module to obtain the required voltage level. The following figure shows PV panels connected in series configuration.



With this series connection, not only the voltage but also the power generated by the module also increases. To achieve this the negative terminal of one module is connected to the positive terminal of the other module.

If a module has an open circuit voltage V_{OC1} of 20 V and other connected in series has V_{OC2} of 20 V, then the total open circuit of the string is the summation of two voltages

$$\mathbf{V_{OC} = V_{OC1} + V_{OC2}}$$

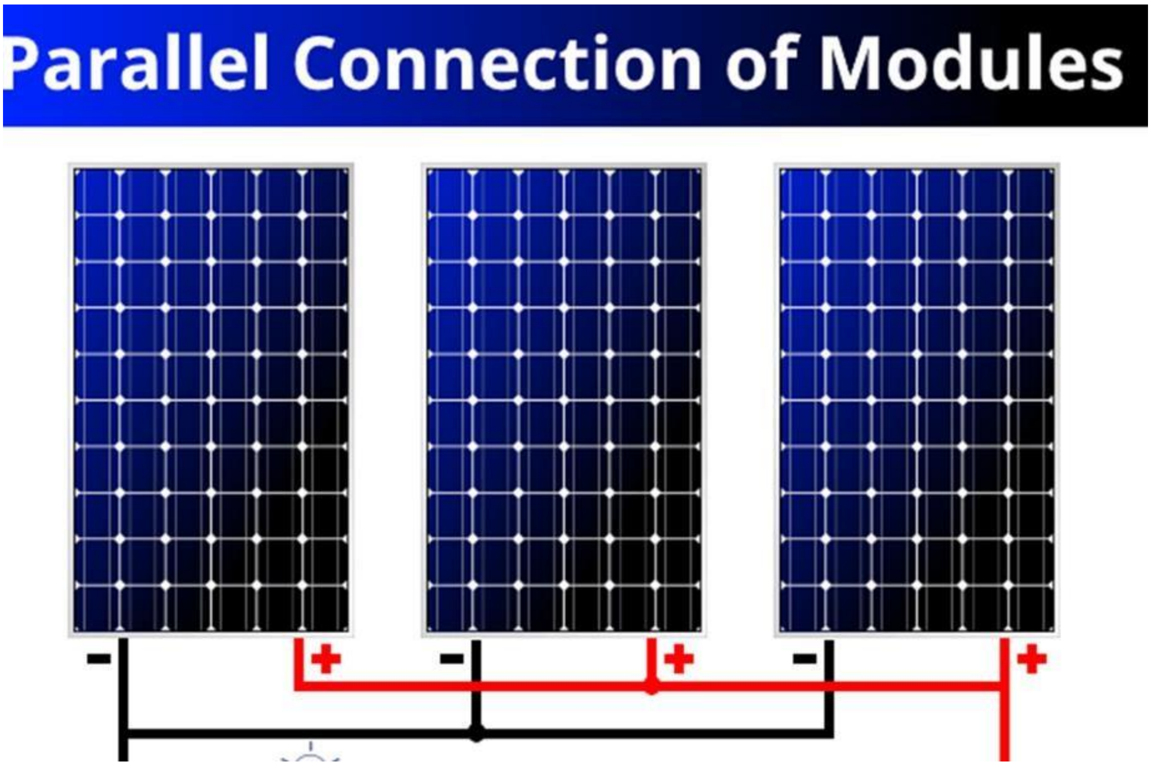
$$V_{OC} = 20\text{ V} + 20\text{ V} = \mathbf{40\text{ V}}$$

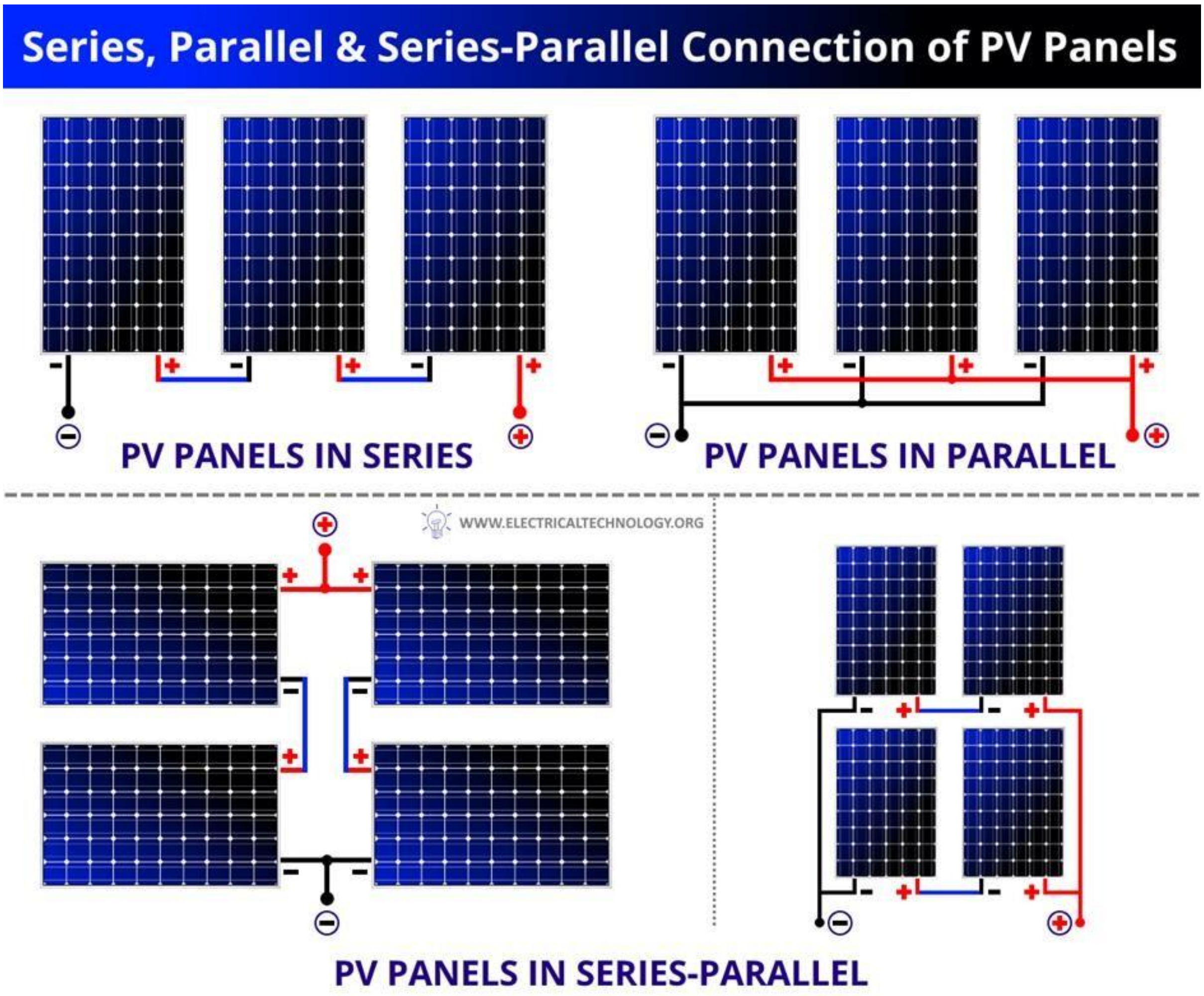
It is important to note that the summation of voltages at the maximum power point is also applicable in case of PV array.

Parallel Connection of Modules

Sometimes to increase the power of the solar PV system, instead of increasing the voltage by connecting modules in series the current is increased by connecting modules in parallel. The current in the parallel combination of the PV modules array is the sum of individual currents of the modules.

The voltage in the parallel combination of the modules remains the same as that of the individual voltage of the module considering that all the modules have identical voltage. The parallel combination is achieved by connecting the positive terminal of one module to the positive terminal of the next module and negative terminal to the negative terminal of the next module as shown in the following figure. The following figure shows solar panels connected in parallel configuration.





Maximum power point tracking (MPPT)

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 shownin Fig. 6.36. An ideal load is one that tracks the maximum power point ,

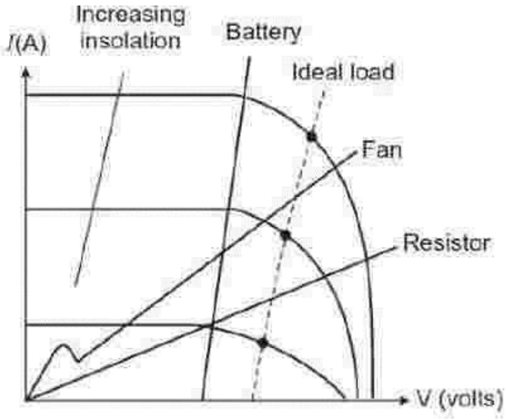


Figure 6.36 Characteristics of PV and some loads

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. Basicelements 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:

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

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 standardbook of power electronics.

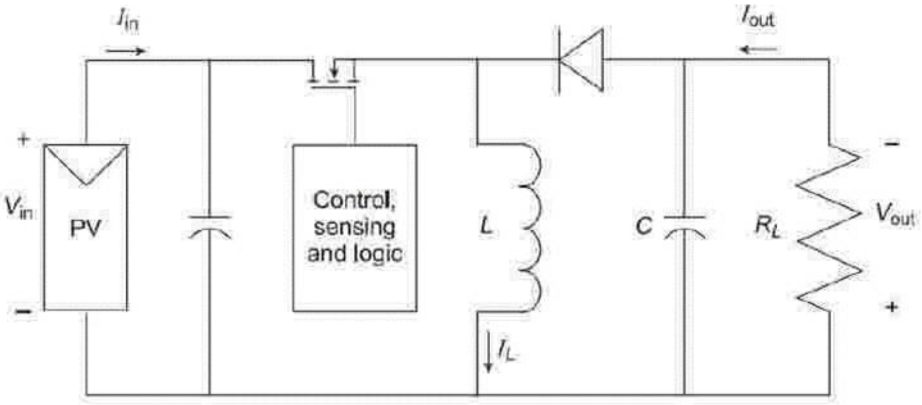


Figure 6.37 Maximum point tracker using buck-boost converter

The power output of a PV system is given by:

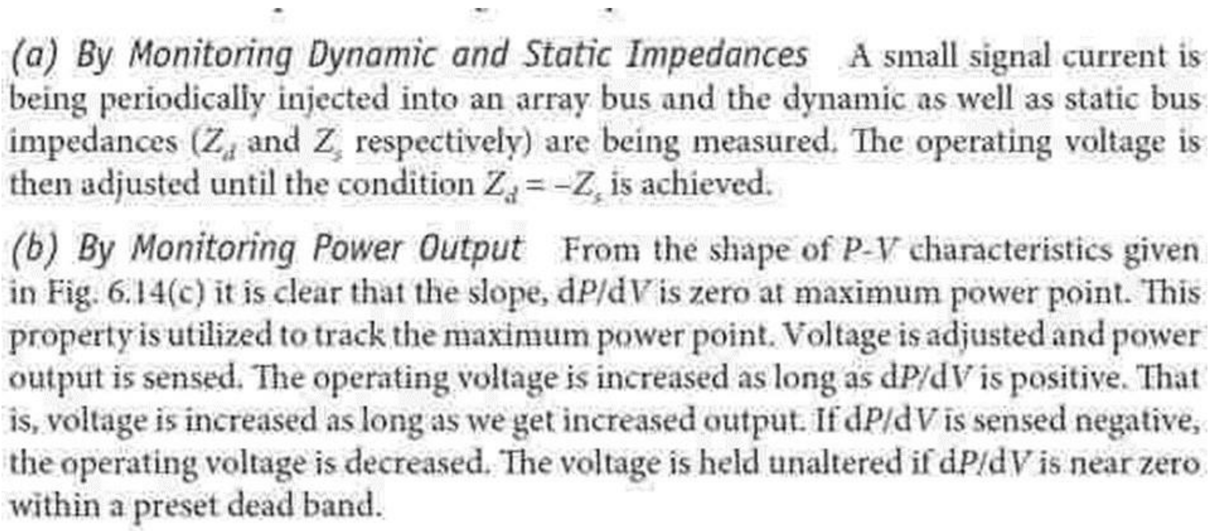
$$\Delta P = \Delta V.I + \Delta I.V \tag{6.41}$$

ΔP must be zero at peak point. Therefore, at peak point the above expression in the limit becomes:

$$\frac{dV}{dI} = -\frac{V}{I} \tag{6.42}$$

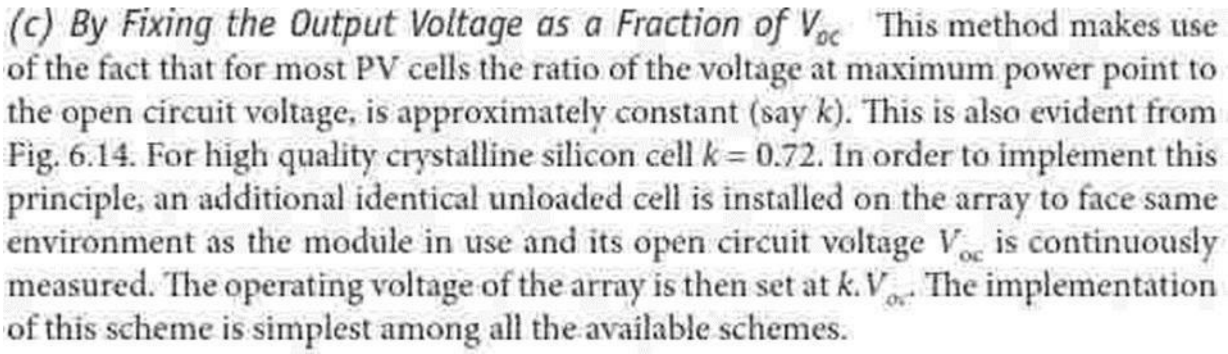
It may be noted here that $\frac{dV}{dI}$ is the dynamic impedance of the source, which is required to be equal to negative of static impedance, $\frac{V}{I}$.

There are three possible strategies for operation of an 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.

Classification of energy Sources.

Solar energy is changing the way in which we look at how we source the energy we need. Given how fast technology has marched on in line with our search for cleaner energy, let's take a look at the **different types of solar energy** available.

Traditionally, our electricity comes via the grid whereby we generate it by burning coal or natural gas. Despite this, our reliance on electricity generated from fossil fuels cannot continue. Thankfully, our quest to go green is helping us in our journey to find less polluting alternatives.

Solar energy is a type of renewable energy that is better for the environment, so what is there to not love about it? Of course, like any technology, solar comes with its own pros and cons. Whether it is commercial systems or residential systems, the various types of solar demonstrate the range of benefits we can expect from renewable energy.

What are the Different Types of Solar Energy?

1. Photovoltaic Solar Energy

The history of solar photovoltaic dates back to around the 1830’s when the photovoltaic effect was discovered. Later, in 1954, Bell Laboratories in the US built the first solar PV panel.

To gain an understanding of this type of solar energy, it helps to think of the solar panel on a calculator. Solar panels work by turning direct sunlight into electricity.

Photovoltaic solar systems are one of the most popular types of solar power systems available. Typically a number of solar cells make up a PV panel, producing direct current that converters turn into alternating current. A group of solar PV panels connected with the required kit to turn sunlight into electricity are known as solar cell systems.

Today we can see some of the largest countries in the world, including China, the United States and the European Union rolling out large scale solar farms to increase solar capacity. As of 2018, these countries had a total solar capacity of 175,018MW, 62,200MW and 115,234MW respectively. Meanwhile, developing countries are moving too seeking freely available energy as populations expand[6].

In 2018, Asia was striding ahead in terms of solar panel installations[5]. The region made up 75% of global solar power installations, proving that PV panels generating power from sunlight look to be one of the most popular forms of solar energy.

Domestically, the price of installing PV solar cells has dropped dramatically as a result of government incentives and rebates. As a result, busting the expense myth, more and more homes now benefit from clean energy derived from the sun.

As far as efficiency goes, a photovoltaic solar panel system will produce around 200kWh under normal test conditions. This is based on a solar panel that has an efficiency of 20% and an area of 1m2

2.Concentrated Solar Energy

Today, concentrated solar power, or CSP, is normally found in large scale installations that provide electricity to the grid.

Concentrated solar has an interesting history that many believe dates back to Archimedes and his burning glass. This form of energy uses mirrors and lenses to concentrate a large area of sunlight onto a receiver.

It was in 1866 that a parabolic trough was used to produce steam making it possible to power the first solar steam engine. However, Alessandro Battaglia obtained the first patent in 1886 and in 1929, Dr. R.H. Goddard created a solar power system using a mirror dish[7].

As it currently stands, there are four types of concentrated solar technologies that exist. These are the parabolic trough, dish, concentrating linear Fresnel reflector and solar power tower[1].

The first system was deployed in 1984 and by the end of that year, the number of systems had reached 14. By 2019, installations globally had reached a total of 6,451. Modern installations use thousands of mirrors, concentrating the sun's energy into a small area which gets very hot. The heat then drives a steam turbine generating electricity.

This form of solar energy best suits those countries that see extremely high levels of sunshine. Therefore, it is no surprise that Spain has the largest capacity of 2,300MW while the US and South Africa follow close behind with 1,738MW and 400MW

Concentrated solar power is not quite as popular for large scale applications as using photovoltaic or PV panels, however, they do have a conversion efficiency of as much as 25% to 35%

3. Water Heating Solar Energy

Water heating solar energy began with black paint painted onto tanks and used to heat water. As the black paint absorbed the heat from the sun, it would heat up the water inside it. As primitive as this may seem, it shows that we understood the power of solar from early on.

The very first thermal solar power plant was located in Maadi, Egypt. However, it wasn’t until the 1920s that flat plate collectors were used for solar water heating in Florida and Southern California[8].

We commonly see this form of solar energy in domestic, commercial, and industrial situations. Using the technology that we have available, a working fluid is heated up using a sun-facing collector. This will then pass into a storage system where we can heat water surrounding pipes containing the working fluid.

To power our electricity grids, the capacity for water heating solar as of 2017 was 472GW. China, the US, and Turkey are leading the way with regards to adoption. However, based per capita, the likes of Barbados, Austria, and Cyprus are dominating the market.

The heat that this system generates is proportionate to the amount of heat from the sun. Therefore, those countries that have warmer, sunnier climates are more likely to benefit from this type of solar energy. This feeds into the efficiency of such systems. Therefore, in areas where the temperatures are higher, water heating can be extremely cost- efficient. As a result, the payback times are shorter when it comes to installing solar in sunnier climates.

4. Solar Pool Heating

Running a heating system to keep a pool warm is an expensive process. Maintaining the water temperature is an ongoing cost which can be reduced by using the solar energy derived from the sun.

The history of commercial solar water heating dates back to 1891. Within five years of this, the technology was heating pools throughout Pasadena, California. Florida was the next state to follow but there were copper shortages as a result of World War II. Along with this, electricity was taking over. At the time, the solar water industry paid the price.

Despite this knockback, around 50 years later, it became mainstream again. The driver for this was an increase in fuel prices and the OPEC oil embargo. However, today, we are now seeking new and innovative ways to reduce our use of fossil fuels and electricity while trying to improve the outlook for our planet.

So, consumer demand has seen solar pool heating explode in popularity. This works much in the same way as water heating solar energy. Photovoltaic panels or panels containing heat conductors capture the heat from sunlight and turn it into energy and in turn hot water.

These systems traditionally consist of four components. These are the solar collector, pump, valve and the filter. The water passes through the filter and then to the solar collectors or panels which are the energy source. Here the heat will warm the water before pumping hot water back into the pool.

Aside from the initial installation costs, these systems are a great way of enhancing efficiency. They reduce costs and use the heat of the sun to warm up the water, all of this reduces the need for grid-derived electric power.

5. Thermal Solar Energy

Thermal solar energy, or solar thermal, utilises the heat from the sun. To heat water or produce electricity, liquid flows through tubes and collects the sun's energy.

Thermal energy, as we know it today, started life back in 1890. In the beginning, this form of energy powered a steam engine. Slightly later, one of the main pioneers of solar thermal technologies was William Bailey. In 1909, he invented a thermosyphon system. This meant that he had access to hot water throughout the day, which he achieved using a water tank with a collector positioned below it.

One of the problems faced by this type of solar energy was the transportation of the heat from the sun. Scientists and inventors tried many fluids, including oil and sodium, but molten salt proved the best option[4]. This is ideal given that it is cost- effective and works perfectly with the steam turbines we use today.

In comparison to solar PV, thermal solar energy is more space-efficient. Solar thermal can offer as much as 70% more efficiency when it comes to collecting heat. Along with this, the technology is far less complex, which makes it ideal for heating up water.

The largest solar thermal power station is located in Morocco and has a capacity of 510MW while the US and Spain both have several large projects. Due to the way in which solar thermal systems work, they can reach an extremely high temperature. As an example, the solar Furnace at Odeillo in the French Pyrenees can reach temperatures of as much as 3,500 degrees.

Extra-terrestrial and terrestrial Radiation.

The sun is a hydrodynamic spherical body of extremely hot ionized gases (plasma), generating energy by the process of thermonuclear fusion. The temperature of the interior of the sun is estimated at 8 ¥ 106 K to 40 ¥ 106 K, where energy is released by fusion of hydrogen to helium. Energy radiated from the sun is electromagnetic waves reaching the planet earth in three spectral regions, ultraviolet 6.4% (l < 0.38 miu m), visible 48% (0.38 mm < l < 0.78 miu m) and infrared 45.6% (l > 0.78 miu m) of total energy. Due to the large distance between the sun and the earth (1.495 ¥ 108 km) the beam radiation received from the sun on the earth is almost parallel.

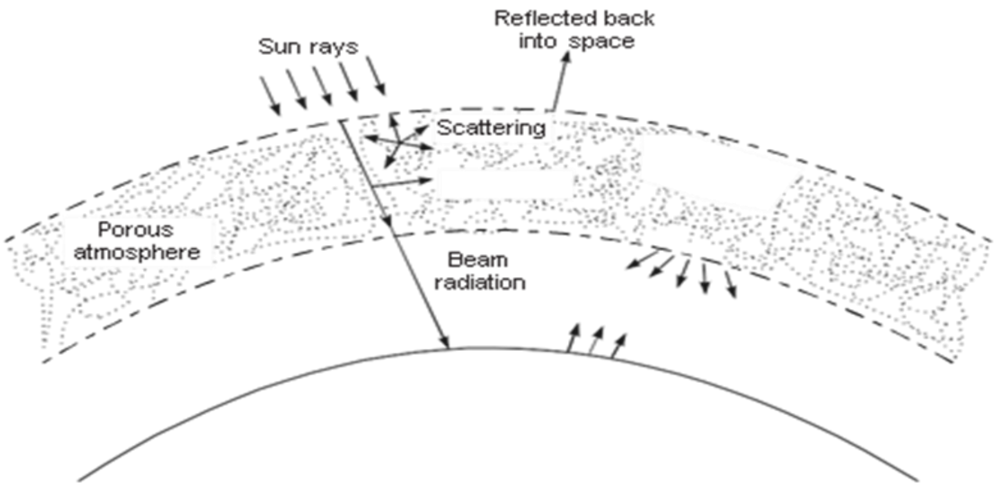
SPECTRAL DISTRIBUTION OF EXTRATERRESTRIAL RADIATION

Extraterrestrial radiation is the measure of solar radiation that would be received in the absence of atmosphere.. Solar radiation reaching the earth is essentially equivalent to blackbody radiation. Using the Stefan–Boltzmann law, the equivalent blackbody temperature is 5779 K for a solar constant of 1367 W/m2 .

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 vapours. Scattering is due to air molecules, dust particles and water droplets that cause attenuation of radiation as detailed in Figure . Minimum attenuation takes place in a clear sky when the earth’s surface receives maximum radiation.



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

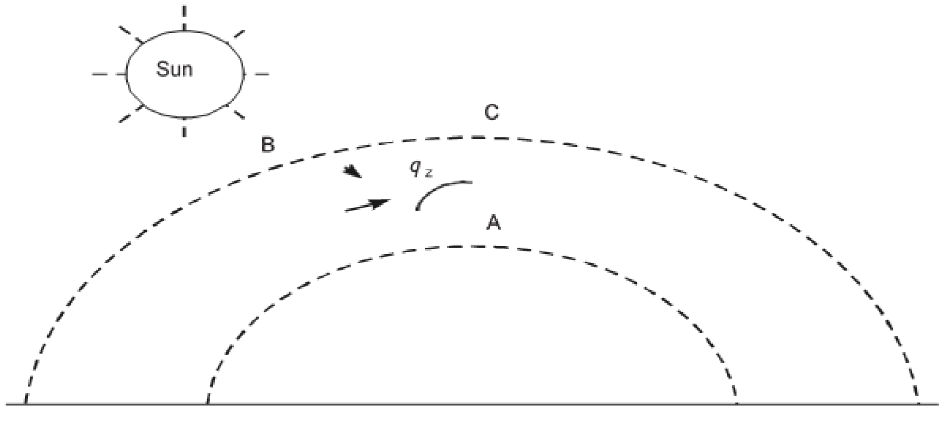
Beam radiation (I_b): Solar radiation received on the earth's surface without change in direction, is called
beam or *direct radiation*.

Diffuse radiation (I_d): The radiation received on a terrestrial surface (scattered by aerosolsand 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.

Air mass (AM): It is the ratio of the path length of beam radiation through the atmosphere,to the path length if the sun were at zenith. At sea level AM = 1, when the sun is at zenith or directly overhead; AM = 2 when the angle subtended by zenith and line of sight of the sun is60°; AM = 0 just above the earth's atmosphere. At zenith angle q_z, the air mass is calculatedas (see Figure 3.4):



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 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

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.

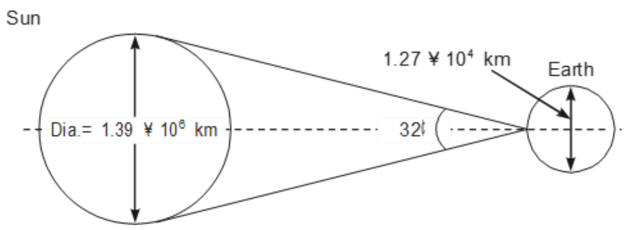
Irradiance (W/m^2):

The rate of incident energy per unit area of a surface is termed *irradiance*.

Albedo: The earth reflects back nearly 30% of the total solar radiant energy to the space by reflection from clouds, by scattering and by reflection at the earth's surface. This is called the *albedo* of the earth's atmosphere system

Solar constant.

The sun, being at a very large distance from the earth, solar rays subtend an angle of only32 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

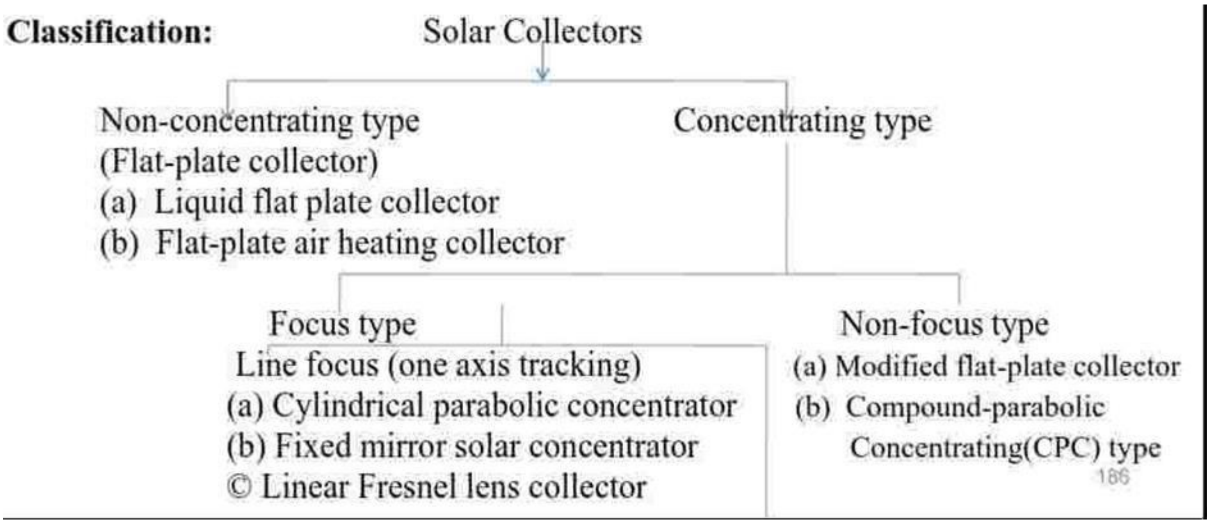


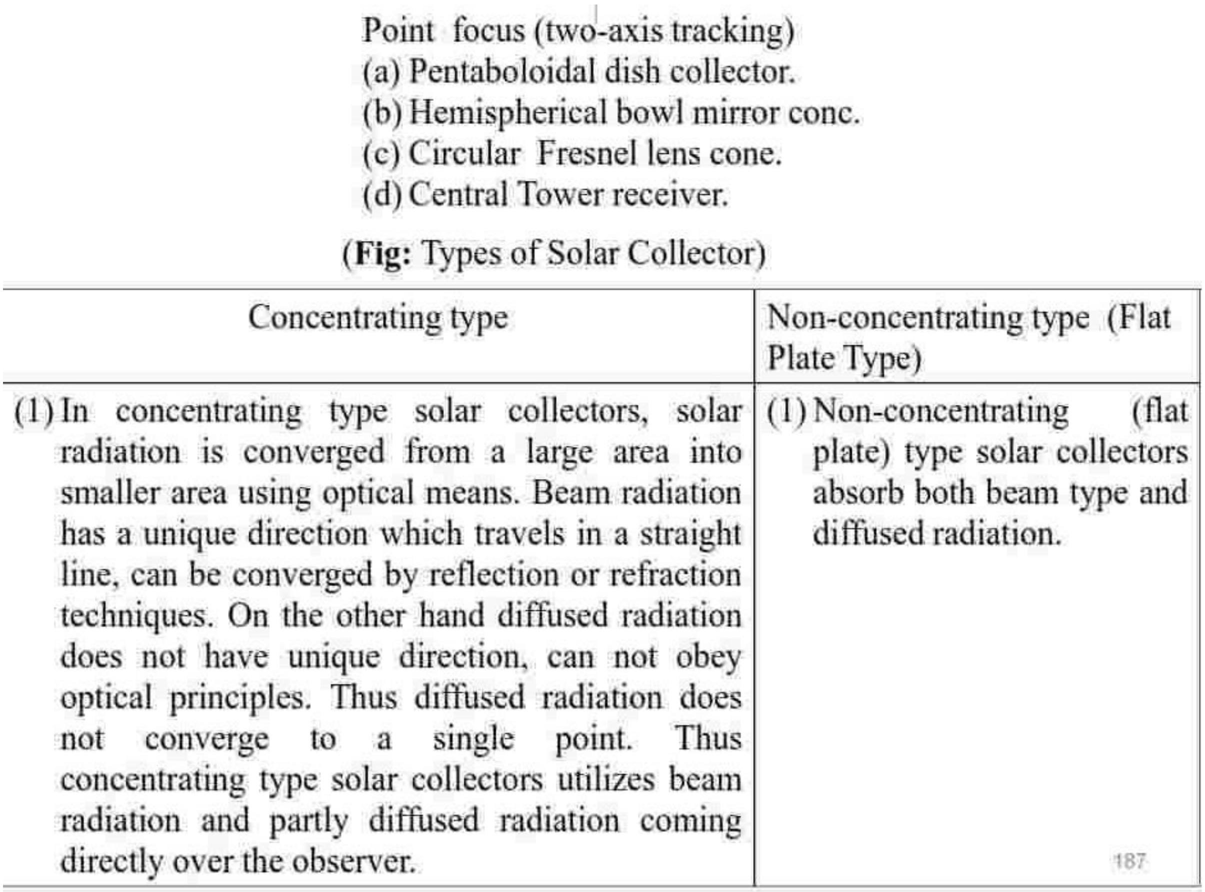
The solar constant, I_{sc}, is the energy from the sun received on a unit area perpendicular tothe solar rays at the mean distance from the sun outside the atmosphere. Based on the experimental measurements, the standard value of the solar constant is 1367 W/m^2 or 1.958 langley per minute (1 langley/min is the unit, equivalent to 1 cal/cm^2/min). In terms of other units, I_{sc} = 432 Btu/ft^2/h or 4.921 MJ/m^2/h

Solar collectors, Types and performance characteristics,

Solar Collectors:-

Solar power has low density (1kW/m^2 to 0.1kW/m^2) per unit area. Hence large amount of solar power collection needs larger area. The solar collector beingthe first unit in the solar thermal system, collects heat from solar radiation then transfers to the transport fluid efficiently. The transport fluid utilizes the heat for necessary purposes

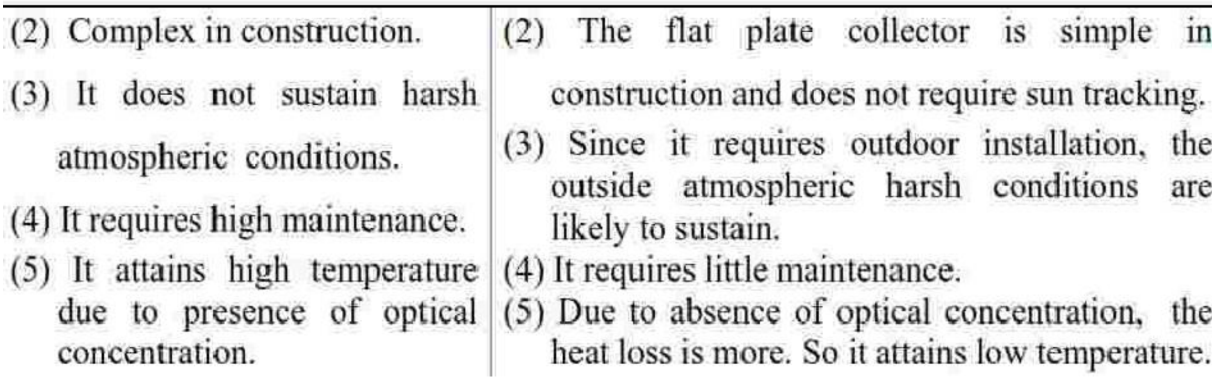




Point focus (two-axis tracking)
(a) Pentaboloidal dish collector.
(b) Hemispherical bowl mirror conc.
(c) Circular Fresnel lens cone.
(d) Central Tower receiver.

(**Fig:** Types of Solar Collector)

Concentrating type	Non-concentrating type (Flat Plate Type)
(1) In concentrating type solar collectors, solar radiation is converged from a large area into smaller area using optical means. Beam radiation has a unique direction which travels in a straight line, can be converged by reflection or refraction techniques. On the other hand diffused radiation does not have unique direction, can not obey optical principles. Thus diffused radiation does not converge to a single point. Thus concentrating type solar collectors utilizes beam radiation and partly diffused radiation coming directly over the observer.	(1) Non-concentrating (flat plate) type solar collectors absorb both beam type and diffused radiation.



(2) Complex in construction.	(2) The flat plate collector is simple in construction and does not require sun tracking.
(3) It does not sustain harsh atmospheric conditions.	(3) Since it requires outdoor installation, the outside atmospheric harsh conditions are likely to sustain.
(4) It requires high maintenance.	(4) It requires little maintenance.
(5) It attains high temperature due to presence of optical concentration.	(5) Due to absence of optical concentration, the heat loss is more. So it attains low temperature.

<u>Performance Indices</u>: The following performance indices are measured in aSolar collector.

(1)<u>*Collector efficiency*</u>:- It is defined as the ratio of the energy actually absorbed and transferred to the heat-transport fluid by the collector (useful energy) to the energy incident on the collector.

<u>*(2).Concentration ratio:*</u>- It is defined as the ratio of the area of the aperture of thesystem to the area of the receiver. The aperture of the system is the projected areaof the collector facing (normal) to the beam

(3) *Temperature range*: It is the range of temperature to which the heat

transportfluid is heated up by the collector.

There are three types of solar collectors based on the temperature ranges.

(i) Low temperature Systems(<150^0 C):

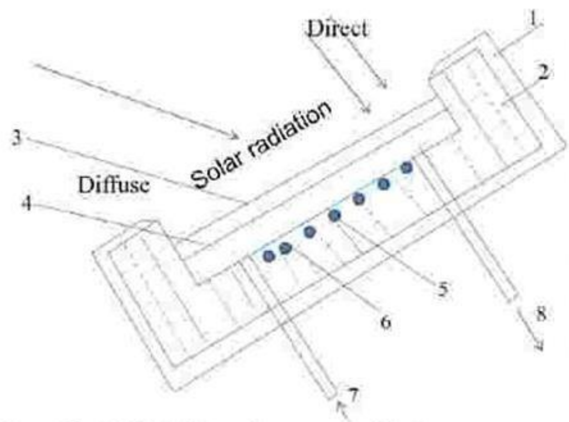
(ii) Medium-temperature Systems(150-400^{0}C):

High-temperature Systems(400-1000^{0}C)

FLAT-PLATE COLLECTORS:

- Flat-plate collectors are the most common solar collector for solar water- heating systems in homes and solar space heating. A typical flat- plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-coloured absorber plate. These collectors heat liquid or airat temperatures less than 180°F.Flat-plate collectors are used for residential water heating and hydronic space- heating installations.
- The flat-plate collector is located in a position such that its length is aligned with longitude and is suitably tilted towards south to have maximum collection.
- Liquid Flat plate collectors:-The schematics of flat plate collectors are shown in the figure (a) and (b). It consists of a black coated plate made of metal or plastic, which absorbs all the solar radiation incident on it and converts into heat. This plate is known as the absorber. Fluid channels are welded below the absorber for carrying a heat transfer fluid generally water. This transport fluid transports the heat from the absorber into the utilisation purposes.

Liquid flat plate collectors heat liquid as it flows through tubes in or adjacentto the absorber plate. The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house.



Fig(b): Schematic of a flat plate solar energy collector

1. Case
2. Insulation
3. Transparent cover (e.g. glass, tedlar etc)
4. Transparent cover (e.g. IR-reflecting glass cover
5. Absorber (black or selectively coated)
6. Fluid channel for collecting heat (air, water or any other fluid can flow through them)
7. Inlet for the heat transfer fluid
8. Outlet for the heat transfer fluid.

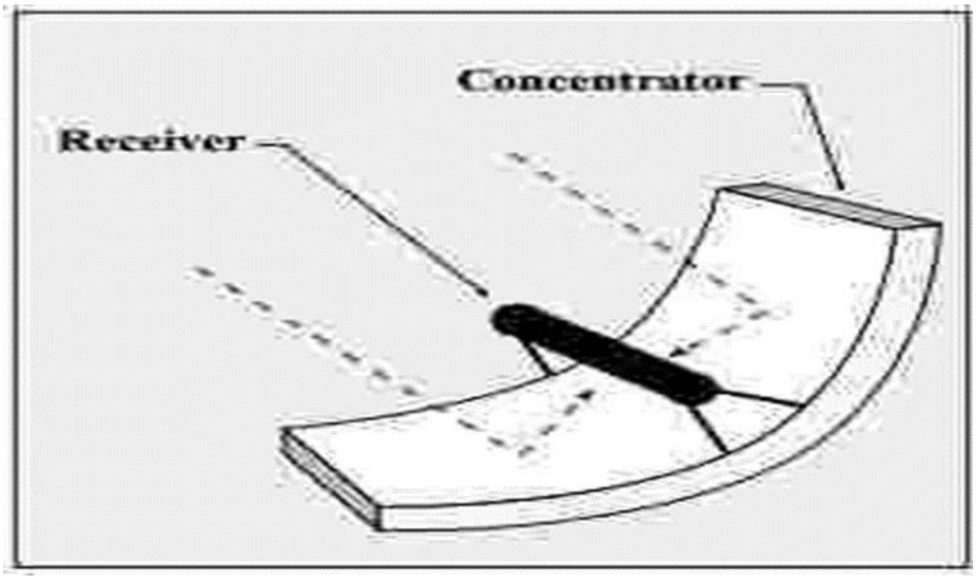
Air flat-plate collectors are used primarily for solar space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or non- metallic materials. The air flows past the absorber by using natural convection or a fan. Because air conducts heat much less readily than liquid does, less heat is transferred from an air collector's absorber than from a liquid collector's absorber, and air collectors are typically less efficient than liquid collectors.

Air heating solar collectors are mostly used for agricultural drying and space heating applications. The basic advantages are low sensitivity to leakage, less corrosion and no need for additional heat exchanger. The main disadvantage isthe requirement of larger surface area for heat transfer and higher flow rate

Concentrating collectors

- Unlike solar (photovoltaic) cells, which use light to produce electricity, concentrating solar power systems generate electricity with heat. Concentrating solar collectors use mirrors and lenses to concentrate and focus sunlight onto a thermal receiver, similar to a boiler tube. The receiverabsorbs and converts sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity.
- There are three main types of concentrating solar power systems: parabolic troughs, dish/engine systems, and central receiver systems.
- These technologies can be used to generate electricity for a variety of applications, ranging from remote power systems as small as a few kilowatts(kW) upto grid-connected applications of 200-350megawatts (MW) or more.

- A concentrating solar power system that produces 350MW of electricitydisplaces the energy equivalent of 2.3 million barrels of oil.



These solar collectors use mirrored parabolic troughs to focus the sun's energy to a fluid-carrying receiver tube located at the focal point of a parabolically curved trough reflector (see Fig.1 above). The energy from the sun sent to the tube heats oil flowing through the tube, and the heat energy is then used to generate electricityin a conventional steam generator. Many troughs placed in parallel rows are called a "collector field." The troughs in the field are all aligned along a north south axis so they can track the sun from east to west during the day, ensuring that the sun is continuously focused on the receiver pipes. Individual trough systems currently can generate about 80 MW of electricity. Trough designs can in corporate thermal storage—setting aside the heat transfer fluid in its hot phase—allowing for electricity generation several hours into the evening. Currently, all parabolic troughplants are "hybrids," meaning they use fossil fuels to supplement the solar output during periods of low solar radiation.

Each dish produces 5 to 50 kW of electricity and can be used independently or linked together to increase generating capacity.

Central Receiver Systems

Central receivers (or power towers) use thousands of individual sun-tracking mirrors called "heliostats" to reflect solar energy onto a receiver located on top of at all tower. The receiver collects the sun's heat in a heat-transfer fluid (molten salt) that flows through the receiver. The salt's heat energy is then used to make steam to generate electricity in a conventional steam generator, located at the foot of the tower. The molten salt storage system retains heat efficiently,so it can be stored for hours or even days before being used to generate electricity. Therefore, a central receiver system is composed of five main components: heliostats, receiver, heat transport and exchange, thermal storage, and controls (see Fig. 3).

Receiver and generator Concentrator individual dish/engine systems currently can generate about 25 kW of electricity.

Solar Two—a demonstration power tower located in the Mojave Desert—cangenerate about 10 MW of electricity. In this central receiver system, thousandsof sun-tracking mirrors called heliostats reflect sunlight onto the receiver. Molten salt at 554ºF (290ºC) is pumped from a cold storage tank through the receiver where it is heated to about 1,050ºF (565ºC). The heated salt then moves on to the hot storage tank. When power is needed from the plant, the hot salt is pumped to a generator that produces steam. The steam activates a turbine/generator system that creates electricity. From the steam generator, the salt is returned to the cold storage tank, where it stored is and can be eventually reheated in the receiver. By using thermal storage, power tower plants can potentially operate for 65percent of the year without the need for a back-up fuel source. Without energy storage, solar technologies like this are limited to annual capacity factors near25 percent.
The power tower's ability to operate for extended periods of time on stored solar energy separates it from other renewable energy technologies. Hot salt storage tank Steam generator 1,050˚F Cold salt storage tank Condenser cooling tower554˚FSystem boundary Substation Steam turbine and electric generator.

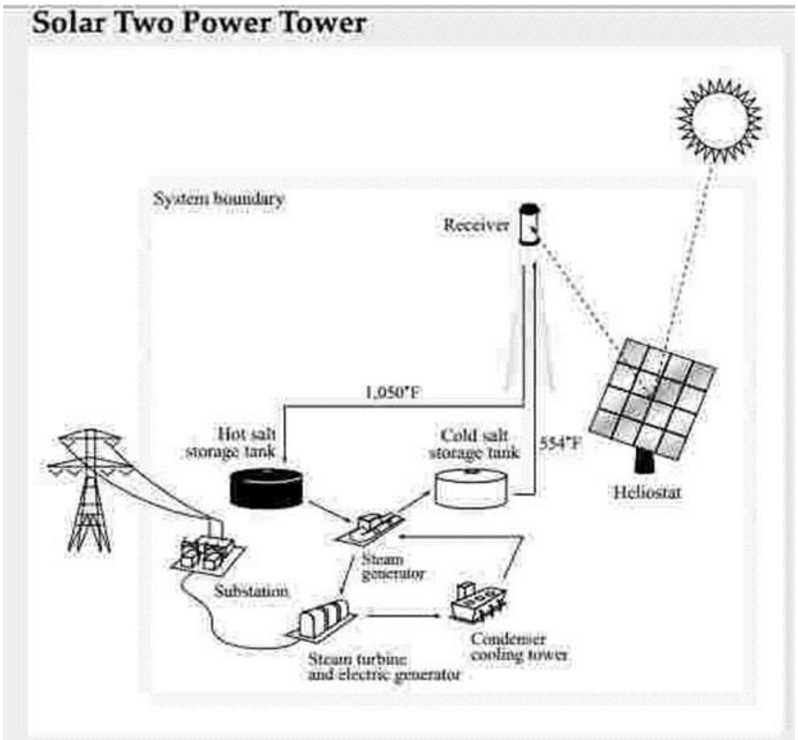


Fig. 3 Solar Two power tower system

Applications: Photovoltaic - battery charger

Batteries

As solar energy is not available continuously and steadily, some form of energy storage is normally required in most PV systems. Lead acid battery, Nickle cadmiumbattery and Lithium ion storage batteries are commonly used in PV applications for this purpose. The principles of operation of these batteries are already covered in Section 3.4.2. Some general parameters of batteries are discussed here.

(a) Battery Voltage Three types of voltage available across its terminals are specified: (a) open circuit voltage (maximum voltage); (b) nominal or working voltage (available operating voltage during use), (c) cut-off voltage (minimum voltage after which the battery should be disconnected from the load for recharging). Rechargeablebatteries are available with nominal voltages of 3 V, 6 V, 12 V, 24 V, etc.

(b) Battery Capacity It is the maximum charge storage capacity of a battery expressed in Ah. (Ampere-hour). Higher Ah requires more active material. Therefore,as the Ah capacity of a battery increases, the size of the battery also increases. Multiplying Ah with voltage gives energy storage of the battery in Wh (Watt-hours).

(c) Battery Life Cycle It is defined as the number of complete charge/discharge cycles that a battery can perform before its storage capacity falls below 80 per cent ofits rated capacity. The aging process (for instance shedding of active material from plates) results in gradual reduction in storage capacity over time. The battery can stillbe used but its available storage capacity will be lower.

(d) State of Charge (SoC) The SoC at a particular instant indicates the amount of charge available with the battery at that instant. In lead acid battery, the electrolyte'sspecific gravity provides a convenient indication of the state of charge of the battery.

(e) Depth of Discharge (DoD) This is a measure of energy withdrawn from the battery expressed as percentage of its full capacity. If a battery has a state of charge as 60 per cent, it indicates that its DoD is 40 per cent. The DoD increases as the battery is discharged more and more. Large DoD adversely affects the life cycle of the battery.

(f) Discharge Rate or C-rating C-rating is defined as the charge or discharge current given in terms of capacity of the battery divided by number of hours for full Solar Photovoltaic Systems charge or discharge. For instance a 120 Ah capacity battery with C-rating of C/10(or 0.1C), will have a charge or discharge current of 120/10 = 12 A. Similarly, a 180

Ah capacity battery with C-rating of C/20 (or 0.05C) will have a charge or discharge current of 180/20 = 9 A.

(g) Self-discharge Self-discharge is the loss of stored charge (or energy) when the battery is not in use. It is caused due to internal electrochemical processes and may beconsidered as equivalent to having a small external load. The self-discharge capacity increases with increase in temperature. Therefore, in order to reduce self-discharge, batteries must be stored at lower temperatures. In SIL batteries some antimony is alloyed with lead to improve mechanical strength. But it also results in increased self-discharge of the battery.

Deep Discharge Batteries

Ordinary batteries are not allowed to discharge beyond 50 per cent DoD. Batteries alloweddischarging up to 80 per cent or more are known as deep discharge batteries.

In traction applications where batteries are used to supply the load for longer duration,

deep discharge batteries are used. Normal SLI (starting, lighting and ignition) batteries are shallow discharge batteries. They cannot be used in such applications as battery life cycle is significantly reduced due to deep discharge. In deep discharge batteries, the electrode plates are made thicker and stronger to avoid possible wrap of plates. In case of lead acid batteries, tubular batteries are used for such applications.

SLI batteries remain at float charging most of the time. They are normally subjected to only 2–5 per cent depth of discharge during starting of a vehicle. Therefore, these

batteries use thin plates with large surface area to supply large current during starting process.

Battery Temperature During Discharge

Both battery capacity and battery voltage decrease, if used at lower temperature. At high temperature also, its capacity may decrease due to deterioration in chemical reaction. Normally, the best battery performance is obtained in temperature range of20 to 40 °C.

Battery Charging

Different methods of charging are suggested for different type of batteries. A lead acidbattery may be charged by constant current, constant voltage or a combination of the two. A typical charging cycle for a lead acid battery is shown in Fig. 6.39. The lead acidbattery is charged in three stages: (i) constant-current charge, (ii) topping charge and

(iii) float charge (or trickle charge). The battery is first charged with a constant current(specified in data sheet) until its terminal voltage reaches the float potential value,

$V_{B,\ \mathrm{float}}$ (typically 2.3 V to 2.45 V per cell). The constant current charge applies the

bulk of the charge (about 70 per cent) and takes up roughly half of the required chargetime. Thereafter the battery is charged by constant voltage $V_{B,\ \mathrm{float}}$ as the current into the battery tappers off. This phase is known as topping charge phase and continues

for few hours to fill the remaining 30 per cent. The battery is fully charged when the Non-Conventional Energy Resources current drops to a set low level. Subsequently the applied voltage across the battery is reduced so that small amount of charge keeps trickling into the battery. The float charge compensates for the loss caused by self-discharge. Lead acid battery charging is sluggish and cannot be charged as quickly as other battery systems.

current drops to a set low level. Subsequently the applied voltage across the battery is reduced so that small amount of charge keeps trickling into the battery. The float charge compensates for the loss caused by self-discharge. Lead acid battery charging is sluggish and cannot be charged as quickly as other battery systems.

SOLAR PV APPLICATIONS

Batteries used in PV Applications

The most commonly used batteries in PV applications are the lead acid and nickel cadmium batteries. Lithium-ion and nickel-metal hydride are also used, but to a much lesser extent. Leadacid batteries are most popular. These batteries perform well in deep discharging mode than any other battery.

Grid Interactive PV Power Generation

The first large sized (1 MW $_p$) grid interactive PV plant was installed in Lugo, in California, USA. The second and largest (6.5 MW$_p$) plant was installed in Carissa Plains, California, USA. Also some other large sized plants are operating in various countries and many others are proposed in Italy, Switzerland, Germany, Austria ,Spain and Japan. Presently, the biggest solar PV plant of

579 MW capacity, solar star project, is located at Antelope valley, Los Angeles County, California. This is followed by a 550 MW Desert Sunlight Star at Riverside County, and 550 MW Topaz Solar farm at San Louis, Obispo County, California.

In India, a 221 MW solar PV plant at Chankara, Gujarat is the biggest plant.Another 750 MW plant is underway at Rewa, MP.

A large number of small rooftop grid interactive systems are successfully being operated invarious parts of the world

Water Pumping

Pumping of water for the purpose of drinking or for minor irrigation, during sunshinehours, is very successful application of stand-alone PV system without storage. Water

pumping appears to be most suited for Solar PV applications as water demand increases during dry days when plenty of sunshine is available. There would be less need of water during rainy season when the availability of solar energy is also low.

SPV water pumping systems have been successfully used in many parts of the world in the range of few hundred W$_p$ to 5 kW.

An SPV water pumping system is expected to deliver a minimum of 15,000 liters per day for 200 W$_p$ panel and 1, 70,000 liters per day for 2,250 W$_p$ panel from suction of 7 meters and / or a total head of 10 meters

on a clear sunny day. Three types of motors have generally been used: (i) permanent magnet dc motor (in low capacity pumping systems), (ii) brush-less dc motors and

(iii) variable voltage and variable frequency ac motors, with appropriate electronic control and conversion system

Lighting

Next to water pumping, lighting is the second most important and extensive application ofstand-alone solar PV system.

As lighting is required when sun is not available battery storage is essential. Energy efficient compact fluorescent lamps (CFL) or low-pressure sodium vapour lamps(LPSVL) are used at 25– 35 kHz frequencies, as SPV is an expensive power source. Pole mounted out-door lighting, shown in Fig. 6.54, is designed for 3–6 hours an evening. A typical system has two 35 W modules connected in parallel, an 11W (900 lumens) CFL, a 90 or 120 Ah, 12 V storage battery and associated electronics including inverter, battery charger and timer to switch on and off thelight. The approximate cost of one pole mounted streetlight is Rs 30,000..

Village Power

Solar PV power can be used to meet low energy demands of many remote, small, isolated and generally unapproachable villages in most developing countries. Twoapproaches have generally been used:

(i) Individual SPV system for every household
(ii) A centralized SPV plant to meet combined load demand of the wholevillage.

SOLAR PONDS

The concept of solar pond was derived from the natural lakes where the temperature rises (of the order of 45°C) towards the bottom. It happens due to natural salt gradient in these lakes where water at the bottom is denser. In salt concentration lakes, convection does not occur and heat loss from hot water takes place only by conduction.

This technique is utilised for collecting and storing solar energy. An artificially designed pond filled with salty water maintaining a definite concentration gradient is called a 'Solar Pond'.. The top layers remain at ambient temperature while the bottom layer attains a maximum steady-state temperature of about 60°C – 85°C

For extracting heat energy from the pond, hot water is taken out continuously from the bottom and returned after passing through a heat exchanger. Alternatively, heat is extracted by water flowing through a submerged heat exchanger coil. As a result of continuous movement and mixing of salty water at the top and bottom, the solar pond can have three zones.

(i) Surface Convective Zone (SCZ) having a thickness of about 10 cm– 20 cm with a low uniform concentration at nearly the ambient air temperature.

(ii) Non-Convective Zone (NCZ) occupying more than half the depth of the pond. It serves as an insulting layer from heat losses in the upward direction.

(iii) Lower Convective Zone (LCZ) having thickness nearly equal to NCZ. This zone is characterized by constant temperature and concentration. It operates as the major heat- collector and also as the thermal storage medium.

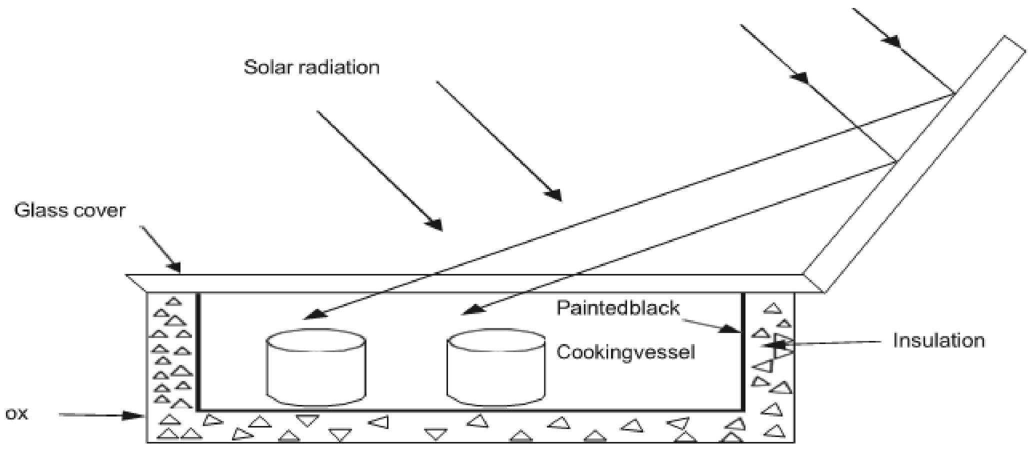
(iv) The largest solar pond so far built is the 250,000 m^2 pond at Bet Ha Arava in Israel. Based on the Rankine cycle principle, this pond is used to generate 5 MWe of electrical power with an organic fluid.

(v) In India, the first solar pond with an area of 1200 m^2 was built at the Central Salt Research Institute, Bhavnagar in 1973. Since then several solar ponds have been built and are in operation.The latest pond with an area of 6000 m^2, built at Bhuj (Gujarat) is the second largest in theworld. It provides daily 90,000 litres of hot water at 80°C as process heat for can-sterilization. This pond maintains a stable salinity gradient with a maximum temperature of 99°C due to high radiation intensity and low thermal losses. The pond stores sufficient heat capable of generating 150 kW of power.

SOLAR COOKERS

Box Solar Cooker

. It consists of an outer box made of either fibre glass or aluminium sheet, a blackened aluminium tray, a double glass lid, a reflector, insulation and cooking pots as detailed in Figure.



blackened aluminium tray is fixed inside the box, and sides are covered with an insulating material to prevent heat loss. A reflecting mirror provided on the box cover increases the solar energy input. Metallic cooking pots are painted black on the outer side. Food to be cooked is placed in cooking pots and the cooker is kept facing the sun to cook the food. An electric heater may also be installed to serve as a back-up during non-sunshine hours.

Dish Solar Cooker

A dish solar cooker uses a parabolic dish to concentrate the incident solar radiation. A typical dish solar cooker has an aperture of diameter 1.4 m with focal length of 0.8 m. The reflecting material is an anodized aluminium sheet having reflectivity of over 80%. The cooker needs to track the sun to deliver power of about 0.6 kW. The temperature at the bottom of the vessel may reach up to 400°C which is sufficient for roasting, frying and boiling. It can meet the requirementof cooking for 15 people.

Community Solar Cooker for Indoor Cooking

Like the dish solar cooker, the community solar cooker is a parabolic reflector cooker. It has a large reflector ranging from 7 m^2 to 12 m^2 of aperture area. The reflector is placed outside the kitchen so as to reflect solar rays into the kitchen. A secondary reflector further concentrates the rays on to the bottom of the cooking pot painted black. Temperature can reach up to 400°C and food can be cooked quickly for 50 persons.

Wind Energy

Introduction to Wind energy

Wind power or **wind energy** is the use of wind to provide mechanical power through wind turbines to turn electric generators and traditionally to do other work, like milling or pumping.

- Wind power is a sustainable, renewable energy source that has a much smaller impact on the environment compared to burning fossil fuels.
- Wind turbines convert the kinetic energy in the wind into mechanical power.

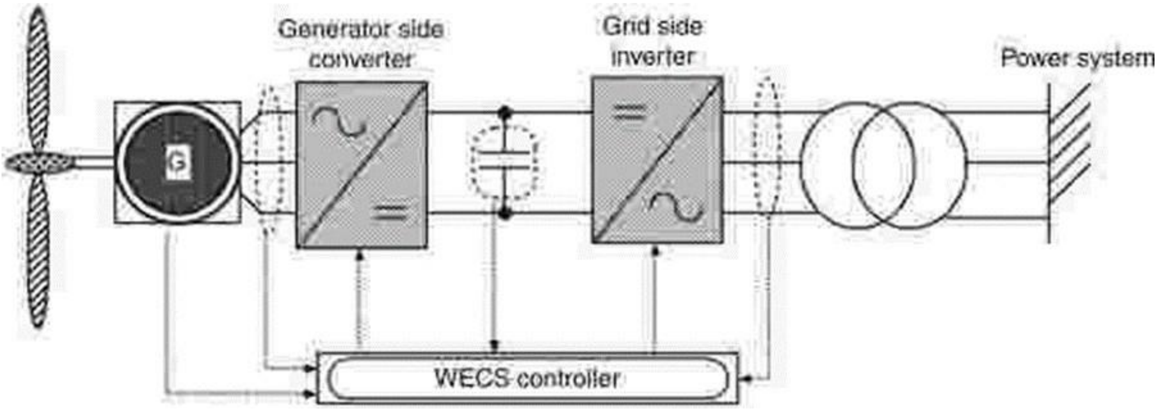
Wind turbines convert the energy in wind to electricity by rotating propeller- like blades around a rotor. The rotor turns the drive shaft, which turns an electric generator. Three key factors affect the amount of energy aturbine can harness from the wind: wind speed, air density, and swept area.

Equation for Wind Power

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

V=Wind speed, $\rho =$ Density of the air, A=Swept area of the turbine

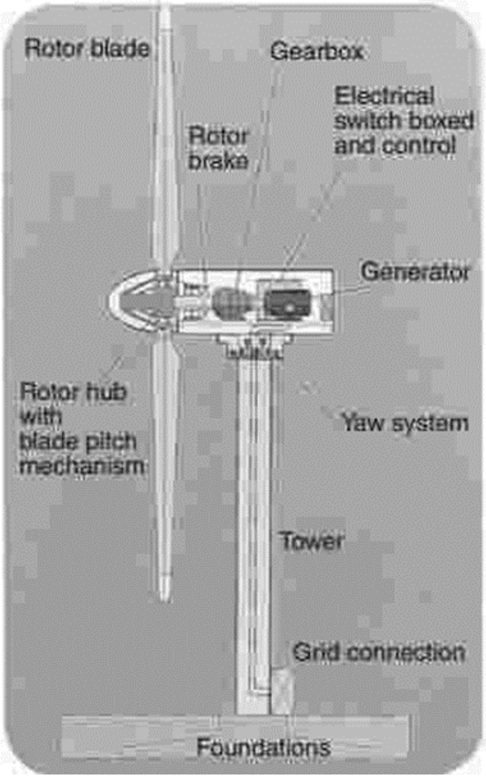
A wind energy conversion system (WECS) is powered by wind energy and generates mechanical energy that sends energy to the electrical generator for making electricity. Fig. 1.3 shows the interconnection of a WECS. The generator ofthe wind turbine can be a permanent magnet synchronous generator (PMSG), doubly fed induction generator, induction generator, synchronous generator, etc.Wind energy acquired from the wind turbine is sent to the generator. To achieve maximum power from the WECS, the rotational speed of the generator is controlled by a pulse width modulation converter. The output power of the generator is supplied to the grid through a generator-side converter and a grid- side inverter. A wind farm can be distributed in onshore, offshore, seashore, or hilly areas. The WECS might be the most promising DG for future SG.



Wind energy is an alternative to fossil fuels, it is plentiful, renewable, widely distributed, clean, low cost, produces no emissions during operation, and uses a tiny land area . The effects on the environment are generally less problematicthan those from other conventional power sources. Due to the variable wind speed, the output power of the WECS fluctuates and may create a frequency deviation of the power grid. To solve this problem, much research has already been conducted.

The world wind energy association (WWEA) published the key statistics of theWorld Wind Energy Report 2013.

The world wind energy capacity reached 318.5 GW by end of 2013 (this was 282.2 GW in 2012). In total, 103 countries are today using wind power on commercial basis. China was still by far the leading wind market with a new capacity of 16 GW and a total capacity of 91.3 GW. Wind power contributes closeto 4% of the global electricity demand. For the year 2020, the WWEA predicts a wind capacity of more than 700 GW



Horizontal-axis wind turbine showing major components.

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

$$\text{specific power of the site} = \frac{1}{2}\rho V^3$$

This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed. The blades cannot extract all of the upstream wind power, as some power is left in the downstreamair that continues to move with reduced speed.

Wind energy conversion

Generator:

The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic fieldto produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine'sblades because more energy is captured by longer blades.

It is important to select the right type of generator to match intended use. Mosthome and office appliances operate on 240 volt, 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC. Storage systems using batteries storeDC and usually are configured at voltages of between 12 volts and 120 volts

Generators that produce AC are generally equipped with features to produce theCorrect voltage of 240 V and constant frequency 50 cycles of electricity, even when the Wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC

Transmission:

The number of revolutions per minute (rpm) of a wind turbine rotor can rangebetween 40 rpm and 400 rpm, depending on the model and the wind speed.Generators typically require rpm's of 1,200 to 1,800. As a result, most windturbines require a gear-box transmission to increase the rotation of the generatorto the speeds necessary for efficient electricity production. Some DC- type windturbines do not use transmissions. Instead, they have a direct link between therotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements arereduced, but a much larger generator is required to deliver the same poweroutput as the AC-type wind turbines.

Tower:

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what heighttower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect. These towers cost less than freestanding towers, but require more land area to anchor the guy wires.
Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to thetower top. This simplifies not only installation, but maintenance as well. Towers can be constructed of a simple tube, a wooden pole or a lattice of tubes, rods, andangle iron. Large wind turbines may be mounted on lattice towers, tube towers orguyed tilt-up towers.

Towers must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of thewind turbine.
Their costs will vary widely as a function of design and height.

Types 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 rotoraxis 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 orto generate electric power. Wind turbines are further classified into ‘lift’ and ‘drag’ type

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 blades

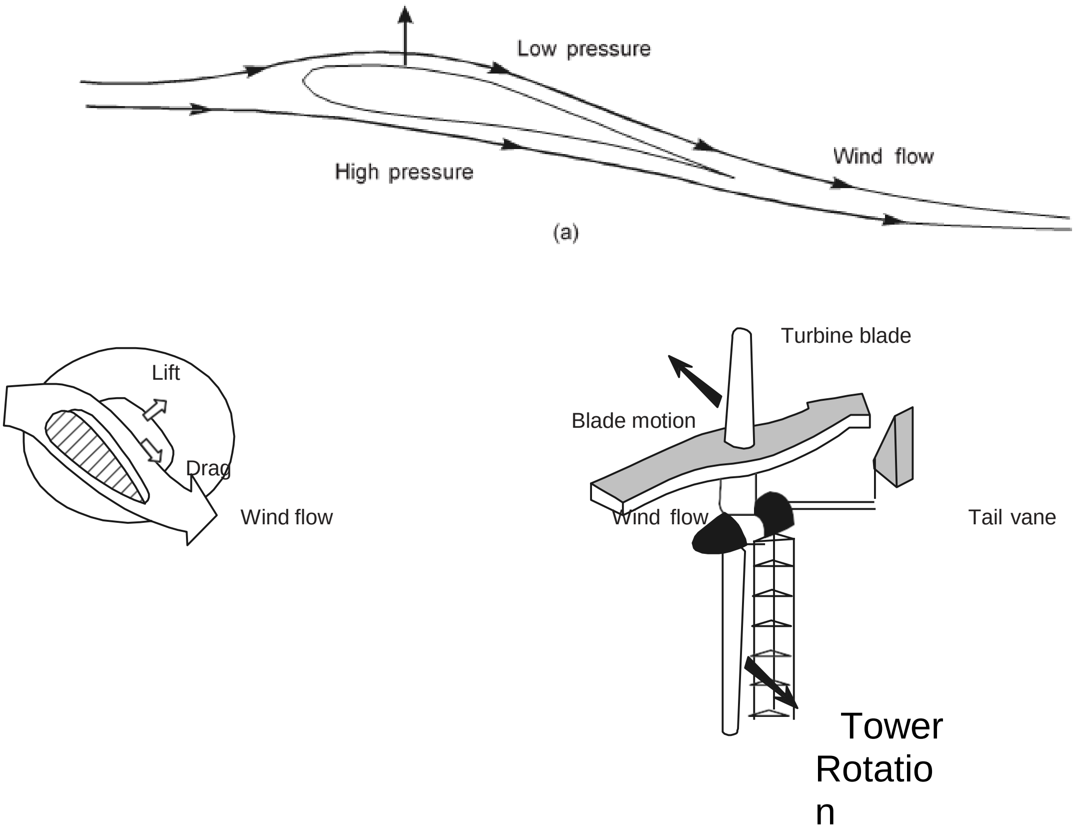
Slow-speed turbines are mainly driven by the drag forces acting on the rotor. The torque at the rotor shaft is comparatively high which is of prime importance for mechanical applications such as water pumps. For slower turbines, a greater blade area is required, so the fabrication of blades is undertaken 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.

Aerodynamics of wind rotors.

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 rotorblade, 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 intorotational motion. In addition to the lift force, a drag force perpendicular to the lift force alsoacts on the blade which impedes rotor rotation. The prime objective in wind turbine design isthe 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.



(a) Aerodynamic lift force on blade cross-section of wind turbine, and (b) the basicoperating 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, thelift 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.

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 outerspace burns due to friction with the earth’s atmosphere, saving the inhabitants on earth from catastrophic impact.

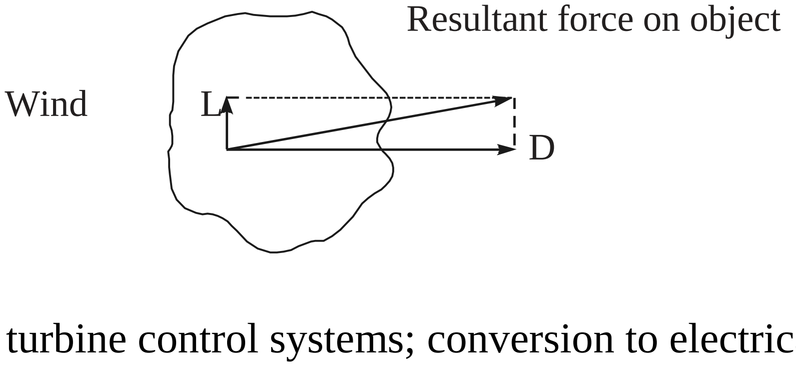
Friction acts to help us as a ‘life saver’ in brakes of automobiles. Similarly, the drag forceis useful in safe landing with a parachute.

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). It creates a pressure difference that generates an upward force which tends to lift the

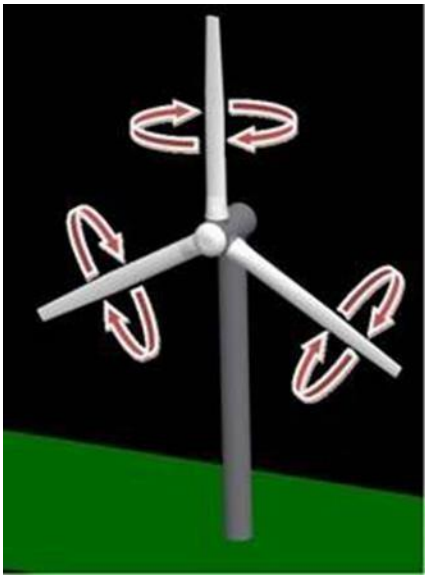
airfoil causing rotation of the wind turbine rotor. Good airfoils can have lift 30 times greater than drag.

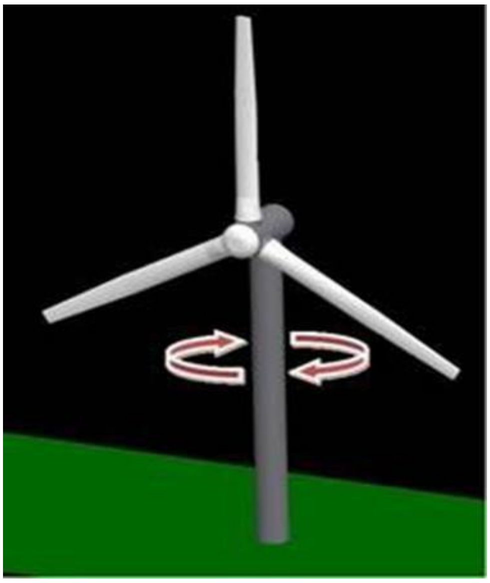


Wind turbine control systems; conversion to electrical power:

We can use different control methods to either optimize or limit power output. You can

control a turbine by controlling the generator speed, blade angle adjustment, and rotation of the entire wind turbine. Blade angle adjustment and turbine rotation are also known as pitch and yaw control, respectively. A visual representation of pitch and yaw adjustment is shown in Figures .





The purpose of pitch control is to maintain the optimum blade angle to achieve certain rotor speeds or power output. You can use pitch adjustment to stall and furl, two methods of pitch control. By stalling a wind turbine, you increase the angle of attack, which causes the flat side of the blade to face further into the wind. Furling decreases the angle of attack, causing the edge of the blade to face the oncoming wind. Pitch angle adjustment is the most effective way to limit output power by changing aerodynamic force on the blade at high wind speeds.

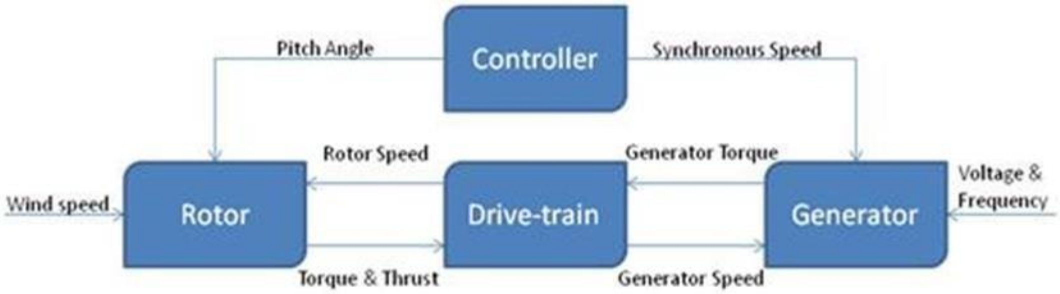
Yaw refers to the rotation of the entire wind turbine in the horizontal axis. Yaw control ensures that the turbine is constantly facing into the wind to maximize the effective rotor area and, as a result, power. Because wind direction can vary quickly, the turbine may misalign with the oncoming wind and cause power output losses. we can approximate these losses with the following equation.

EQ 6: $\Delta P=\alpha \cos(\varepsilon)$ Where ΔP is the lost power and ε is the yaw error angle

The final type of control deals with the electrical subsystem. You can achieve this dynamic control with power electronics, or, more specifically, electronic converters that are coupled to the generator. The two types of generator control are stator and rotor. The stator and rotor are the stationary and nonstationary parts of a generator,

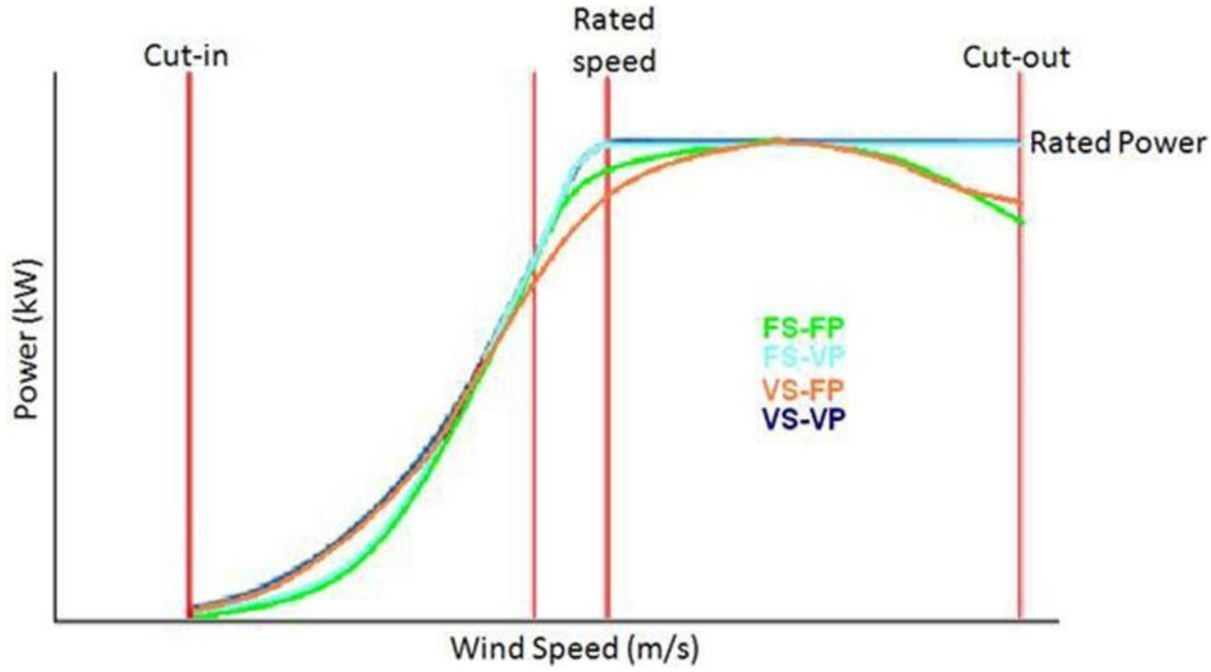
respectively. In each case, you disconnect the stator or rotor from the grid to change the synchronous speed of the generator independently of the voltage or frequency of the grid. Controlling the synchronous generator speed is the most effective way to optimize maximum power output at low wind speeds.

Figure 7 shows a system-level layout of a wind energy conversion system and the signals used. Notice that control is most effective by adjusting pitch angle and controlling the synchronous speed of the generator.



Control Strategies

Recall that controlling the pitch of the blade and speed of the generator are the most effective methods to adjust output power. The following control strategies use pitch and generator speed control to manage turbine functionality throughout the power curve: fixed-speed fixed-pitch, fixed-speed variable-pitch, variable-speed fixed-pitch, and variable-speed variable-pitch. Figure 8 shows the power curves for different control strategies explained below, with variable-speed variable-pitch, VS-VP, being the ideal curve.



Fixed-speed fixed-pitch (FS-FP) is the one configuration where it is impossible to improve performance with active control. In this design, the turbine's generator is directly coupled to the power grid, causing the generator speed to lock to the power line frequency and fix the rotational speed. These turbines are regulated using passive stall methods at high wind speeds. The gearbox ratio selection becomes important for this passive control because it ensures that the rated power is not exceeded. Figure shows the power curve for FS-FP operation.

From the figure, it is apparent that the actual power does not match the ideal power, implying that there is lower energy capture. Notice that the turbine operates at maximum efficiency only at one wind speed in the low-speed region. The rated power of the turbine is achieved only at one wind speed as well. This implies poor power regulation as a result of constrained operations.

Fixed-speed variable-pitch (FS-VP) configuration operates at a fixed pitch angle below the rated wind speed and continuously adjusts the angle above the rated wind speed. To clarify, fixed-speed operation implies a maximum output power at one wind speed. You can use both feather and stall pitch control methods in this configuration to limit power. Keep in mind that feathering takes a significant amount of control design and stalling increases unwanted thrust force as stall increases. Figure 8 shows the power curve for FS-VP using either feather or stall control.

Below the rated wind speed, the FS-VP turbine has a near optimum efficiency around Region II. Exceeding the rated wind speed, the pitch angles are continuously changed, providing little to no loss in power

Variable-speed fixed-pitch **(VS-FP) configuration continuously adjusts the rotor speed relative to the wind speed through power electronics controlling the synchronous speed of the generator. This type of control assumes that the generator is from the grid so that the generator's rotor and drive-train are free to rotate independently of grid frequency. Fixed-pitch relies heavily on the blade design to limit power through passive stalling. Figure 8 shows the power curve for VS-FP.**

Figure 8 shows that power efficiency is maximized at low wind speeds, and you can achieve rated turbine power only at one wind speed. Passive stall regulation plays a major role in not achieving the rated power and can be attributed to poor power regulation above the rated wind speed. In lower wind speed cases, VS-FP can capture more energy and improve power quality.

Variable-speed variable-pitch **(VS-VP) configuration is a derivation of VS-FP and FS-VP. Operating below the rated wind speed, variable speed and fixed pitch are used to maximize energy capture and increase power quality. Operating above the rated wind speed, fixed speed and variable pitch permit efficient power regulation at the rated power. VS-VP is the only control strategy that theoretically achieves the ideal power curve.**

Induction and synchronous generators.

Induction Generator as a Wind Power Generator

Rotating electrical machines are commonly used in wind energy systems and most of these electrical machines can function as either a motor or a generator, depending upon its particular application. But as well as the *Synchronous Generator* we looked at in the previous tutorial, there is also another more popular type of 3-phase rotational machine that we can use as a wind turbine generator called an **Induction Generator**.

Both the synchronous generator and the *Induction Generator* have similar fixed stator winding arrangement which, when energised by a rotating magnetic field, produces a three-phase (or single phase) voltage output.

However, the rotors of the two machines are quite different with the rotor of an induction generator typically consisting of one of two types of arrangement: a “squirrel cage”, or a “wound rotor”.

Induction Generator construction is based on the very common squirrel-cage induction motor type machine as they are cheap, reliable, and readily available in a wide range of electrical sizes from fractional horse power machines to multi-megawatt capacities making them ideal for use in both domestic and commercial renewable energy wind power applications.

Also, unlike the previous synchronous generator which has to be “synchronised” with the electrical grid before it can generate power, the induction generator can be connected directly to the utility grid and driven by the turbines rotor blades at variable wind speeds once it is brought on line from stand still.

For economy and reliability many wind power turbines use induction motors as generator which are driven through a mechanical gearbox to increase their speed of rotation, performance and efficiency. However, induction generators require reactive power usually provided by shunt capacitors in the individual wind turbines.

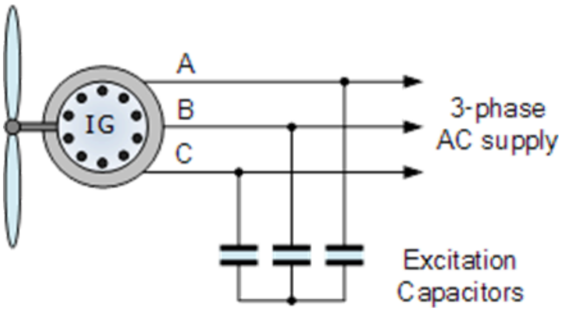
Induction machines are also known as **Asynchronous Machines**, that is they rotate below synchronous speed when used as a motor, and above synchronous speed when used as a generator. So when rotated faster than its normal operating or no-load speed, an induction generator produces AC electricity. Because an induction generator synchronises directly with the main utility grid – that is, produces electricity at the same frequency and voltage – no rectifiers or inverters are required.

However, the induction generator may provide the necessary power directly to the mains utility grid, but it also needs reactive power to its supply which is provided by the utility grid. Stand alone (off-grid) operation of the induction generator is also possible but the disadvantage here is that the generator requires additional capacitors connected to its windings for self-excitation.

Capacitor Start Induction Generator

The excitation capacitors are standard motor-starting capacitors that are used to provide the required reactive power for excitation which would otherwise be supplied by the utility grid. The induction generator will self-excite using these external capacitors only if the rotor has sufficient residual magnetism.

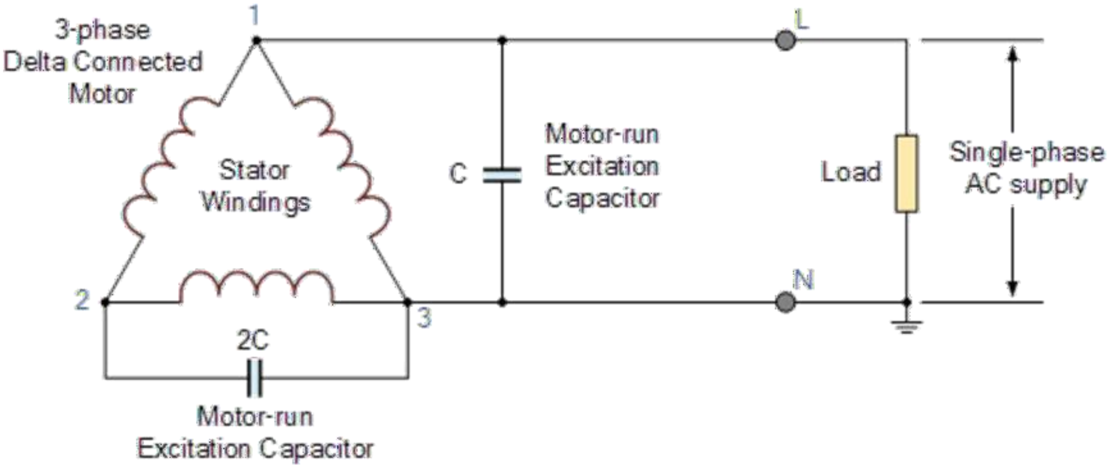
In the self-excited mode, the generator output frequency and voltage are affected by the rotational speed, the turbine load, and the capacitance value in farads of the capacitors. Then in order for self-excitation of the generator to occur, there needs to be a minimum rotational speed for the value of capacitance used across the stator windings.



The “Self-excited induction generator”, (SEIG) is a good candidate for wind powered electric generation applications especially in variable wind speed and remote areas, because they do not need external power supply to produce the magnetic field. A three-phase induction generator can be converted into a variable speed single-phase induction generator by connecting two excitation capacitors across the three-phase

windings. One of value C amount of capacitance on one phase and the other of value 2C amount of capacitance across the other phase as shown.

Single-phase Output from a 3-phase Induction Generator



By doing this the generator will run more smoothly operating nearer to unity (100%) power factor (PF). In the single-phase operation, it is possible to obtain near three phase efficiency producing approximately 80% of the machines maximum rating. However, care must be taken when converting a 3-phase supply into a single-phase supply as the single phase line-to-line voltage output will be twice that of the rated winding.

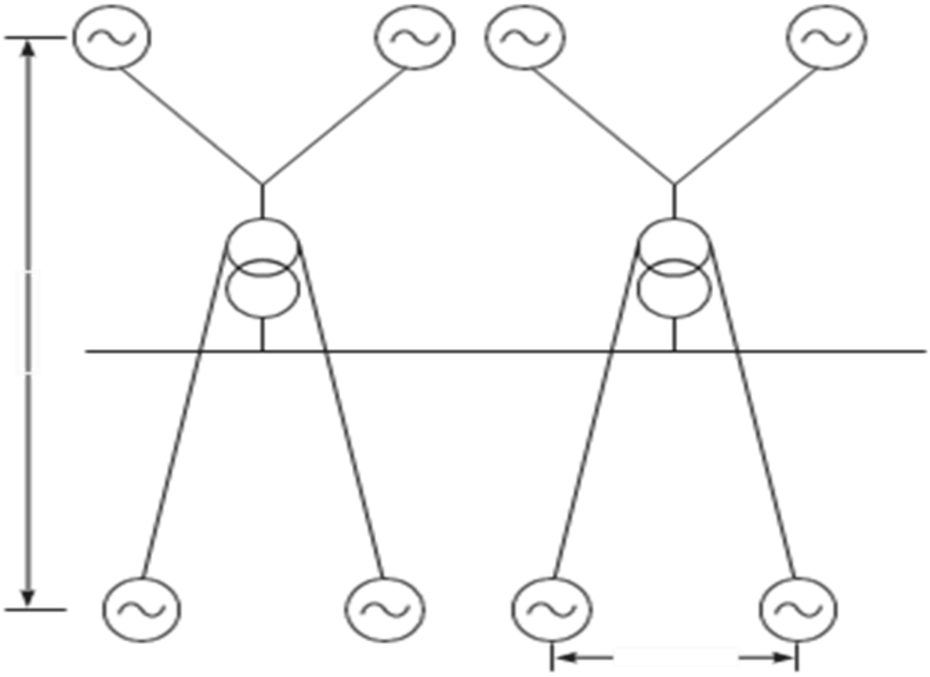
Induction generators work well with single-phase or three-phase systems that are interconnected to the utility or as a self-excited stand alone generator for small scale wind power applications allowing for variable speed operation. However, induction generators require reactive excitation to operate at full power thus they are ideally suited for interconnection to the utility grid as part of an grid-tied wind power system.

Synchronous Generator:-

These generators are equipped with a fixed stator at the outside and a rotor at the inside located on a pivoting shaft. Normally DC is supplied to the rotor to create a magnetic field. When the shaft drives the voltage is created in the stator whose frequency matches exactly the rotational speed of the rotor. This type of generators are used most of the places but the disadvantage is that it runs with constant speed of the rotor and fixed frequency. It is therefore not suitable for variable speed operations in the wind plants.

Grid connected and self excited induction generator operation.

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



Generated power of wind farm, collected at 11 kV or 33 kV, is then further stepped up tothe appropriate class of voltage while integrating with the state power grid,

It is assumed that the 66 kV grid/substation is located 20 km away from the wind farmwhich 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.

Constant voltage and constant frequency generation with power electronic control.

Voltage Regulation

Voltage variation at the common coupling point should be within 15% when the wind farm is connected or disconnected. Difficulty in controlling voltage regulation is accentuated when the wind farm is located in a remote area and connected to the grid through the existing transmissionlines designed to serve only the load in the area. Solutions to voltage regulation are: alternative line arrangement and addition of static or adaptive VAR controllers

Frequency Control

Utilities operating wind power plants connected to a weak, isolated grid, can have difficulty in maintaining the normal system frequency of 50 Hz. The system frequency shows fluctuations.

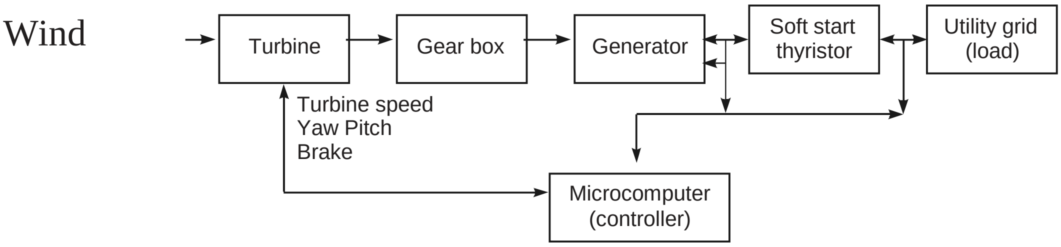
when gusting winds cause the power output of wind plants to change rapidly. Low frequency operation affects the output of WEGs in two ways:

- Several WEGs do not get cut in when the frequency is less than 48 Hz, thus resultingin loss of output.

The output of WEGs at low frequency operation is reduced due to low speed of the rotor

MICROPROCESSOR-BASED CONTROL SYSTEM FORWIND FARMS

Large wind farms need a fast and an accurate control system to obtain optimum output. A microprocessor-based control system, as shown in Figure , is used with the grid-connected wind farms. It is equipped with remote control and automatic call facility. The controller can communicate with the wind farm through a PC and a modem on a telephone line. The control system is equipped to change settings and adjust parameters for optimal output.



The microcomputer receives the input of wind speed and direction along with load requirement of voltage and frequency. It sends signals to the turbine to establish proper yaw (direction control), blade pitch and to activate the brakes in high winds. The microcomputer mayturn on optimal loads in strong winds and can also adjust the power conditioner to change the load voltage and frequency.

Single and double output systems.

Within the scope of a single turbine, like many other power plants, a wind turbine is modeled with its individual major components included. Thus, different turbine types have to be modeled differently. Similarly, the control block diagram and control algorithm are modified as the new edition is manufactured. A typical module consists of the following blocks: • Aerodynamic • Pitch mechanism • Wind input • Shaft dynamic • Relay protections • Generator and power electronics • Control algorithm. The components that govern the behavior of a wind turbine are represented above. These components are normally built in modules to allow sharing of modules for different turbines with minimum modifications. Aerodynamic characterizes the aerodynamic behavior of a wind turbine. In this module, information about the turbine blade, the air density, the performance coefficient curve, and tip speed ratio are given as input or calculated in the module to compute the aerodynamic power at any wind speed. The pitch mechanism is included for a pitch-able turbine to represent the pitching activities when the wind turbine operates in the power regulation or speed regulation. The wind input is accessible through external file. Ideally, it is available in a time series with varying wind speed versus time. This time domain input wind speed can be useful to examine the power and voltage fluctuations due wind turbulence or wind gusts. The shaft dynamic is available to simulate a single inertia or two inertias with stiffness and damping specified. The shaft dynamic model can tell us about the mechanical damping during disturbance. The relay protection aspects of the wind turbine should reflect the capability of the wind turbine as well as the local regulations. If the local regulation requires that the turbine should always be connected to the grid under a certain voltage profile (low voltage ride through, LVRT), we need to test the turbine for this capability. The characteristics of the relay should be programmed based on the wind turbine manufacturers standard.

Within the scope of wind farm, the behavior of the wind farm embodies the collective behavior of all the turbines within the wind farm. To represent a more realistic model of the wind farms, the diversity in the wind farms and aggregate impact are included in the models. Typical aspects of diversity in a wind farm include the following: • Spatial distribution • Line impedance • Different settings of relay protections • Different types of wind turbines • Different settings and control set-points • Different control strategies • Different types of reactive power compensation. Although this list could be extended, if most of the listed items are taken into account, the modeled wind farm should be acceptably realistic. The spatial distribution has an impact on the total output of the wind farm because the modern large wind farm is normally spread across a very large area. The wind speeds driving each individual turbine will not be identical. Thus, the response of individual turbines will be different at any instant of time. In addition, because the wind turbines are geographically dispersed, the line impedance of the feeders and the voltage drops across the feeders will not be the same at each turbine. The impact of voltage drop differences among the turbines leads to the difference in voltage at the terminals of each turbine. Voltage relay protection is based on terminal voltage to protect the wind turbine generator against over voltage or under voltage. Thus, the difference in terminal voltage may result in different set-off times. This fact is a positive contribution. For example, if a wind farm is connected to a weak grid, and the reactive power compensation is not properly designed or controlled, only a portion of the turbines will be disconnected from the grid during a fault event. Thus, the wind farm does not lose 100% of the generation and it is still contributing to the power grid. In a very large area or even on the same wind farm, there may be several types of wind turbines installed (for example, in the Tehachapi, California, and McCamey, Texas, areas there are many wind farms connected to the same power grid located within the same area). The differences can be in the year of make, the model, the size, or the manufacturer. Different types of turbines are normally built differently, and therefore, the control mechanisms or control algorithms are different. Because the controllers mostly consist of microprocessors or microcontrollers, two identical turbines, can be easily set to operate differently (for example, two identical turbines located within proximity can be set to start at slightly different cut in wind speeds or have different time delays to avoid start-up at the same time). Similarly, two identical wind turbines can be operated at different control algorithms. This difference signifies the signature of different turbines or different wind farms. The reactive power compensation can be implemented at the turbine level to compensate an individual turbine. Most of the turbines are manufactured this way. Some wind farm operators add additional reactive compensation at the point of interconnection (POI) to improve the power quality of the interface at the POI.

Characteristics of wind power plant.

All wind machines share certain operating characteristics, such as cut-in, ratedand cutout wind speeds.

Cut-in Speed:

Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

Rated Speed

The rated speed is the minimum wind speed at which the wind turbine willgenerate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed.

Most manufacturers provide graphs, called "power curves, "showing how their wind turbine output varies with wind speed.

Cut-out Speed

At very high wind speeds, typically between 72 and 128 kmph, most wind turbinescease power generation and shut down. The wind speed at which shut down occurs is called the cut out speed. Having a cut-out speed is a safety feature whichprotects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind.

Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm's, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream. Normalwind turbine operation usually resumes when the wind drops back to a safe level

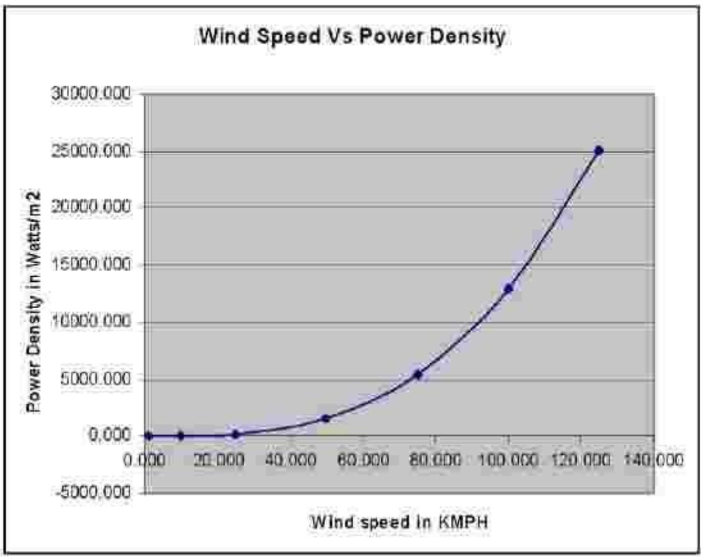
Betz Limit:

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. Thetheoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately

59%. This value is known as the Betz limit. If the blades were 100%efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as highas 59% . A more typical efficiency is 35% to 45%.

A complete wind energy system, including rotor, transmission, generator, storage and other devices, which all have less than perfect efficiencies, will deliver between 10% and 30% of the original energy available in the wind.

The following plot gives the relationship between wind speed in KMPH and thepower density



In the last column of the table, we have calculated the output of the turbine assuming that the efficiency of the turbine is 30%. However, we need to remember that the efficiency of the turbine is a function of wind speed. *It varies with wind speed*.

Now, let us try to calculate the wind speed required to generate power equivalentto 1square meter PV panel with 12% efficiency. We know that solar insolation available at the PV panel is 1000 watts/m^{2}at standard condition. Hence the output of the PV panel with 12% efficiency would be 120 watts. Now the speed required to generate this power by the turbine with 30% efficiency can be calculated as follows:
Turbine output required = 120 Watts/m^2

Power Density at the blades = 120/ (0.3) = 400 watts/m^2

Origin of Wind:

The flow of air starts when there is pressure difference between two places. The region where solar radiation is less the atmospheric air gets low temperature and hence low pressure region. On the contrary where the solar radiation is high the atmospheric air gets heated and pressure is high. These differences in atmospheric air pressure (*pressure gradient*) cause acceleration of the air particles which is called wind.
The rotation of earth about its own axis creates Coriolis force which superimposeson the pressure gradient. The direction of wind motion is affected by this*Coriolis force*. In the Northern hemisphere, the moving object turns towards right due to the effect of the Coriolis force if the observer moves in the direction of wind movement. Similarly, the moving object turns towards left in the southern hemisphere.

Biomass Power:

Energy from Biomass.

Biomass includes all the living or dead organic materials like wastes and residues. The animal and plant wastes and their residues are regarded as biomass. Inaddition to this the products originate from the conversion processes like paper, cellulose, organic residues for food industry and organic wastes from houses and industries are in this category.

Origin of Bio-mass:

Animals feed on plants and plants grew up through the photosynthesis process using solar energy. Thus photosynthesis process is primarily responsible for generation of biomass energy. A small portion of solar radiation is captured and stored in plants during photosynthesis process. Therefore biomass energy is an indirect form of solar energy.
To use biomass energy, the initial biomass may be transformed by chemical orbiological processes to produce more convenient intermediate bio-fuels such asmethane, producer gas, ethanol and charcoal. On combustion it reacts with oxygen to release heat In nature bio-mass is formed by the process of photosynthesis of inorganicmaterials With the help of the solar radiation in the visible region (0.4-0.8 µm), the coloured material molecules (mainly chlorophyll) split water in organic cells (photolysis). The originating hydrogen along with carbon dioxide forms the biomass. During this process molecular oxygen is released into the air. The production of bio-mass can be understood by the following equation.

$$\underbrace{H_2O + b.\ NO_2 + c.\ SO_4 + d.\ PO_4}_{\text{(From soil of water)}} + \underset{\text{(From air)}}{CO_2} + \underset{\text{(From Sun)}}{(8\text{-}10)\ h\nu} \xrightarrow{\text{Chlorophyl}} \underset{\text{Biomass}}{C_kH_mO_n} + \underset{\text{Water Vapour}}{H_2O} + O_2$$

$$+ \text{ Other material products}$$

where *b*, *c*, *d* are various small quantities (ppm)
h is a Planck's constant = 6.625 X 10^{-34} JS
v is frequency = *C*/λ (s-1)
C is the speed of light = 2.99 X 10^8 m/sec.

$$12\ H_2O + 6\ CO_2 + 2.8\ MJ \xrightarrow{\text{Chlorophyl}} C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

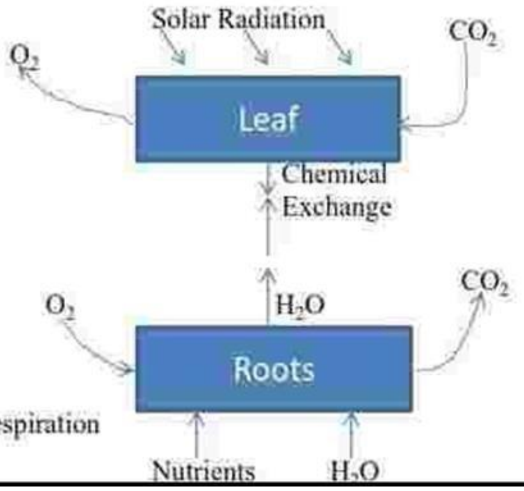


Fig: Photosynthesis and respiration processes in the plant

The energy obtained from biomass is known as biomass energy. Animals feed on plants and plants grow through photosynthesis process usingsolar energy. Thus, photosynthesis process is primarily responsible for generation of biomass energy.

A small portion of the solar radiation is captured and stored in the plants during photosynthesis process. Therefore, it is an indirect form of solar energy. The average efficiency of photosynthetic conversion of solar energy into biomass energy is estimated to be 0.5–1.0 per cent. To use biomass energy, the initial biomass may be transformed by chemical or biological processes to produce more convenient intermediate bio-fuels such as methane, producer gas, ethanol and charcoal etc. On combustion it reacts with oxygen to release heat, but the elements of the material should be available forrecycling in natural ecological or agricultural processes. Thus the use of industrial bio-fuels, when linked carefully to natural ecological cycle, may be nonpolluting and sustainable. For the biomass to be considered as renewable, growth must at least keep pace with its use. It is disastrous that forest and firewood consumption is significantly outpacing their growth in ever-increasing areas of the world. It is estimated that the biomass, which is 90 per cent in trees, is equivalent to the current proven extractable fossil fuel reserves in the world. The dry matter mass of biological material cycling in biosphere is about 250×10^9 tons/year. The associated energy bound in photosynthesis is 2×10^{21} J/year (equivalent to continuous flow of 0.7×10^{14} W) [49]. Biomass, mainly in the form of wood, is mankind’s oldest form of energy. It has traditionally been used both in domestic as well as industrial activities, basicallyby direct combustion. However, it still plays a significant role in the supply of primary energy in many countries of the world.

The conversion of biomass either in the form of heat or solid, liquid or gas form of energy fuels. Using these individual elements in a particular process chain, a number of bio-conversion processes can be defined which is representedbelow.

Raw materials in all these processes is biomass, that is available in nature either inland or in water beds, but all is available in the form of residues or waste. Biomasswaste materials cannot be used as food or for wood production like rice husk, sawdust and animal waste, etc. The biomass waste material (like straws, twigs, stem pieces may also be used for bio-conversion).
These waste materials are also used for fertilizer on the earth.

From the table, it is observed that there are four forms of biomass that getsconverted into useful energy forms by several processes of biomass energy conversion into useful products .

Biomass as Renewable Energy Source

Biomass is organic material made from plants and animals. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. The chemical energy in plants gets passed on to animals and people that eat them. Biomass is a renewable energy source because we can always grow more trees and crops, and waste will always exist. Some examples of biomass fuels are wood, crops, manure, and some garbage. When burned, the chemical energy in biomass is released as heat. If you have a fireplace, the wood you burn in it is a biomass fuel. Wood waste or garbage can be burned to produce steam for making electricity, or to provide heat to industries and homes.

Burning biomass is not the only way to release its energy. Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Methane gas is the main ingredient of natural gas. Smelly stuff, like rotting garbage, and agricultural and human waste, release methane gas - also called "landfill gas" or "biogas." Crops like corn and sugar cane can be fermented to produce the transportation fuel, ethanol. Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats. Biomass fuels provide about 3 percent of the energy used in the United States .

WOOD AND WOOD WASTE

The most common form of biomass is wood. For thousands of years people have burned wood for heating and cooking. Wood was the main source of energy in the U.S. and the rest of the world until the mid-1800s. Biomass continues to be a major source of energy in much of the developing world. In the United States wood and waste (bark, sawdust, wood chips, and wood scrap) provide only about 2 percent of the energy we use today. About 84 percent of the wood and wood waste fuel used in the United States is consumed by the industry, electric power producers, and commercial businesses. The rest, mainly wood, is used in homes for heating and cooking. Many manufacturing plants in the wood and paper products industry use wood waste to produce their own steam and electricity. This saves these companies money because they don't have to dispose of their waste products and they don't have to buy as much electricity. The photograph to the right is of biomass fuel, probably wood chips, being stored and dried for later use in a boiler.

MUNICIPAL SOLID WASTE, LANDFILL GAS, AND BIOGAS

Another source of biomass is our garbage, also called municipal solid waste (MSW). Trash that comes from plant or animal products is biomass. Food scraps, lawn clippings, and leaves are all examples of biomass trash. Materials that are made out of glass, plastic, and metals are not biomass because they are made out of non-renewable materials. MSW can be a source of energy by either burning MSW in waste-to-energy plants, or by capturing biogas. In waste-to-energy plants, trash is burned to produce steam that can be used either to heat buildings or to generate electricity. In landfills, biomass rots and releases methane gas, also called biogas or landfill gas. Some landfills have a system that collects the methane gas so that it can be used as a fuel source. Some dairy farmers collect biogas from tanks called "digesters" where they put all of the muck and manure from their barns. Read about a field trip to a real waste-to-energy plant or learn about the history of MSW.

BIOFUELS -- ETHANOL AND BIODIESEL

"Biofuels" are transportation fuels like ethanol and biodiesel that are made from biomass materials. These fuels are usually blended with the petroleum fuels - gasoline and diesel fuel, but they can also be used on their own. Using ethanol or biodiesel means we don't burn quite as much fossil fuel. Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace but they are also cleaner burning fuels, producing fewer air pollutants. Ethanol is an alcohol fuel made from the sugars found in grains, such as corn, sorghum, and wheat, as well as potato skins, rice, sugar cane, sugar beets, and yard clippings. Scientists are working on cheaper ways to make ethanol by using all parts of plants and trees. Farmers are experimenting with "woody crops", mostly small poplar trees and switchgrass, to see if they can grow them cheaply and abundantly. Most of the ethanol used in the United States today is distilled from corn. About 99 percent of the ethanol produced in the United States is used to make "E10" or "gasohol" a mixture of 10 percent ethanol and 90 percent gasoline. Any gasoline powered engine can use E10 but only specially made vehicles can run on E85, a fuel that is 85 percent ethanol and 15 percent gasoline. Biodiesel is a fuel made with vegetable oils, fats, or greases - such as recycled restaurant grease. Biodiesel fuels can be used in diesel engines without changing them. It is the fastest growing alternative fuel in the United States. Biodiesel, a renewable fuel, is safe, biodegradable, and reduces the emissions of most air pollutants.

Types of Biomass Fuels - Solid, Liquid and Gas

Biomass fuels are organic materials produced in a renewable manner. Two categories of biomass fuels, woody fuels and animal wastes, comprise the vast majority of available biomass fuels. Municipal solid waste (MSW) is also a source of biomass fuel. Biomass fuels have low energy densities compared to fossil fuels. In other words, a significantly larger volume of biomass fuel is required to generate the same energy as a smaller volume of fossil fuel.

The low energy density means that the costs of fuel collection and transportation can quickly outweigh the value of the fuel. Biomass fuels are typically consumed on-site or transported short distances only (e.g., less than 50 miles). Biomass fuels tend to have a high moisture content, which adds weight and increases the cost of transportation. The moisture content also decreases combustion performance.

There are two primary factors to be considered in the evaluation of biomass fuels: Fuel supply, including the total quantities available, the stability of the supply or of the industry generating the fuel, and competitive uses or markets for the fuel. Cost of biomass fuel collection, processing, and transportation, and who pays these costs.
This section discusses three sources of biomass fuel: woody fuels, animal waste, and MSW. These discussions include the issues of fuel supply and costs. These fuels are summarized, along with their respective benefits and barriers, in Table 2 at the end of this section.

Woody Fuels

Wood wastes of all types make excellent biomass fuels and can be used in a wide variety of biomass technologies. Combustion of woody fuels to generate steam or electricity is a proven technology and is the most common biomass-to-energy process. Different types of woody fuels can typically be mixed together as a common fuel, although differing moisture content and chemical makeup can affect the overall conversion rate or efficiency of a biomass project. There are at least six subgroups of woody fuels. The differentiators between these subgroups mainly have to do with availability and cost. Forestry residues—in-forest woody debris and slash from logging and forest management activities. Mill residues—byproducts such as sawdust, hog fuel, and wood chips from lumber mills, plywood manufacturing, and other wood processing facilities. Agricultural residues—byproducts of agricultural activities including crop wastes, vineyard and orchard prunings or turnings, and rejected agricultural products. Urban wood and yard wastes—residential organics collected by municipal programs or recycling centers and construction wood wastes. Dedicated biomass crops—trees, corn, oilseed rape, and other crops grown as dedicated feedstocks for a biomass project. Chemical recovery fuels (black liquor)—woody residues recovered out of the chemicals used to separate fiber for the pulp and paper industry.

Forestry Residues

Forestry residues have been the focus of many recent biomass studies and feasibility assessments due to increasing forest management and wildfire prevention activities under the National Fire Plan. The USDA Forest Service and the Bureau of Land Management have been tasked with reducing the hazardous fuel loading within the forests and the urban-wildland interface.

Forestry residues are typically disposed of by on-site (in-forest) stacking and burning. This results in substantial air emissions that affect not only the forest lands and nearby populations, but the overall regional air quality as well. Open burning can also cause water quality and erosion concerns. The Forest Service and other public and private land management entities would like to have viable alternatives for disposing of their forestry residues in a more environmentally benign manner. An ideal situation, from the perspective of forest managers, would be the creation of a market for the forestry residues. The market they envision would generate revenues for the forest managers, which in turn would allow much needed expansion of the forest management programs .

Mill Residues

Mill residues are a much more economically attractive fuel than forestry residues, since the in-forest collection and chipping are already included as part of the commercial mill operations. Biomass facilities collocated with and integral to the mill operation have the advantage of eliminating transportation altogether and thus truly achieve a no-cost fuel. Mill residues have long been used to generate steam and electricity.

In Washington State alone, there are approximately 38 facilities that combust about 3 million BDT of mill residues per year to generate steam and electricity. All but two of these mill-residue-fired biomass projects are owned and operated by the mills or wood products companies that supply their fuel. The in-plant facilities primarily generate steam for lumber drying and processing. Any electricity produced is used to offset plant use, although a few facilities do sell excess electrical power to the local utility.

One example of a mill residue biomass-to-energy facility not owned by a mill is Avista Utility's Kettle Falls Station in northeastern Washington. The facility is strategically located within an average distance of 46 miles from 15 different mills, and purchases approximately 350,000 BDT per year of residues to generate 46 MW of electrical power. The facility was conceived in the late 1970s when mills were facing stricter pollution regulations that required them to replace their wigwam burners. Rather than invest in new equipment, the mills were willing to enter into long-term contracts with the private electric utility to supply a biomass facility with mill residues. The facility continues to operate successfully, due in large part to its unique location in one of the most heavily forested areas in the Pacific Northwest .

Agricultural Residues

Agricultural residues can provide a substantial amount of biomass fuel. Similar to the way mill residues provide a significant portion of the overall biomass consumption in the Pacific Northwest, agricultural residues from sugar cane harvesting and processing provide a significant portion of the total biomass consumption in other parts ofthe world. One significant issue with agricultural residues is the seasonal variation of the supply.

Large residue volumes follow harvests, but residues throughout the rest of the year are minimal. Biomass facilities that depend significantly on agricultural residues must either be able to adjust output to follow the seasonal variation, or have the capacity to stockpile a significant amount of fuel.

Urban Wood and Yard Wastes

Urban wood and yard wastes are similar in nature to agricultural residues in many regards. A biomass facility will rarely need to purchase urban wood and yard wastes, and most likely can charge a tipping fee to accept the fuel. Many landfills are already sorting waste material by isolating wood waste. This waste could be diverted to a biomass project, and although the volume currently accepted at the landfills would not be enough on its own to fuel a biomass project, it could be an important supplemental fuel and could provide more value to the community in which the landfill resides through a biomass project than it currently does as daily landfill cover.

Dedicated Biomass Crops

Dedicated biomass crops are grown specifically to fuel a biomass project. The most prevalent example of dedicated biomass crops are corn varieties grown for ethanol production. Fast-growing poplar trees have also been farm-raised for a biomass fuel, but this has not proven to be economically sustainable. Another dedicated crop example is soybean oils used in the production of biodiesel.

Chemical Recovery Fuels

Chemical recovery fuels are responsible for over 60 percent of the total biomass energy consumption of the United States, and therefore must be mentioned in any analysis of biomass. By and large, the chemical recovery facilities are owned by pulp and paper facilities and are an integral part of the facility operation.

Animal Wastes

Animal wastes include manures, renderings, and other wastes from livestock finishing operations. Although animal wastes contain energy, the primary motivation for biomass processing of animal wastes is mitigation of a disposal issue rather than generation of energy. This is especially true for animal manures. Animal manures are typically disposed of through land application to farmlands. Tightening regulations on nutrient management, surface and groundwater contamination, and odor control are beginning to force new manure management and disposal practices. Biomass technologies present attractive options for mitigating many of the environmental challenges of manure wastes. The most common biomass technologies for animal manures are combustion, anaerobic digestion, and composting. Moisture content of the manure and the amount of contaminants, such as bedding, determine which technology is most appropriate.

The dairy industry in particular is well suited to biomass-to-energy opportunities because of the large volume of manure that a milking cow produces, and because dairy operations have automated and frequent manure collection processes. Yakima County is the largest producer of dairy products of any county in the State, and the dairy populations within the County include approximately 75,000 to 85,000 active milking cows on about 80 separate dairies.

Dry Animal Manure

Dry animal manure is produced by feedlots and livestock corrals, where the manure is collected and removed only once or twice a year. Manure that is scraped or flushed on a more frequent schedule can also be separated, stacked, and allowed to dry. Dry manure is typically defined as having a moisture content less than 30 percent. Dry manure can be composted or can fuel a biomass-to-energy combustion project.

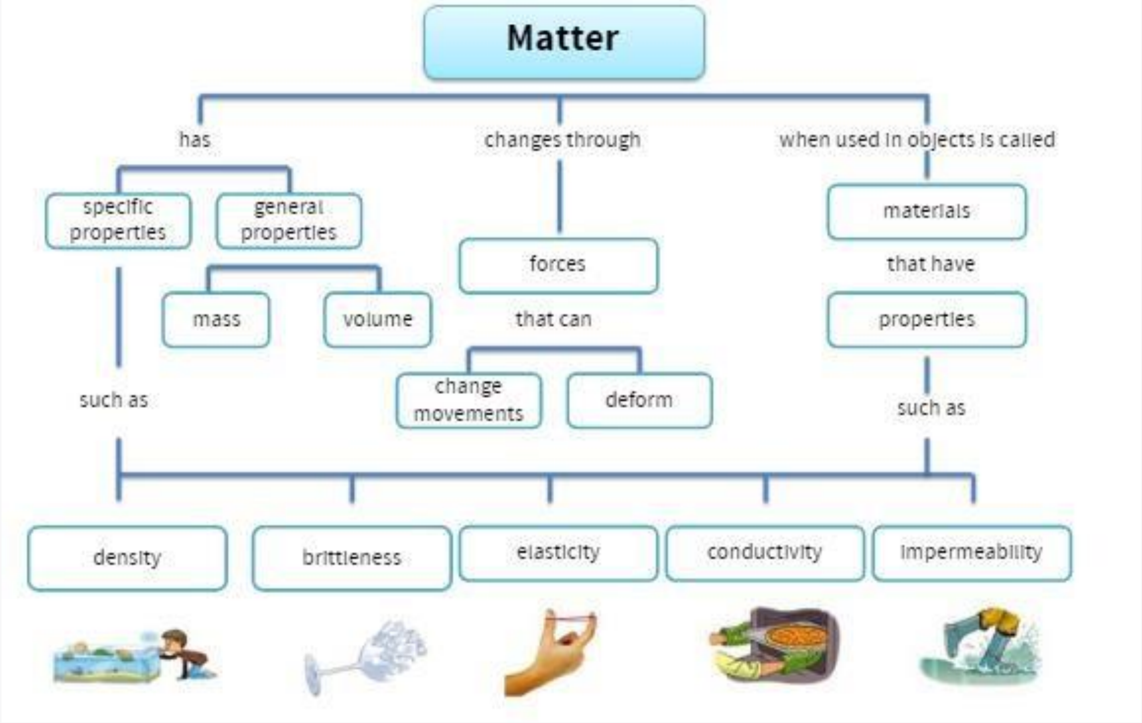
Animal manure does have value to farmers as fertilizer, and a biomass-to-energy project would need to compete for the manure. However, the total volume of manure produced in many livestock operations exceeds the amount of fertilizer required for the farmlands, and Nutrient Management Plans are beginning to limit the over-fertilization of farmlands. Therefore, although there are competitive uses for the manure and low-cost disposal options at this time, manure disposal is going to become more costly over time, and the demand for alternative disposal options, including biomass-to-energy, will only increase .

Wet Animal Manure (Dairy Manure Slurry)

Wet animal manure is typically associated with larger and more modern dairy operations that house their milking cows in free-stall barns and use a flush system for manure collection. The combination of free-stall barns and manure flushing collects all of the milking cow manure with every milking cycle, two or three times a day. The manure is significantly diluted through the addition of the flush water, but after separation of some of the flush water, the slurry is an excellent fuel .

4.4 Combustion and fermentation.

Everything around us is made of matter: our bodies, the air we breathe, the ground we walk on and the water we drink. Matter can’t be created or destroyed; it just changes. Some of the changes it undergoes are physical and others are chemical. During physical changes the appearance of the matter changes, but its chemical properties remain the same. Chemical reactions, such as fermentation or combustion, change a substance into a new one with different properties.



MATTER CHANGES

"Matter can’t be created or destroyed; it just changes."

Matter changes continuously. It can change shape or form or it can be also transform into different matter. So, some of the changes it undergoes are physical and others are chemical.

1. Physical changes:

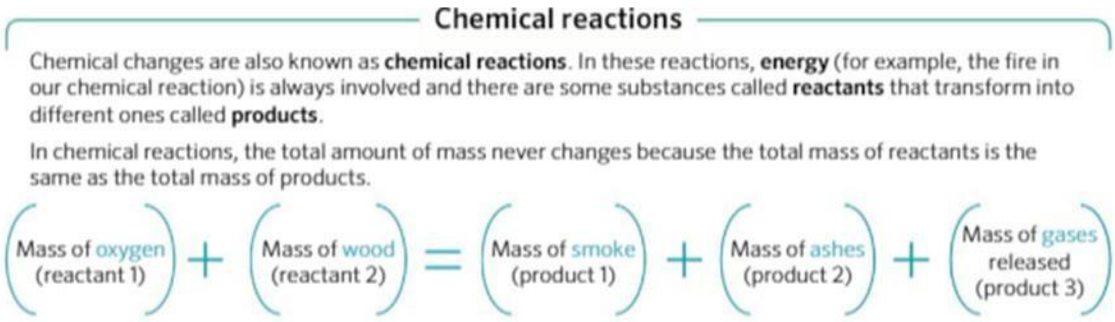
shape or form changes but mass and volume stay the same (its chemical properties remain the same).

Example: when a paper breaks into smaller pieces, changes of state in water.

2. CHEMICAL CHANGES: Matter changes into a new substance with different properties.

Example: When paper is burn and become ashes, iron (Fe) **rusts** when it is exposed to oxygen gas in the air.

Chemical reactions



Chemical reactions

Chemical changes are also known as **chemical reactions**. In these reactions, **energy** (for example, the fire in our chemical reaction) is always involved and there are some substances called **reactants** that transform into different ones called **products**.

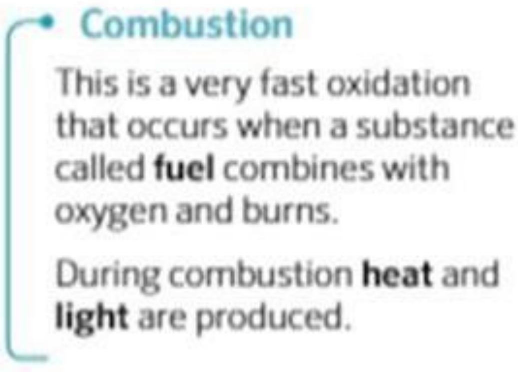
In chemical reactions, the total amount of mass never changes because the total mass of reactants is the same as the total mass of products.

(Mass of oxygen (reactant 1)) + (Mass of wood (reactant 2)) = (Mass of smoke (product 1)) + (Mass of ashes (product 2)) + (Mass of gases released (product 3))

we may think that chemical reactions only happen in science labs, but they are actually happening all the time in the everyday world. Every time you eat, your body uses chemical reactions to break down your food into energy. Other examples include metal rusting, wood burning, batteries producing electricity, and photosynthesis in plants...

Combustion and fermentation are **irreversible** changes.

Combustion:

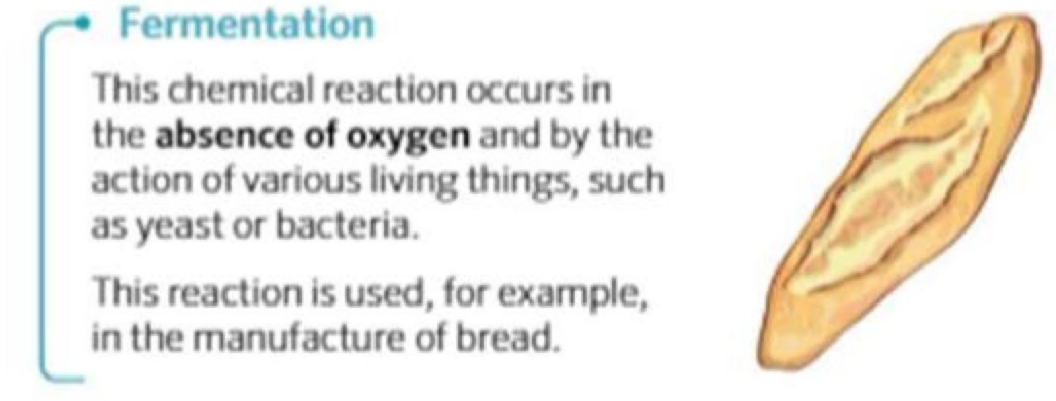


Combustion

This is a very fast oxidation that occurs when a substance called **fuel** combines with oxygen and burns.

During combustion **heat** and **light** are produced.

Fermentation:



Fermentation

This chemical reaction occurs in the **absence of oxygen** and by the action of various living things, such as yeast or bacteria.

This reaction is used, for example, in the manufacture of bread.

Fermentation is used to make foods such as cheese or bread and drinks such as wine. Fermentation also occurs naturally in sugars in fruits or vegetables, which helps with decomposition. Fermentation is also used to preserve food all over the world. Vegetables, fruit, fish, and meat can all be stored for longer if they are fermented first.

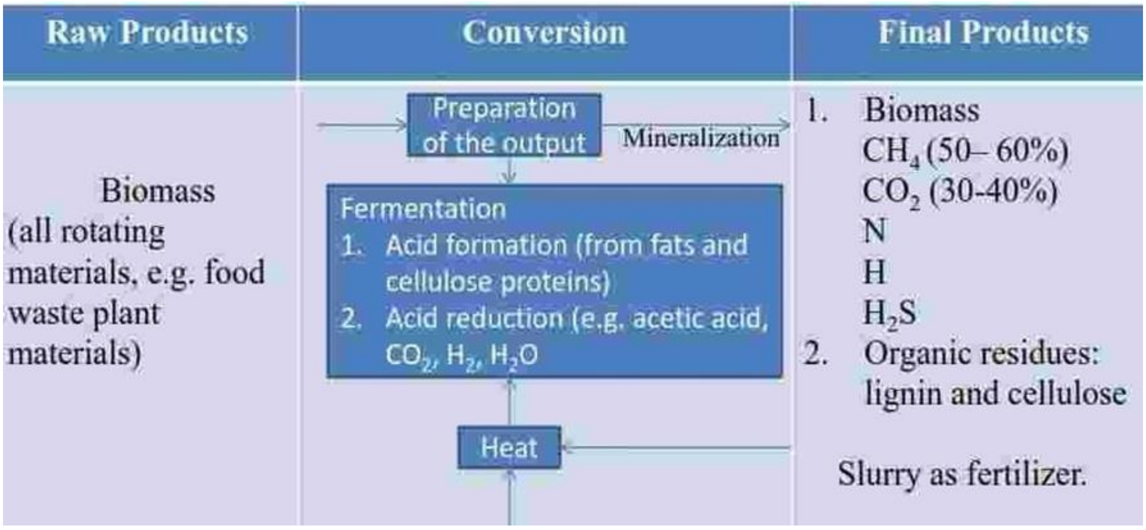
4.5. Anaerobic digestion.

When the moist biomass comes in contact withair, it automatically decays with the help of aerobic micro-organisms. As a result Cand H oxides into CO_2 and H_2O with simultaneous release of heat at temperature of $70\text{-}90^0$ C. In the carbon dioxide cycle, the aerobic bacteria plays an important role. The bacteria releases CO_2 and thus mineralize the bounded carbon in the organic substance.

In anaerobic digestion the organic material is allowed to decay in absence of oxygen. The different types of bacteria make a number of exchange processes resulting the digestion of biomass and conversion into a mixture of methane andcarbon dioxide.

The energy obtained is much higher than of a low temperature decaying process.There three steps in the production of methane. These are:

1. Acid production (hydrolysis) →Where the bonds are broken and acid is formed.
2. Acid reduction
3. Methane production →is formed from anaerobic bacteria



Raw Products	Conversion	Final Products
Biomass (all rotating materials, e.g. food waste plant materials)	Preparation of the output Mineralization Fermentation 1. Acid formation (from fats and cellulose proteins) 2. Acid reduction (e.g. acetic acid, CO_2, H_2, H_2O Heat	1. Biomass CH_4 (50– 60%) CO_2 (30-40%) N H H_2S 2. Organic residues: lignin and cellulose Slurry as fertilizer.

Step – I: (Acid production and hydrolysis):

In this hydrolysis process, the biomass like protein, fat and carbohydrates are broken through the influence of water. The polymers (large molecules) arereduced to monomers (basic molecules). The reaction is accelerated throughenzymes, which are separated from bacteria. The resulting products are: Fat Protein, Carbohydrates, Fatty acids, Amino acids, Sugar. These products are fermented by the fermentation bacteria (bacteria which are active in this step) leading to the formation of the following products:

1. H_2, H_2O, CO_2, NH_3
2. Acetic acid (CH_3COOH)
3. Alcohol and low organic acids.

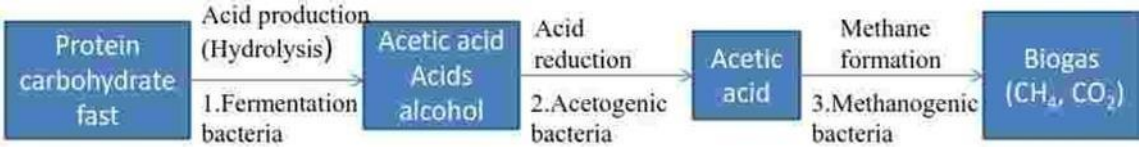
Step-II (Acid Reduction):

In the second step, the alcohol and the low organic acids are fermented into thefollowing products through the action of acetogenic bacteria. (i) H_2O, (ii) CO_2, (iii) H, (iv) Acetic acid (CH_3COOH)

The final product of fermentation process is the acetic acid.

Step-III (Methane Production):

The acetic acid produced in the first and second step is converted into methane and CO_2 (biogas) through the effect of methanographic bacteria. At the end the residual waste is rich in nitrogen and can be used as a good fertilizer. In each stepof the anaerobic digestion, a variety of bacteria are formed which cause the decaying of the organic material and which are specialized for the reduction of intermediate products .



Influencing parameters: The amount of biogas produces through anaerobic Digestion of organic waste and also the methane content in it depends upon thefollowing parameters:

1. Kind of substrate, 2. Dry matter content, 3. Temperature, 4.Digestionperiod,5. Mode of operation, 6. PH value.

Description of biogas Digesters: There are various types of digesters according tothe need of the situation.

But there are two basic types of distinguishable digesters according to the loadingused.

1. Batch type digester
2. Continuous flow digester.

A batch type digester is a simple digester in which organic material is filled in a closed container and allowed to be digested an aerobically over a period of two to six months time depending upon the feed material and other parameters like temperature, pressure etc .

TYPES OF BIOGAS DIGESTERS

- **Fixed dome biogas plants** : This is a dome shaped with immovable gas holder and a displacement pit. The upper part of the digester stores the gas and the waste is displaced in the displacement pit. When the volume of the gas increases, the pressure increases.
- **Floating drum biogas plants** : This consists of underground digesters and movable gas holders. The gas gets collected in the drum which is above the digester. This moves up and down according to the gas collected.
- **Balloon plants** : This consist of a rubber bag or balloon and it combines the digester and gas holder. The input and output is connecter to the skin of the rubber bag.

BIOCHEMICAL PROCESS IN ANAEROBIC DIGESTION

The process of anaerobic digestion can be divided into 4 stages like hydrolysis, acidogenesis, acetogenesis and methanogenesis.

- **Hydrolysis** : In this stage the organic compound is degradated into simple form so that micro organisms can utilize them easily. The rate of hydrolysis depends on lot of factors like organic substance shape, surface area, size and biomass.
- **Acidogenesis** : This is the second step and it involves fermentation. This is one of the quick steps in anaerobic digestion. Here the anaerobic microbes further degradate the products into simpler compounds like volatile fatty acids and acetic acid.
- **Acetogenesis** : The volatile fatty acids and acetic acid produced in acidogenesis cannot be utilized by methanogenesis, so it is further simplified into acetate and hydrogen. This process of conversion is known as acetogenesis carried out by acetogens which are sensitive organisms.

- **Methanogenesis** : This is the last step in anaerobic digestion. Here the methanogenic bacteria convert acetate to methane and carbon dioxide. This is an important pathway in yielding energy. Methanogenic growth is of key importance in anaerobic processes. The methanogens and acetogens share a mutually beneficial relationship which maintains equilibrium in anaerobic process.

To conclude, biogas technology can be used in different ways to contribute to its development. Farmers can use it as a substitute for chemical fertilizers for developing healthy crops. Industries can use it for generating light and heat. Municipalities can use this to solve problems like waste disposal and waste water treatment. The national government can use this for the overall development of the country like reduce deforestation, increase agricultural productivity and reduce the use of chemical fertilizers .

4.7. Wood gasifier

Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas which is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass.

In a gasifier, the carbonaceous material undergoes several different processes:
The dehydration or drying process occurs at around 100°C. The pyrolysis (or de-volatilization) process occurs at around 200-300°C. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The combustion occurs as the volatile products and some of the char reacts with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions. The gasification process occurs as the char reacts with carbon and steam to produce carbon monoxide and hydrogen. In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen.

In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. This third reaction occurs more abundantly in reactors that increase the residence time of the reactive gases and organic materials, as well as heat and pressure. Catalysts are used in more sophisticated reactors to improve reaction rates, thus moving the system closer to the reaction equilibrium for a fixed residence time.

The choice of feedstock determines the gasifier design. Three designs are common in wood gasification: updraft, downdraft and crossdraft. In an updraft gasifier, wood enters the gasification chamber from above, falls onto a grate and forms a fuel pile. Air enters from below the grate and flows up through the fuel pile. The syngas, also known as producer gas in biomass circles, exits the top of the chamber. In downdraftor crossdraft gasifiers, the air and syngas may enter and exit at different locations.

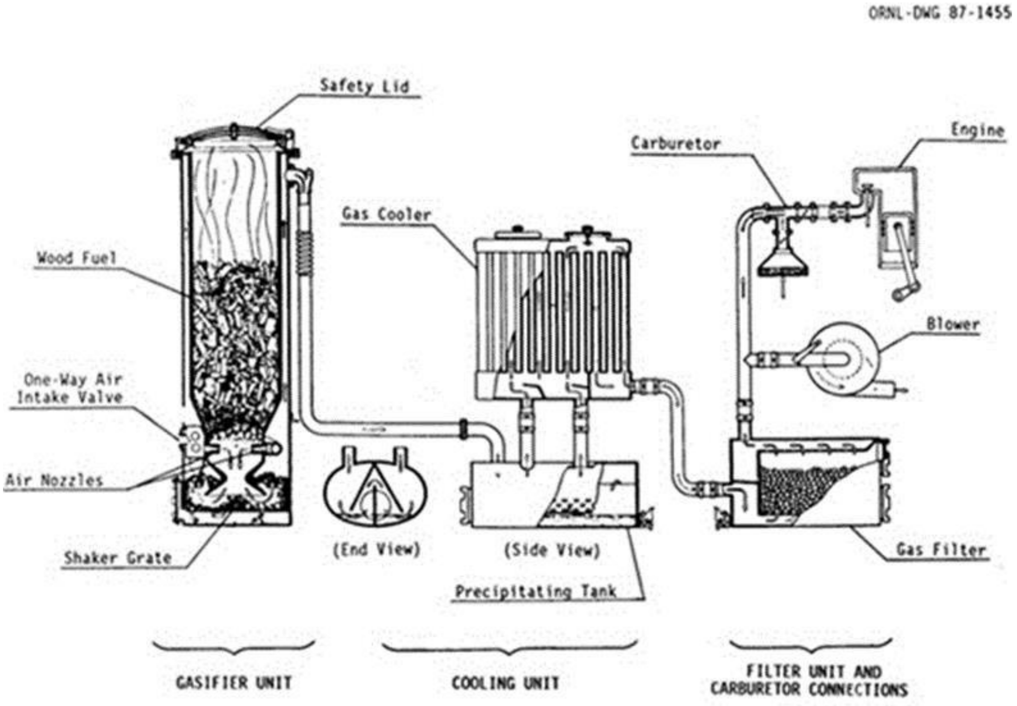


Fig. 1-2. Schematic view of the World War II, Imbert gasifier.

4.8 Pyrolysis

Pyrolysis is a thermochemical decomposition of organic material at temperatures between 400 °C and 900 °C without the presence of oxygen or other reagents. The pyrolytic breakdown of wood produces a large number of chemical substances. Some of these chemicals can be used as substitutes for conventional fuels. The distribution of the products varies with the chemical composition of the biomass and the operating conditions.

Slow Pyrolysis :

Primarily to produce Char through Carbonization Utilizes low temperatures around 400 °C over a long period of time to maximize char formation. Product yields from slow pyrolysis are approximately 35% biochar, 30% bio-oil, and 35% gaseous products.

Rapid/Fast Pyrolysis :

Primarily to produce BioOil and Gas -Biomass is very rapidly heated (~1000-10,000 °C/s) to a temperature around 650 °C-1,000 °C depending if bio-oil or gas products are desired. -Product gases are quickly removed and quenched

Fast pyrolysis product yields are typically 50–70% bio-oil, 10–30% biochar, and 15–20% syngas by mass. Biomass must first be dried and ground to particle size before entering a fast pyrolyzer .

Pyrolysis Parameters

- Biomass type and preparation of feeding
- Pyrolysis temperature
- Catalyst
- Sweeping gas velocity
- Particle size
- Reactor geometry
- Heating rate

4.9. Applications: Bio gas, Bio diesel

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 manurein agriculture lands

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 / hydrobyticbacteria) 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.

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 processwhere 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 vegetableoil. 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 .

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

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 inTable 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 differentIndian 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.

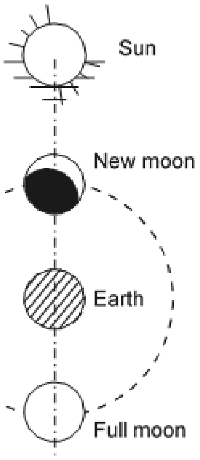
Other Energy Sources

Tidal Energy: Energy from the tides, Barrage and Non Barrage Tidal power systems.

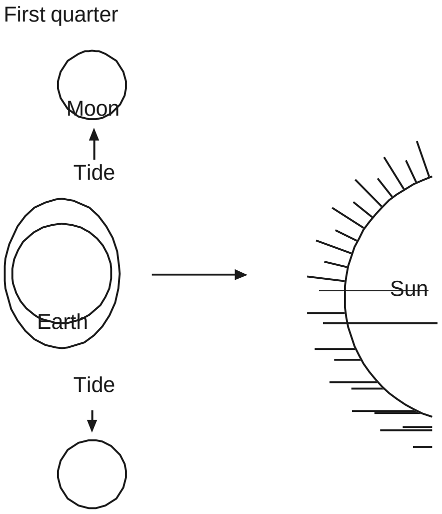
All forms of energy available on the earth are, in the first instance, derived from solar energy, with the exception of nuclear, geothermal and tidal energy. Wind, ocean waves, and rivers are driven by the energy from the sun. Coal, oil, gas, wood and grasses are formed by solar energy, which splits carbon dioxide with water to produce cellulose which has either been fossilized (to form coal, oil and gas) or been turned to starch and sugar to produce biomass. In view ofthe rising prices of fossil and nuclear fuels, combined with adverse environmental impacts with their use in electric power generation, of late *there has been an increased interest in theexploitation of tidal energy.*

The tides are caused by the combined attraction of the sun and the moon on the waters of the revolving globe. The effect of the moon is about 2.6 times more than that of the sun, influencing the tides of the oceans. Thus, tide is a periodic rise and fall of the water level of the ocean. Twiceduring a lunar* day (i.e., within 24 hours 50 minutes) the water in oceans and seas rises and falls. The excess of 50 minutes over the solar day results in the maximum water level, occurring at different times on different days. The amplitude of water level variations at different points on the earth depends on the latitude and the nature of the shore. The rotation of the earth causestwo high tides and two low tides to occur daily at any place.

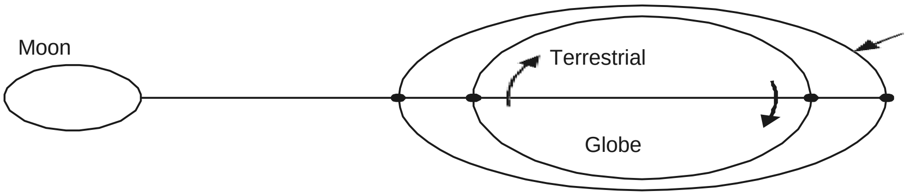
The revolution of the moon around the earth increases the time interval between twosuccessive high tides from 12 hours to about 12 hours and 25 minutes. As the moon revolution takes about 28 days, the three bodies, i.e., the sun, the moon and the earth are in alignment everytwo weeks at new and full moon. During these periods the sun and the moon act in combination to produce tides of maximum range as shown in Figure



The solar pull comes in line with the lunar pull at 'New Moon' and 'Full Moon', causing greater flow and ebb, known as spring tides. On the other hand, if the two pulls act at right angles toeach other, as at waxing and waning 'Half Moons', i.e., in the first and the third quarters, weget low tides called 'Neap Tides' as shown in Figure



The spring tide is particularly great when the moon is 'New' and 'Full' at which time it isat the closest point of its orbit to the earth. The revolution of the earth and the moon together around the sun gives rise to further variation, and due to this effect the highest spring tide occurs at the equinoxes in March and September as shown in Figure , on the design of a tidal power plant. A high tide is experienced at a point which is directly under the moon. At the same time, at a diameterically opposite point on the earth's surface, there also occurs a high tide due to dynamic balancing of the ocean water over the globe. In the courseof the earth's rotation the water buldges out.



Barrage (Dam or Dyke)

The barrage should be constructed by the material available at site or from a nearby place. Barrages for tidal power projects have to withstand the force of sea waves, so the design should be suitable to site conditions and to economic aspect of development. The rockfill dams or barrages are preferred due to their stability against flows. The dyke (barrage) crest and slopes should be armoured for protection against waves

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 .

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 .

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 4

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.

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.

Tidal lagoon

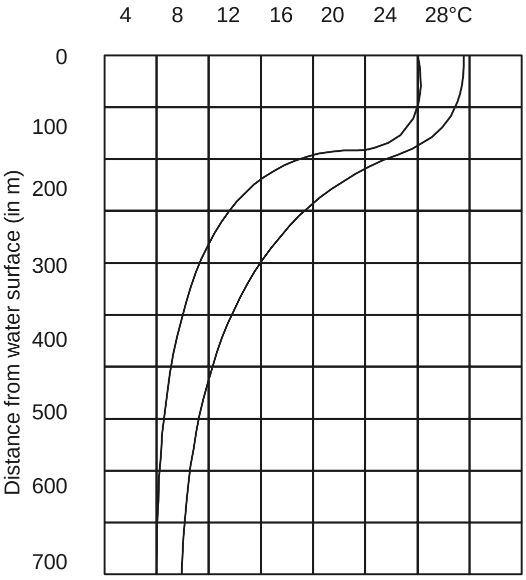
A tidal lagoon is a power station that generates electricity from the natural rise and fall of the tides. Tidal lagoons work in a similar way to tidal barrages by capturing a large volume of water behind a manmade structure which is then released to drive turbines and generate electricity. Unlike a barrage, 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 .

Ocean Thermal Energy Conversion (OTEC).

Ocean Thermal Energy Conversion (OTEC) is a new technology, needed to be harnessed especially in India where the coastline is about 6000 km. Basically, the OTEC converts the thermal energy, available due to temperature difference between the warm surface water and the cold deep water, into electricity. Power from the OTEC is renewable and eco-friendly. An OTEC plant can operate in remote islands and sea-shore continuously. It is very low grade solar thermalenergy, so the efficiency of energy recovery is quite low. However, since the ocean thermal energy is dispersed over a large ocean surface area, it has a big potential. According to MNRE, the overall potential of ocean energy in the country may be in excess of 50,000 MW. There isan enormous opportunity to tap this renewable source of energy.

WORKING PRINCIPLE—OTEC

There exists a temperature difference of about 20°C between the warm surface water of the sea (receiving and absorbing solar radiation) and the cold deep water (which flows from the Arctic regions in deep layers) in equatorial areas between latitude 30° S and 30° N. Solar heat energyis absorbed by ocean water. It can be explained by 'Lambert's law of absorption'. The law statesthat "each water layer of identical thickness absorbs an equal fraction of light that passes throughit". Thus, the intensity of heat decreases with the increase in water depth. Due to large heat transfer at the ocean surface water, the highest temperature is attained just below the top surface.A typical temperature variation curve with distance from the surface is shown in Figure

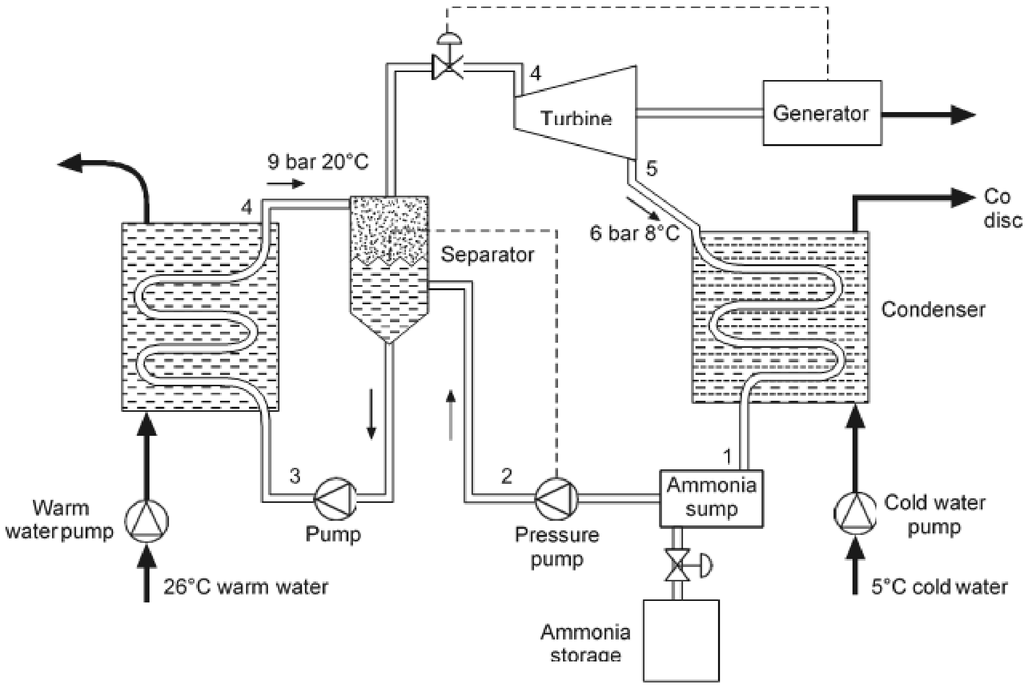


It may be seen that the temperature at the surface changes slowly, then remains constant ata depth of about 200 m. Subsequently, the temperature decreases asymptotically and approaches a low value of about 4°C at a depth of 1000 metres. The difference in temperature between the surface and the deeper parts of the ocean is utilised to generate electrical energy. The basic process of OTEC is to bring the warm surface water and the cold water from a certain depthof the sea through pipes so as to act as 'heat source' and 'heat sink' for operating a heat engine.It will form the same system as that of conventional thermal power station with nil fuel consumption.

The OTEC plants are of three types, namely 'closed', 'open', and thermoelectric. Theimportant broad features of these plants are as follows.

CLOSED RANKINE CYCLE OR ANDERSON CLOSED CYCLEOTEC SYSTEM

The closed cycle system using a low boiling point working fluid like ammonia or propane is shown in Figure



It may be seen that warm water from the surface which is at a temperature of about 26°Cis brought in one pipe, and cold water at a temperature of around 5°C is brought in another pipe from a depth of about 1000 metres. In OTEC plants two water pipes are used in conjunction witha working fluid to generate electric power. Different operational activities of the plant are:

(a) The warm sea water evaporates the liquid ammonia into vapour in a unit called an evaporator. This can be done because ammonia exists in the form of gas at the temperature corresponding to the surface sea water.

(b) The liquid ammonia which is not evaporated collects in a unit known as separator, which again recirculates through the evaporator.

(c) The evaporated ammonia in the form of high pressure vapour is made to pass througha turbine where its pressure and temperature make the turbine to rotate, thus converting thermal energy into mechanical energy. The rotating turbine if coupled to an electric generator produces electric power.

(d) The ammonia vapour coming out of the turbine, which is now at the lower pressurethan when it entered the turbine is condensed back into liquid ammonia by cooling it with the colder sea water brought up from the deep part.

(e) The liquified ammonia collects in an ammonia sump. After a few hours of operation, the make-up quantity of ammonia is added from the ammonia storage to make up for the operational loss.

(f) The liquified ammonia is then pumped back to the evaporator, thus completing the cycle. The cycle repeats to run the plant continuously.

THERMOELECTRIC OTEC

The thermoelectric OTEC system was developed by Solar Energy Research Institute Colorado USA, during 1979. The OTEC system which operates on the thermoelectric principle is simple

in construction and economical. Semiconductors are used to design two separate packs covered by a thin thermal conducting sheet . Warm water from the surface ofthe ocean is circulated over one device and the cold water pumped from the depth of the oceanis allowed to flow over the other device. The temperature difference between these two water with the solid state semiconductor devices generates the electric power. The OTEC plant economy is dependent on large variation of water temperature used from the surface and thedeep ocean (minimum 20°C).

Geothermal Energy – Classification.

The earth is a great reservoir of heat energy in the form of molten interior. Surface manifestationof this heat energy is indicated by hot water springs and geysers discovered at several places. Heat can be experienced from the temperature rise of the earth's crust with increasing depth below the surface. Radial temperature gradient increases proportionally to depth at a rate ofabout 30°C per km. At a depth of 3– 4 km, water bubbles up; while at a depth of 10–15 km the earth's interior is as hot as 1000° to 1200°C. The core of the earth consists of a liquid rockknown as **'Magma'** having a temperature of about 4000°C.

This geothermal heat is transferred to the underground reservoir of water which also circulates under the earth's crust. Its heat dissipates into the atmosphere as warm water and the steam vents up through the fissures in the ground as hot springs and geysers. Limitless heat content in magma plus the heat generated by radioactive decay of unstable elements such as K_{40},Th_{232} and U_{235} which are abundant in the earth's crust are forms of geothermal energy and considered as a renewable energy resource

GEOTHERMAL RESOURCES

Geothermal resources are of five types:

1. Hydrothermal
   (a) Hot water
   (b) Wet steam (superheated water from highly pressurized underground reservoirs)
2. Vapour dominated resource
3. Hot dry rock resource
4. Geo-pressured resource
5. Magma resource

Hydrothermal Resource

Hydrothermal resources (geothermal reservoirs) are hot water or steam reservoirs that can be tapped by drilling to deliver heat to the surface for thermal use or generation of electricity.
It may be seen that only a part of the rock is permeable constituting the geo-fluid reservoir, so the field is able to produce commercially a viable resource. Sites of these resources adopt the geographical name of their locality such as Larderallo field in Italy, Wairakei field in New Zealand and Geysers geothermal field in California.

Hot water fields

At these locations hot water below 100°C gushes out as hot spring. The geothermal aquifers being covered by confining layers keep the hot water under pressure. Generally the geothermal water contains sulphur in colloidal form widely used as medicated curative water for skin diseases. In northern India, such a spring exists at Tatapani on the right bank of river Sutlej 54 km from Shimla. Other locations are 'Sahestra Dhara' near Dehradun, sacred kund at Badrinath in Uttarakhand, Sohna sulphur water tank in Gurgaon (Haryana) and Manikaran in Kulu Valley (Himachal Pradesh). Internationally known fields are Pannonian basin (Hungary), Po river valley (Italy) and Klamath Falls Oregon (USA

Wet steam fields

The pressurized water is at more than 100°C and contains small quantities of steam and vapour in the geothermal reservoir (370°C). With this formation, liquid is in dominant phasethat controls pressure in the reservoir. Steam occurs in the form of bubbles surrounded byliquid water. Sites where the steam escapes through cracks in the surface are called 'fumaroles'.

An impermeable cap-rock prevents the fluid from escaping into the atmosphere. Drilling is carried out to bring the fluid to the surface. The fluid is used to produce steam and boiling water in predominant phase.

Examples of wet steam fields generating electrical energy are: Los Azufre (Mexico), Puna (Hawaii, USA), Dieng (Indonesia), Azores (Portugal), Latera (Italy) and Zunil (Guatemala).

Vapour-dominated Resource

Vapour dominated reservoirs produce dry saturated steam of pressure above the atmosphere and at high temperature about 350°C. Water and steam co-exist, but steam is in dominant phase and regulates pressure in the reservoir. Steam obtained from such a geothermal field directly drives a turbine. Major geothermal power plants in the world are: Malsukawa (Japan), The Geysers California (USA), Mt. Amiata (Italy) and Kamojang (Indonesia). A hot dry rock field also comes under this category. This is the geological formation with high temperature rocks at 650°C, heated by conductive heat flow from magma but contains no water. To tap its energy the impermeable rock is fractured and water is injected to create an artificial reservoir. Water circulates and hot fluid returns to the surface through the other drilled well as steam and hot water which are used to generate electricity.

Geopressured Resource

Geopressured resources contain moderate temperature brines (160°C) containing dissolved methane. These are trapped under high pressure (nearly 1000 bar or 987 atmosphere) in a deep sedimentary formation sealed between impermeable layers of shale and clay at depths of 2000 m–10,000 m. When tapped by boring wells, three sources of energy are available— thermal, mechanical (pressure) and chemical (methane).

Technologies are available to tap geopressured brines as investigated in off-shore wells in Texas and Louisiana at the US Gulf Coast zone up to a depth of nearly 6570 m but have not proved economically competitive. Extensive research is yet to confirm the long-term use of thisresource.

Magma

Magma is a molten rock at temperatures ranging from 700°C to 1600°C. This hot viscous liquid comes out at active volcanic vents and solidifies. It may form reservoirs at some depth from the earth's surface. Magma Chambers represent a huge energy source, but the existing technology does not allow recovery of heat from these resources .

5.4. Hybrid Energy Systems.

Renewable energy sources dealt in various chapters are distributed systems of energy widely spread in the country that is most suitable for dispersed population located not reachable by stategrid. It is inherent with renewable energy systems that energy supply is not continuous. Reason for this shortcoming is to be understood and solution searched.

NEED FOR HYBRID SYSTEMS

Solar water heaters, air heaters, solar distillation and wax melters, PV arrays, PV pumps, operateat optimal efficiency for the months of April to September when solar radiation contain high energy flux. To meet the load demand during night and cloudy days, battery bank is provided. During winter, load demand shoots up and solar energy reduces, so designer is compelled to select large size equipment, PV arrays and battery bank. Similar situation is faced for a stand alone wind power generating system, when wind speed drops below cut-in speed and Wind Turbine Generator (WTG) stops. For emergency, loads of hospitals, defense installations and communication services, a back up source (1) diesel generator, (2) gas turbine generator, (3) biogas, (4) small hydro, and (5) fuel cell is required. Two different energy systems installed ata location to ensure continuity of electrical supply is known as *hybrid energy system*. Thus, hybrid energy system provides an edge over the *stand-alone* and even *grid interactive systems*for reliability of energy supply and lower capital cost. However, engineer's selection of the back up source is done by maximum capacity of the prime energy source at peak energy demand period.

TYPES OF HYBRID SYSTEMS

Few hybrid energy systems that are operative in prevailing Indian conditions in various statesare given

It is assumed that a battery bank of a suitable size is installed as the storage tank for the period of low wind speed, during 'No Sun' cloudy day and night period. Correct choice for an option will include the parameters .

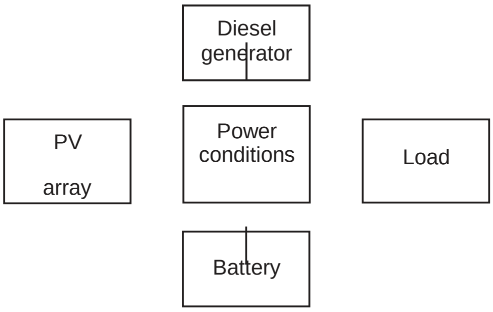
(i) available solar insolation at optimum array tilt,
(ii) free wind velocity at 10 m or 20 m height,
(iii) number of cattle available in a village or a cluster community.

(A) PV – Diesel (B) Wind – Diesel (C) Biomass – Diesel
(D) Wind – PV (E) Micro hydel – PV (F) Biogas – Solar Thermal
(G) Solar – Biomass (H) Electric and electric hybrid vehicles

Diesel-PV, Wind-PV, Microhydel-PV

PV Hybrid with Diesel Generator

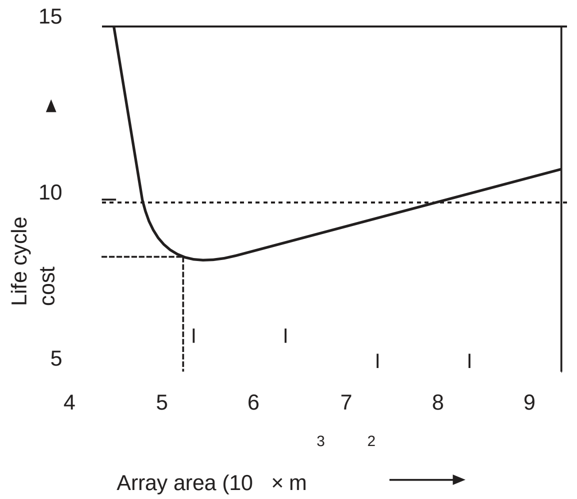
Renewable energy technologies are possible for electrification of remote villages including small hydro, wind, biomass and solar energy, yet solar PV lighting remains the most preferred. Such systems are used in Orissa, Assam, Sikkim, Jammu and Kashmir, and Uttarakhand. This power plant contains one PV array with a Diesel electric generator and a battery bank. Energy generated from PV array feeds load demand and then charges the battery bank. Diesel generator keeps the battery fully charged and some time supplies load demand when PV output is not sufficient and battery charge is low to supplement. Figure is a block diagram of such a power plant where.



Power conditioner perform three functions:

(i) To convert alternating current (ac) diesel generated output into direct current (dc) for charging battery bank.
(ii) To invert direct current (dc) from PV array and battery bank into ac for feeding load.
(iii) To regulate battery current and voltage for input from generator and output for load.

Several experiments have been carried out to find where 10 per cent diesel fuel would be required with a given solar PV array area to replace 90 per cent of diesel fuel that would be consumed for a diesel system only. Experimental values have been used to draw a graph. Figure shows 'life cycle cost' versus array area ($10^3 \times m^2$).



Graph indicates a minimum cost point corresponding to a cost effective design for a PV-diesel hybrid power plant where PV has replaced 90 per cent of the diesel fuel; had it been a diesel system only. Thus, a PV-diesel hybrid power plant ensures continuous power supply andis more cost effective as compared to stand alone PV system or stand alone diesel .

Wind-PV Hybrid System

Wind and solar hybrid energy systems are located in open terrains away from multistorey buildings and forests. Locations are selected in those areas where the sunshine and wind are favourable for more than 8 months during a year.

A schematic wind-PV hybrid system is shown in Figure 15.5. During the day when sun shines, the solar photovoltaic plant generate dc electric energy conditioner provided, converts dc to ac and supplies power to the load. During favourable wind speed, wind turbine generator produce ac electrical power. It supplies power to the load and excess energy after conversion to dc is stored by the battery bank. The plant may operate as stand alone load or may be connected to the state grid

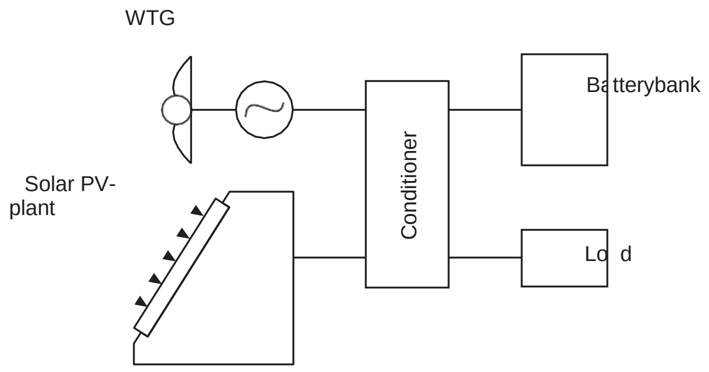


Figure 15.5 Wind-PV hybrid system.

Micro Hydel-PV Hybrid System

Micro hydel (up to 100 kW) power stations are low head (less than 3 m) installations and provide decentralised power in mountain regions, also in plains on canal falls. In remote areas of J & K, boarder districts of Arunachal Pradesh micro hydro power plants are the only source of energy. With the help of micro hydro power, rural electrification can be achieved besides providing power for pumped irrigation and grinding mills.

In Arunachal Pradesh, 425 villages are being electrified by completing 46 small/micro hydro power projects.

However, there are 1058 villages which cannot be illuminated by micro hydel projects asat several locations, head is very low, while at other, quantity of water is small. Solution is to provide micro hydel-PV hybrid system as sunshine is available practically at all locations.

Portable micro hydel sets of 15 kW capacity are installed with solar PV panels to compliment each other as given in Figure 15.6.

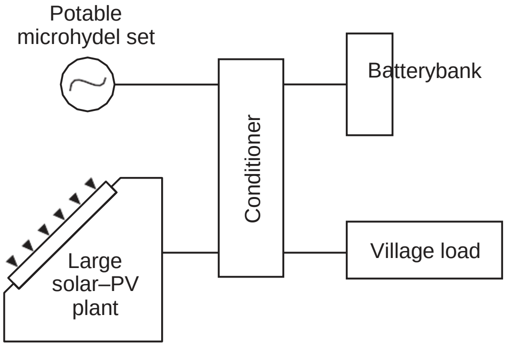


Figure 15.6 Micro hydel-PV hybrid system.

Micro hydel systems are provided with small dam store water to be used during night when solar PV panels stops power supply. A battery bank may be provided for emergency power supply. A battery bank may be provided for emergency power supply wherever required. Load management is carried out to maintain continuity of supply for 24 hours matching with the capacity of generating equipment.

Electric and hybrid electric vehicles.

Electric vehicles are propelled by an electric motor powered by rechargeable battery packs. These vehicles need not have Internal Combustion Engines (IEC) system, the drive train and fueltank.

Electric motor replaces the engine and it gets power from rechargeable batteries through a controller. The electronic motor controller provides electric power to the motor based on inputs from accelerator. Electric power is delivered from battery pack, which is like the fuel tank ofan electric (e) vehicle. However, they are slow in speed and move only up to 80 km on a charge. Full battery recharge takes nearly four hours.

A hybrid electric vehicle combines a conventional internal combustion engine with an electric propulsion system. Presence of electric power train is intended to achieve better fuel economy than conventioanl vehicle or better performance. Most common of HEV is the hybrid electric car.

Hybrid vehicles use both petrol and electric propulsion systems. In such vehicles, the electric motor provides a boost during starting and is recharged during vehicle operations. This cuts emissions significantly and improves fuel economy.

E-Vehicle Need

E-vehicle are gaining popularity concerning to: (i) High oil prices (ii) Green house gas emissions (iii) Ambient air quality Concern over high oil prices and stringency in pollution and climate regulations have spurred new interest in e-vehicles. These are fuel-efficient, as, technically conversion of electrical energy into motive power is more efficient than burning fuel in an internal combustion engine. According to California Air Resource Board, fuel efficiency of an e-vehicle is three times higher than convention car. As electricity costs less than oil, operating cost per km falls to a fraction of a petrol car.