UNIT I
RENEWABLE ENERGY (RE) SOURCES

Environmental consequences of fossil fuel use, Importance of renewable sources of energy, Sustainable Design and development, Types of RE sources, Limitations of RE sources, Present Indian and international energy scenario of conventional and RE sources.

Introduction

Renewable energy is energy produced from sources that do not deplete or can be replenished or refilled within a human's life time. The most common examples of renewable energy sources include wind, solar, geothermal, biomass, and hydropower. Non-renewable energy comes from sources that will run out or will not be replenished in our lifetime or even in many lifetimes. Most of the non-renewable energy sources are fossil fuels, which influence the environment greatly and contribute to harmful global warming and climate change. Renewable energy is sustainable as it originates from sources that are inexhaustible (unlike fossil fuels). Despite of many advantages renewable energy sources have certain limitations like higher capital cost, intermittency, storage capabilities, geographic limitations, etc., which make them inevitable.

Environmental consequences of fossil fuel use

Fossil fuels are formed from the fossilized, buried remains of plants and animals that lived millions of years ago so they are named accordingly. Fossil fuels, which include coal, natural gas, petroleum, shale oil, and bitumen, are the main sources of heat and electrical energy. All these fuels contain the major constituents like carbon, hydrogen, oxygen and other materials like metal, sulphur and nitrogen compounds. During the combustion process different pollutants like fly ash, sulphur oxides (SO_2 and SO_3), nitrogen oxides ($NO_x = NO_2 + NO$) and volatile organic compounds are emitted. Gross emission of these pollutants constitutes to atmospheric pollution and can affect human beings and environment.

> *TEDA is Tamil Nadu Energy Development Agency. It is an independent agency setup by Government of Tamil Nadu in the year 1984, as a registered society with a specific purpose – to create awareness and migrate the State from using fossil fuels to renewable energy.*

Atmospheric Pollution

Atmospheric pollution occurs in many forms but can generally be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere. Chemicals discharged into the air that have a direct impact on the environment are called primary pollutants. These primary pollutants sometimes react with other chemicals in the air to produce secondary pollutants. The most commonly found air pollutants are oxides of Sulphur, oxides of nitrogen, oxides of carbon, hydrocarbons, particulates (fly ash).

Oxides of Sulphur (SO2)

Sulphur dioxide (SO_2) is a colourless gas with a sharp, irritating odour. It is produced by burning fossil fuels and by the smelting of mineral ores that contain sulphur. Erupting volcanoes can be a significant natural source of sulphur dioxide emissions.

Environmental effects

When sulphur dioxide combines with water and air, it forms sulphuric acid, which is the main component of acid rain. Acid rain can:

- Cause deforestation
- Acidify waterways to the detriment of aquatic life
- Corrode building materials and paints.

Health effects

- Sulphur dioxide affects the respiratory system, particularly lung function and can irritate the eyes.
- Sulphur dioxide irritates the respiratory tract and increases the risk of tract infections.
- It causes coughing, mucus secretion and aggravates conditions such as asthma and chronic bronchitis.

Oxides of Nitrogen (NOx)

The term nitrogen oxides (NOx) describes a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2), which are gases produced from natural sources, motor vehicles and other fuel burning processes. Nitric oxide is colourless and is oxidised in the atmosphere to form nitrogen dioxide. Nitrogen dioxide has an odour and is an acidic and highly corrosive gas that can affect our health and environment. In poorly ventilated situations, indoor domestic appliances such as gas stoves and gas or wood heaters can be significant sources of nitrogen oxides.

Environmental and health effects of nitrogen oxides

- Elevated levels of nitrogen dioxide can cause damage to the human respiratory tract and increase a person's vulnerability to respiratory infections and asthma.
- Long-term exposure to high levels of nitrogen dioxide can cause chronic lung disease.
- It may also affect the senses of smell an odour.
- High levels of nitrogen dioxide are also harmful to vegetation, damaging foliage, decreasing growth or reducing crop yields.
- Nitrogen dioxide can fade and discolour furnishings and fabrics, reduce visibility and react with surfaces.

Oxides of Carbon (CO, CO2)

Carbon monoxide is a colourless, odourless gas formed when substances containing carbon (such as petrol, gas, coal and wood) are burned with an insufficient supply of air. Motor vehicles are the main source of carbon monoxide pollution in urban areas.

Health effects

- Carbon monoxide has serious health impacts on humans and animals.
- When inhaled, the carbon monoxide bonds to the haemoglobin in the blood in place of oxygen to become carboxyhaemoglobin. This reduces the oxygen-carrying capacity of the red blood cells and decreases the supply of oxygen to tissues and organs, especially the heart and brain.
- For people with cardiovascular disease, this can be a serious problem.
- The effects are reversible, so symptoms decrease gradually when exposure to carbon monoxide stops.

Hydrocarbons

A hydrocarbon is any compound that consists of carbon and hydrogen atoms. They are organic compounds. Because of the unique covalent nature of carbon, there are thousands upon thousands of hydrocarbons in the world. Gasoline, petroleum, coal, kerosene, charcoal, natural gas, etc., are all a form of hydrocarbons.

Environmental and health effects of hydrocarbons

- These substances contribute to the greenhouse effect and climate change
- Deplete the ozone
- Reduce photosynthetic ability of plants
- Increase occurrences of cancer and respiratory disorders in humans.

India uses about 500 million T of coal every year to produce electricity, about 3.6 trillion cubic feet of natural gas for power, chemicals and fertilizers and over 160 million T of oil for transport and industry.

Particulates (Fly Ash)

Fly ash is composed of tiny, airborne particles and is thus considered as a type of particulate matter or particle pollution. Fly ash contains different trace elements (heavy metals).

Environmental and health effects of fly ash

Wet ash ponds can pollute groundwater and if ingested, the arsenic contaminated water increases a person's risk of developing cancer.

Inhalation or ingestion of the toxins in fly ash can have impacts on the nervous system, causing cognitive defects, developmental delays, and behavioural problems while also increasing a person's chance of developing lung disease, kidney disease, and gastrointestinal illness.

When ash is disposed in dry landfills or wet ponds, there are associated environmental effects. Wet surface impoundments account for a fifth of coal ash disposal. These wet impoundments can be an issue if they do not have proper liners for the landfill or pond to prevent leaking and leaching. Both leaking and leaching lead to groundwater contamination.

Leaching is a process that occurs when fly ash is wet, and it simply means that the toxic components of the ash dissolve out and percolate through water. This groundwater contamination can be harmful to human health if the groundwater is a source of drinking water. In addition to leaching, fly ash toxics are able to travel through the environment as a result of erosion, runoff, or through the air as fine dust. The fact that the chemicals in the ash can escape and move through the environment is what makes fly ash harmful

Green House Gas Emissions from Various Energy Sources

Greenhouse gases are gases in earth's atmosphere that trap heat. They let sunlight pass through the atmosphere, but they prevent the heat that the sunlight brings from leaving the atmosphere.

Most of the emissions of human-caused (anthropogenic) greenhouse gases come primarily from burning fossil fuels like coal, hydrocarbon gas liquids, natural gas and petroleum, for energy use. Global warming or climate change has been observed for around 150 years and is a growth in this phenomenon.

The other GHG that are emitted as a result of human activity are

- Methane (CH_4), which comes from landfills, coal mines, agriculture, and oil and natural gas operations
- Nitrous oxide (N_2O), which comes from using nitrogen fertilizers and certain industrial and waste management processes and burning fossil fuels
- High global warming potential (GWP) gases, which are human-made industrial gases
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)
- Nitrogen trifluoride (NF_3)

Importance of renewable sources of energy

Renewable energies are obtained from sources of clean, inexhaustible and increasingly competitive energy. They differ from fossil fuels principally in their diversity, abundance and potential for use anywhere on the planet. In addition, they produce neither greenhouse gases – which cause climate change – nor polluting emissions. Their costs are also falling at a sustainable rate, whereas the general cost trend for fossil fuels is in the opposite direction in spite of their present volatility.

Renewable energies received assistance from the international community through the Paris Accord signed at the World Climate Summit held in Paris on December 2015. The agreement, which will enter into force in 2020, establishes, for the first time in history, a binding global objective. Nearly 200 signatory countries pledged to reduce their emissions so that the average temperature of the planet at the end of the current century remains well below 2° C, the limit above which climate change will have more catastrophic effects. However the aim is to keep it to 1.5° C.

Of the total renewable energy capacity of about 32,730MW installed all over India, TN alone has about 8326.86MW, thus about 25.44% of the total installed capacity, with Tamil Nadu having about 34.31% of the total wind energy installed capacity in India.

Other importance of renewable energy are:

Indispensable partner in the fight against climate change: Renewables do not emit greenhouse gases in energy generation processes, making them the cleanest, most viable solution to prevent environmental degradation. Most renewable energy sources produce little to no global warming emissions. Even when including “life cycle” emissions of clean energy (i.e, the emissions from each stage of manufacturing, installation, operation, decommissioning), the global warming emissions associated with renewable energy are minimal.

Inexhaustible: Compared to conventional energy sources such as coal, gas, oil and nuclear - reserves of which are finite - clean energies are just as available as the sun from which they originate and adapt to natural cycles, hence their name “renewables”. This makes them an essential element in a sustainable energy system that allows development today without risking that of future generations.

Reducing energy dependence: The indigenous nature of clean sources gives local economies an advantage and brings meaning to the term “energy independence”. Dependence on fossil fuel imports results in subordination to the economic and political short-term goals of the supplier country, which can compromise the security of energy supply.

Increasingly competitive: The main renewable technologies – such as wind and solar photovoltaic – are drastically reducing their costs, such that they are fully competitive with conventional sources in a growing number of locations. Economies of scale and innovation are already resulting in renewable energies becoming the most sustainable solution, not only environmentally but also economically, for powering the world. Renewable energy is providing affordable electricity across the country right now, and can help stabilize energy prices in the future.

Benefiting from a favourable political horizon: The international community has understood its obligation to firm up the transition towards a low-carbon economy in order to guarantee a sustainable future for the planet. International consensus in favour of the “de-carbonization” of the economy constitutes a very favourable framework for the promotion of clean energy technologies.

Improved public health: Wind, solar, and hydroelectric systems generate electricity with no associated air pollution emissions. Geothermal and biomass systems emit some air pollutants, though total air emissions are generally much lower than those of coal- and natural gas-fired power plants. In addition, wind and solar energy require essentially no water to operate and thus do not pollute water resources or strain supplies by competing with agriculture, drinking water, or other important water needs.

Jobs and other economic benefits: Compared with fossil fuel technologies, which are typically mechanized and capital intensive, the renewable energy industry is more labour intensive. Solar panels need humans to install them; wind farms need technicians for maintenance. This means that, on average, more jobs are created for each unit of electricity generated from renewable sources than from fossil fuels.

Reliability and resilience: Wind and solar are less prone to large-scale failure because they are distributed and modular. Distributed systems are spread out over a large geographical area, so a severe weather event in one location will not cut off power to an entire region. Modular systems are composed of numerous individual wind turbines or solar arrays. Even if some of the equipment in the system is damaged, the rest can typically continue to operate. Wind and solar photovoltaic systems do not require water to generate electricity and can operate reliably in conditions that may otherwise require closing a fossil fuel-powered plant due to water scarcity.

Sl. No	Renewable Energy	Advanatges
1	Solar energy (From the sun)	• Sunlight does not produce any wastes or pollutants for environment. • It is free to collect sunlight as it is always present
2	The Wind	• The wind does not produce any wastes or pollutants for environment. • It takes up little ground space
3	Hydropower	• Hydropower is considered as inexpensive source. • It does not leave any harmful chemicals as waste.
4	Biomass	• Growing biomass crops use up carbon dioxide and increase oxygen

		• Biomass is always available, thus, it can be used as renewable resource.
5	Geothermal Energy:	• For heating and cooling, geothermal heat pump systems use 25% to 50% less electricity than conventional systems. • Biomass is always available and can be used as a renewable resource

Sustainable Design and development

Sustainable energy is a form of energy that meet our today's demand of energy without putting them in danger of getting expired or depleted and can be used over and over again. Sustainable energy should be widely encouraged as it do not cause any harm to the environment and is available widely free of cost. All renewable energy sources like solar, wind, geothermal, hydropower and ocean energy are sustainable as they are stable and available in plenty.

Sustainable energy sources

Fossil fuels are not considered as sustainable energy sources because they are limited, cause immense pollution by releasing harmful gases and are not available everywhere on earth. There are many forms of sustainable energy sources that can be incorporated by countries to stop the use of fossil fuels. Sustainable energy does not include any sources that are derived from fossil fuels or waste products. This energy is replenishable and helps to reduce greenhouse gas emissions and causes no damage to the environment. Hydropower is the most common form of alternative energy used around the world.

Need for Sustainable Energy

During ancient times, wood, timber and waste products were the only major energy sources. In short, biomass was the only way to get energy. When more technology was developed, fossil fuels like coal, oil and natural gas were discovered. Fossil fuels proved boom to the mankind as they were widely available and could be harnessed easily. When these fossil fuels were started using extensively by all the countries across the globe, they led to degradation of environment. Coal and oil are two of the major sources that produce large amount of carbon dioxide in the air. This led to increase in global warming. Also, few countries have hold on these valuable products which led to the rise in prices of these fuels. Now, with rising prices, increasing air pollution and risk of getting expired soon, forced scientists to look out for some alternative or renewable energy sources. Sustainable Energy came into the picture as it could meet our today's increasing demand of energy and also provide us with an option to make use of them in future also.

Sustainable Design

Sustainable design seeks to reduce negative impacts on the environment and the health and comfort of human beings, thereby improving performance of energy systems. Sustainable design principles include the ability to:

- optimize site potential;
- minimize non-renewable energy consumption;
- use environmentally preferable products;
- protect and conserve water;
- enhance indoor environmental quality; and
- optimize operational and maintenance practices.

Utilizing a sustainable design philosophy encourages decisions at each phase of the design process that will reduce negative impacts on the environment and the health of mankind, without compromising the bottom line. It is an integrated, holistic approach that encourages compromise and trade-offs. Such an integrated approach positively impacts all phases of an energy source life-cycle, including design, construction, operation and decommissioning.

- *25068 Solar domestic lighting systems installed in Tamil Nadu with assistance from Government.*
- *6095 Solar street lights installed in pubic places/streets mostly in village panchayats with Government assistance and active support and involvement of Rural Development Department.*

Examples of sustainable green buildings in Chennai

Anna Centenary Library

The Anna Centenary Library is located at Kotturpuram, Chennai and has also been awarded the LEED (Leadership in Energy and Environmental Design) Gold rating. An artificial tree is established at the middle of the library to promote awareness about conservation of trees. Water is recycled by an on-plant treatment unit and subsequently uses 64% less water than any other building of the same size. Power conservation steps are also taken which translates to a saving of 17.5% than buildings of the same size.

Government Super Specialty Hospital

Govt. Super Specialty Hospital which is located at Triplicane contributes to the ever-growing list of Green Buildings in Chennai. The large building has adopted excellent eco-conservative methods and continues to be successful in preserving energy and water resources

World Bank

The World Bank is located at Tharamani and is a certified green building. The office has always strived hard to entwine environmental concern with development and operational strategy. The office boasts of water recycling plant, carbon sensors, automated lighting, etc., Also, the World Bank office at Chennai is its largest branch outside of Washington DC and encompasses a wide area of 1,28,000 square feet which showcases the steadfast dedication shown by the employees and the administrators to conserve natural resources.

Express Avenue

Located at Royapettah, Express Avenue is also recognized as a green building which further shows that builders are becoming conscious about the environment. The mall is covered with windows made up of an environmentally-conservative material or more specifically with tensile fabric. It also has an in-built sewage treatment plant and is worthy of a place in the top 10 green buildings list.

Raintree Hotel

The Raintree Hotel is considered to be one of the first Green Buildings of South India and has an eco-sensitive policy. The hotel has adopted a set of eco-friendly steps without compromising quality for the customers. Water for the air-conditioners is processed and recycled using a sewage treatment plant which helps preserve water resources. The heat generated by the air conditioners is used to heat the waters in the washroom. The employees working at the Raintree Hotel are also made to emphasize and adopt the eco-sensitive policy.

Solar Panels

In Brisbane Australia, the Kurilpa Bridge holds the title of the largest foot bridge powered by solar panels. Solar photovoltaic systems are the easiest and most common form of renewable energy within residential homes and now in public structures as well. The Kurilpa bridge save 37.8 tonnes of carbon emissions yearly as its LED lighting system is powered solely by the sun.

Wind Turbines

The Bahrain World Trade Centre is a revolutionary structure. It is the first commercial building to use wind turbines on a horizontal axis, attached to the actual building for electricity. The wind powers a generator resulting in electricity. The Bahrain World Trade Centre has just over 15% of its entire energy needs powered by the 675 kW (kilowatt) turbines.

Renewable energy and sustainable development

Renewable energy has a direct relationship with sustainable development through its impact on human development and economic productivity. Renewable energy sources provide opportunities in energy security, social and economic development, energy access, climate change mitigation and reduction of environmental and health impact.

Energy security

The notion of energy security is generally used, however there is no consensus on its precise interpretation. Yet, the concern in energy security is based on the idea that there is a continuous supply of energy, which is critical for the running of an economy. Renewable energy sources are evenly distributed around the globe as compared to fossils and in general less traded on the market. Renewable energy reduces energy imports and contribute diversification of the portfolio of supply options and reduce an economy's vulnerability to price volatility and represent opportunities to enhance energy security across the globe. The introduction of renewable energy can also make contribution to increasing the reliability of energy services, to be specific in areas that often suffer from insufficient grid access. A diverse portfolio of energy sources together with good management and system design can help to enhance security.

Social and economic development

Generally, the energy sector has been perceived as a key to economic development with a strong correlation between economic growth and expansion of energy consumption. Globally, per capita incomes are positively correlated with per capita energy use and economic growth can be identified as the most essential factor behind increasing energy consumption in the last decades. It in turn creates employment; renewable energy study in 2008, proved that employment from renewable energy technologies was about 2.3 million jobs worldwide, which also has improved health, education, gender equality and environmental safety.

Energy access

The sustainable development seeks to ensure that energy is clean, affordable, available and accessible to all and this can be achieved with renewable energy source since they are generally distributed across the globe. Access concerns need to be understood in a local context and in most countries there is an obvious difference between electrification in the urban and rural areas, this is especially true in sub-Saharan Africa and South Asian region. Distributed grids based on the renewable energy are generally more competitive in rural areas with significant distances to the national grid and the low levels of rural electrification offer substantial openings for renewable energy-based mini-grid systems to provide them with electricity access.

Climate change mitigation and reduction of environmental and health impacts

Renewable energy sources used in energy generation helps to reduce greenhouse gases which mitigates climate change, reduce environmental and health complications associated with pollutants from fossil fuel sources of energy.

The Indian renewable energy is ranked fourth in wind power, fifth in solar power and fifth in renewable power installed capacity as of 2018. In 2019, India was ranked as the fourth most attractive renewable energy market in the world.

Types of RE sources

Alternative or renewable energy comes from natural processes that can reliably produce cheap energy with minimal impact to the environment. The most popular renewable energy sources currently are:

- Solar energy
- Wind energy
- Hydro energy
- Tidal energy
- Geothermal energy
- Biomass energy
- Hydrogen

Solar energy

Sunlight is a renewable resource, and its most direct use is achieved by capturing the sun's energy. A variety of solar energy technologies are used to convert the sun's energy and light into heat: illumination, hot water, electricity and (paradoxically) cooling systems for businesses and industry.

Photovoltaic (PV) systems use solar cells to convert sunlight into electricity. Solar hot water systems can be used to heat buildings by circulating water through flat-plate solar collectors. Mirrored dishes that are focused to boil water in a conventional steam generator can produce electricity by concentrating the sun's heat. Commercial and industrial buildings can also leverage the sun's energy for larger-scale needs such as ventilation, heating, and cooling. Finally, thoughtful architectural designs can passively take advantage of the sun as a source of light for heating and cooling.

Homeowners, businesses and government entities can take advantage of the benefits of solar power in many ways: Install a home solar system or commercial solar panels; construct or retrofit a building to incorporate solar hot water, cooling or ventilation systems; design from scratch structures that take advantage of the sun's natural attributes for passive heating and lighting.

Wind energy

Wind can be considered a form of solar energy because of the uneven heating and cooling of the atmosphere cause winds (as well as the rotation of the earth and other topographical factors). Wind flow can be captured by wind turbines and converted into electricity. On a smaller scale, windmills are still used today to pump water on farms.

Commercial grade wind-powered generating systems are available to meet the renewable energy needs of many organizations.

Single-wind turbines can generate electricity to supplement an existing electrical supply. When the wind blows, the power generated by the system goes to offset the need for utility-supplied electricity.

Utility-scale wind farms generate electricity that can be purchased on the wholesale power market, either contractually or through a competitive bid process.

Hydro energy

Hydropower is not a new invention, though the waterwheels once used to operate the gristmills and sawmills of early America are now largely functioning as historic sites and museums. Today, the kinetic energy of flowing rivers is captured in a much different way and converted into hydroelectricity. Probably the most familiar type of hydroelectric power is generated by a system where dams are constructed to store water in a reservoir which, when released, flows through turbines to produce electricity. This is known as "pumped-storage hydropower," where water is cycled between lower and upper reservoirs to control electricity generation between times of low and peak demand.

Another type, called "run-of-river hydropower," funnels a portion of river flow through a channel and does not require a dam. Hydropower plants can range in size from massive projects such as Hoover Dam to micro-hydroelectric power systems. The direct use of hydroelectric power is naturally dependent on geographic location. Assuming a dependable waterway source is accessible and available, micro-hydroelectric plants can be constructed to supply electricity to farm and ranch operations or small municipalities.

Ocean energy

There are two types of energy that can be produced by the ocean: thermal energy from the sun's heat and mechanical energy from the motion of tides and waves.

Ocean thermal energy can be converted into electricity using a few different systems that rely on warm surface water temperatures. "Ocean mechanical energy" harnesses the ebbs and flows of tides caused by the rotation of the earth and the gravitational influence of the moon. Energy from wind-driven waves can also be converted and used to help reduce one's electricity costs.

There are also lesser developed technologies that leverage ocean currents, ocean winds and salinity gradients as sources of power conversion.

Cold ocean water from deep below the surface can be used to cool buildings (with desalinated water often produced as a by-product), and seaside communities can employ the methods to tap natural ocean energy described above to supplement municipal power and energy needs.

Ocean energy is an evolving source of alternative energy production, and with more than 70 percent of the surface of our planet covered by ocean, its future looks promising, depending on geographies and regulatory guidelines.

Geothermal energy

Geothermal energy is derived from the heat of the earth. This heat can be sourced close to the surface or from heated rock and reservoirs of hot water miles beneath our feet. Geothermal power plants harness these heat sources to generate electricity. On a much smaller scale, a geothermal heat pump system can leverage the constant temperature of the ground found just 10 feet under the surface to help supply heat to a nearby building in the winter or to help cool it in the summer.

Geothermal energy can be part of a commercial utility energy solution on a large scale or can be part of a sustainable practice on a local level. Direct use of geothermal energy may include Heating office buildings or manufacturing plants; helping to grow greenhouse plants; heating water at fish farms; and aiding with various industrial processes (e.g., pasteurizing milk).

Biomass energy

Bioenergy is a type of renewable energy derived from biomass to create heat and electricity or to produce liquid fuels such as ethanol and biodiesel used for transportation.

Biomass refers to any organic matter coming from recently living plants or animals. Even though bioenergy generates about the same amount of carbon dioxide as fossil fuels, the replacement plants are grown as biomass to remove an equal amount of CO_2 from the atmosphere, keeping the environmental impact relatively neutral.

There are a variety of systems used to generate this type of electricity, ranging from directly burning biomass to capturing and using methane gas produced by the natural decomposition of organic material.

Manufacturing facilities can be equipped to burn biomass directly to produce steam captured by a turbine to generate electricity. In some cases, this process can have a dual purpose by powering the facility as well as heating it. For example, paper mills can use wood waste to produce electricity and steam for heating. Farm operations can convert waste from livestock into electricity using small, modular systems. Towns can tap the methane gas created by the anaerobic digestion of organic waste in landfills and use it as fuel for generating electricity.

Hydrogen - High Energy/Low Pollution

Hydrogen is the simplest (comprised of one proton and one electron) and the most abundant element in the universe, yet it does not occur naturally as a gas on earth. Instead, it is found in organic compounds (hydrocarbons such as gasoline, natural gas, methanol, and propane) and water (H_2O). Hydrogen can also be produced under certain conditions by some algae and bacteria using sunlight as an energy source.

Hydrogen is high in energy yet produces little or no pollution when burned. Liquid hydrogen has been used to launch space shuttles and other rockets into orbit since the 1950s. Hydrogen fuel cells convert the potential chemical energy of hydrogen into electricity, with pure water and heat as the only by-products. However, the commercialization of these fuel cells as a practical source of green energy will likely be limited until costs come down and durability improves. Almost all the hydrogen used in the United States is used in industry to refine petroleum, treat metals, produce fertilizer and process foods. In addition, hydrogen fuel cells are used as an energy source where hydrogen and oxygen atoms are combined to generate electricity.

There are also currently a few hundred hydrogen-powered vehicles operating in the United States, a number that could increase as the cost of fuel cell production drops and the number of refuelling stations increases. Other practical applications for this type of renewable energy include large fuel cells providing emergency electricity for buildings and remote locations, electric motor vehicles powered by hydrogen fuel cells and marine vessels powered by hydrogen fuel cells.

Wind power accounted for the highest at 46% (around 36 GW), followed by solar with a share of 36% (30 GW). The remaining market was captured by biomass at 12% (9 GW) and small hydro projects catering to 6% (5 GW).

Limitations of RE sources

Despite of advantages when it comes to renewable energy, the positives outweigh the negatives. Some of the limitations of renewable energy sources are;

- Some type of renewable energy sources is location-based and commercially feasible
- These types of energies need storage capacities
- Some energy sources cause pollution.
- Renewable energies frequently need funding for making them reasonable

- Some types of energy sources require a huge space

Limitations of solar

1) **Higher Costs than Fossil Energy Forms** –It has been estimated that solar power costs fall by 20% for every 100% increase in supply. The Solar Cost Curve has declined massively in the last 2 years as cheap Chinese solar production has made solar panel costs come down by 50%. Note in the next 4-5 years expect an average decline of around 10% per year which would make solar energy competitive with fossil fuel energy in most parts of the world. Current solar power costs between 15-30/Kwh depending on the solar radiation of the particular location, type of technology used etc.
2) **Intermittent Nature** – One of the biggest problems of Solar Power is that it is intermittent in nature as it generates energy only when the sun shines. This problem can be solved with energy storage however this leads to additional costs. Smart Grids and Cheaper Energy Storage in the future should allow even higher penetrations of Wind and Solar Power possible.

3) **High Capital Investment** – A Solar Plant can cost around 450 lakhs to be spent in building 1 Megawatt. This is said to be too high, however the costs of energy can only be compared by Levelized Cost of Energy (LCOE) which calculates the cost of energy over the lifetime calculating the capex, fuel costs, maintenance, security and insurance costs. While it is true that the initial capital investment for solar power is quite high, the lifecycle cost of solar energy is not that high.

4) **Cannot be Built Anywhere** – This disadvantage of Solar Energy is present with other forms of Energy as well. Some forms of Energy are just better suited to some places. For example you can’t build a nuclear plant on top of an earthquake prone region, you can’t build a wind farm near the Dead Sea., etc.,

Limitations of Hydro Energy

1) **Environmental, Dislocation and Tribal Rights** – Large Dam construction especially in populated areas leads to massive Tribal Displacement, Loss of Livelihood and Religious Infringement as potentially sacred Land is occupied by the Government.

2) **Wildlife and Fishes get affected** – The Fishes are the most affected species from Dam Construction as the normal flow of the river is completely changed from its river character to a lake one. Submergence of land also leads to ecological destruction of the habitat of land based wildlife.

3) **Earthquake Vulnerability** – Large Dam Construction has been linked to increased propensity of Earthquakes. Massive Earthquakes in China and Uttarakhand in India were linked to the building of Massive Dams in these countries

4) **Siltation** – When water flows it has the ability to transport particles heavier than itself downstream. This has a negative effect on dams and subsequently their power stations, particularly those on rivers or within catchment areas with high siltation.

5) **Tail Risk, Dam Failure** – Because large conventional dammed-hydro facilities hold back large volumes of water, a failure due to poor construction, terrorism, or other cause can be catastrophic to downriver settlements and infrastructure. Dam failures have been some of the largest man-made disasters in history.

6) **Cannot be Built Anywhere** – This disadvantage of Hydro Energy is present with other forms of Energy as well. Some forms of Energy are just better suited to some places. For example you can’t build a nuclear plant on top of an earthquake prone region, you can’t build a wind farm near the Dead Sea etc. Hydro Energy can only be built in particular places though enough of those places exist globally.

7) **Long Gestation Time** – The time to construct a large hydro power project can take between 5-10 years which leads to time and cost overruns.

Limitations of Biomass Energy

1) **Pollution in case of Poor Technology** – Biomass Energy can lead to air pollution in the form of char if the biomass is not completely combusted. This happens in the case of biomass energy being produced in rural areas through bad technology.

2) **Feedstock Problems** – One of the biggest drawbacks of biomass energy is the problem of feedstock. The plants are forced to run at lower utilization leading to higher costs if feedstock is not available due to some reason like a drought.
3) **Good Management Required** – The operations of a biomass plant requires very good management otherwise it may run into losses or even in some cases have to shut down. It requires a skill of high order to run the plant optimally and make use of alternative feedstock in case the regular one is not available.

4) **Limited Potential** – Biomass Energy has smaller potential than compared to other forms of energy like solar, hydro, etc.,

5) **Controversial** – Large Biomass Plants like the one in Scotland have run into massive protests as people think it might lead to air pollution and health hazards if constructed near their homes.

Limitations of Wind Energy

1) **Low Persistent Noise** – There have been a large number of complaints about the persistent level of low level noise from the whirring of the blades of a wind turbine. There have been cases reported about animals on farms getting affected by wind turbine noise.

2) **Loss of Scenery** – The sight of giant 200 metres tall towers has drawn objections from neighbours about wind power leading to loss of scenery and beauty.

3) **Land usage** – Wind Turbines can sometimes use large amounts of land if not properly planned and built. The construction of roads to access the wind farms etc also takes up some land.

4) **Intermittent Nature** – Wind Power is intermittent in nature as it generates energy only when the wind blows. This problem can be solved with energy storage however this leads to additional costs.

Limitations of Geothermal Energy

1) **Long Gestation Time Leading to Cost Overruns** – The Gestation Time for permitting, financing, drilling, etc., can easily take 5-7 years to develop a geothermal energy field.

2) **Slow Technology Improvement** – Geothermal Energy has the potential to generate 100s of gigawatts of electricity through new techniques like Enhanced Geothermal Energy. However the technology improvement has been slow with setbacks.

3) Financing is the biggest problem in developing projects particularly for small project developers in this industry. There are few big geothermal developers like Chevron and Calpine.

4) **Regulations** – Drilling for new geothermal energy fields, buying of geothermal companies in foreign geographies faces innumerable hurdles.

5) **Limited Locations** – Geothermal Energy can only be built in places which have the geological characteristics favourable to generation of geothermal power.

Limitations of Tidal Energy

1) **High Initial Capital Investment** – Tidal Barrages require massive investment to construct a Barrage or Dam across a river estuary. This is comparable to construction of a massive dam for Hydro Power. This is perhaps the biggest disadvantage of this technology.

2) **Limited Locations** – The US DOE estimates that there are only about 40 locations in the world capable of supporting Tidal Barrages. This is because this Tidal Energy Technology requires sizable Tides for the Power Plant to be built. The limited number of locations is a big hurdle.

3) **Effect on Marine Life** – The operation of commercial Tidal Power Stations has known to moderately affect the marine life around the Power Plant. It leads to disruption in movement and growth of fishes and other marine life. Can also lead to increase in silt. Turbines can also kill fish passing through it.
4) **Immature Technology** – Except for Tidal Barrage, the other forms of Technology generating Tidal or Wave Power are quite immature, costly and unproven.

5) **Long Gestation Time** – The cost and time overruns can be huge for Tidal Power Plants leading to their cancellation.

6) **Difficulty in Transmission of Tidal Electricity** – Some forms of Tidal Power generate power quite far away from the consumption of electricity. Transportation of Tidal Energy can be quite cumbersome and expensive.

7) **Weather Effects** – Severe Weather like Storms and Typhoons can be quite devastating on the Tidal Power Equipment especially those places on the Sea Floor.

The Ministry of New and Renewable Energy, Government of India, has formulated an action plan to achieve a total capacity of 60 GW from hydro power and 175 GW from other RES by March, 2022, which includes 100 GW of Solar power, 60 GW from wind power, 10 GW from biomass power and 5 GW from small hydro power.

Present Indian and international energy scenario of conventional and RE sources

The World Energy Council has been developing and using World Energy Scenarios for over a decade to support its global member network of energy leaders, to clarify complexity, and to realise new opportunities for successfully managing global energy transition. World energy consumption is the total energy produced and used by the entire human civilization. Energy is essential for every activity of life. There is a strong positive correlation between energy use and the quality of life. At global level, per capita income of a country is directly proportional to the per capita energy consumption.

Country	Installed capacity Unit: TWh
United States	3,291
Russia	1,008
Japan	903
China	754
Germany	537
Canada	520
France	464
India	337
United Kingdom	321
Ukraine	253
Brazil	242
Italy	226

Table: 1. Installed capacity of conventional energy sources across globe

International energy scenario of conventional sources

Oil

Oil reserves at the end of 2018 totalled 1730 billion barrels, up 2 billion barrels with respect to 2017. The global R/P ratio shows that oil reserves in 2018 accounted for 50 years of current production.

Regionally, South & Central America has the highest R/P ratio (136 years) while Europe has the lowest (11 years). OPEC (Organization of the Petroleum Exporting Countries) holds 71.8% of global reserves. The top countries in terms of reserves are Venezuela (17.5% of global reserves), closely followed by Saudi Arabia (17.2%), then Canada (9.7%), Iran (9.0%) and Iraq (8.5%).

Global oil production increased by 2.2 million b/d in 2018. Growth was heavily concentrated in the US (2.2 million b/d), Canada (410,000 b/d) and Saudi Arabia (390,000 b/d) while oil production declined sharply in Venezuela (-580,000 b/d) and Iran (-310,000 b/d). OPEC production declined by 330,000 b/d while non-OPEC production increased by 2.6 million b/d. Oil consumption in 2018 grew by an above average 1.4 million b/d. China (680,000 b/d) and the US (500,000 b/d) accounted for the majority of this year's growth.

Sl.No	Country	Oil production - 2019 (bbl/day)
	World production	80,622,000
1	United States	15,043,000
2	Saudi Arabia (OPEC)	12,000,000
3	Russia	10,800,000
4	Iraq (OPEC)	4,451,516
5	Iran (OPEC)	3,990,956
6	China	3,980,650
7	Canada	3,662,694
8	United Arab Emirates (OPEC)	3,106,077
9	Kuwait (OPEC)	2,923,825
10	Brazil	2,515,459

Table: 2. Installed capacity of Oil across globe

Natural gas

World proved gas reserves in 2018 increased by 0.7 Tcm to 196.9 Tcm mainly as a result of increased reserves in Azerbaijan (0.8 Tcm). Russia (38.9 Tcm), Iran (31.9 Tcm) and Qatar (24.7 Tcm) are the countries with the biggest reserves. The current global R/P ratio shows that gas reserves in 2018 accounted for 50.9 years of current production, 2.4 years lower than in 2017. Middle East (109.9 years) and CIS (75.6 years) are the regions with the highest R/P ratio.

Country	Production in bcm
United States	864
Russia	741
Iran	232
Canada	188
Qatar	168
China	160
Norway	127
Australia	125
Saudi Arabia	98
Algeria	96
Turkmenistan	85
Indonesia	75

Table: 3. Installed capacity of Natural gas across globe

Coal

World coal reserves in 2018 stood at 1055 billion tonnes and are heavily concentrated in just a few countries: US (24%), Russia (15%), Australia (14%) and China (13%). Most of the reserves are anthracite and bituminous (70%). The current global R/P ratio shows that coal reserves in 2018 accounted for 132 years of current production with North America (342 years) and CIS (329 years) the regions with the highest ratio.

Sl.No	Country	Anthracite & bituminous	Subbituminous & lignite	Total
1	United States	111,338 (23.3%)	135,305 (31.4%)	246,643 (27%)

2	Russia	49,088 (10.3%)	107,922 (25.1%)	157,010 (17%)
3	China	62,200 (13%)	52,300 (12.2%)	114,500 (13%)
4	India	48,787 (10.2%)	45,660 (10.6%)	94,447 (10%)
5	Australia	38,600 (8.1%)	39,900 (9.3%)	78,500 (9%)
6	South Africa	48,750 (10.2%)	0 (0%)	48,750 (5%)
7	Ukraine	16,274 (3.4%)	17,879 (4.2%)	34,153 (4%)
8	Kazakhstan	28,151 (5.9%)	3,128 (0.7%)	31,279 (3%)
9	Poland	14,000 (2.9%)	0 (0%)	14,000 (2%)
10	Brazil	0 (0%)	10,113 (2.4%)	10,113 (1%)

Table: 4. Installed capacity of coal across globe

World coal reserves in 2018 stood at 1055 billion tonnes and are heavily concentrated in just a few countries: US (24%), Russia (15%), Australia (14%) and China (13%). Most of the reserves are anthracite and bituminous (70%). The current global R/P ratio shows that coal reserves in 2018 accounted for 132 years of current production with North America (342 years) and CIS (329 years) the regions with the highest ratio.

Global coal production increased by 4.3% in 2018, significantly above the 10-year average of 1.3%. Production growth was concentrated in Asia Pacific (163 mtoe) with China accounting for half of global growth and Indonesian production up by 51 mtoe. Coal consumption increased by 1.4% in 2018, the fastest growth since 2013. Growth was again driven by Asia Pacific (71 Mtoe), and particularly by India (36 Mtoe). This region now accounts for over three quarters of global consumption, while 10 years ago it represented two thirds.

Indian power sector

India’s power sector is one of the most diversified in the world. Sources of power generation range from conventional sources such as coal, lignite, natural gas, oil, hydro and nuclear power to viable non-conventional sources such as wind, solar, and agricultural and domestic waste. The national electric grid in India has an installed capacity of 368.79 GW as of 31 December 2019. Renewable power plants, which also include large hydroelectric plants, constitute 34.86% of India's total installed capacity. During the 2018-19 fiscal year, the gross electricity generated by utilities in India was 1,372 TWh and the total electricity generation (utilities and non utilities) in the country was 1,547 TWh. The gross electricity consumption in 2018-19 was 1,181 kWh per capita.

Sector	MW	% of Total
Central Sector	93,097	25.2%
State Sector	103,292	28.0%
Private Sector	173,039	46.8%
Total	**3,67,281**	

Table: 5. Contribution of various agencies to Indian power sector

Fuel	MW	% of Total
Total Thermal	2,30,701	62.8%
Coal	1,98,495	54.2%
Lignite	6,760	1.7%
Gas	24,937	6.9%
Diesel	510	0.1%
Hydro (Renewable)	45,699	12.4%
Nuclear	6,780	1.9%
RES* (MNRE)	86,759	23.5%
Total	**369,428**	

Table: 6. Contribution of various types of power to Indian power sector

Indian energy scenario of conventional sources

Coal

India's electricity sector consumes about 72% of the coal produced in the country. Coal consumption by utility power was 608 million tons in 2017-18. A large part of the Indian coal reserve is similar to Gondwana coal: it is of low calorific value and high ash content, with poor fuel value. On average, Indian coal has a gross calorific value (GCV) of about 4500 Kcal/kg, whereas in Australia, for example, the GCV is about 6500 Kcal/kg. The result is that Indian power plants using India's coal supply consume about 0.7 kg of coal per kWh of power generation, whereas in the United States thermal power plants consume about 0.45 kg of coal per kWh. In 2017, India imported nearly 130 Mtoe (nearly 200 million tons) of steam coal and cooking coal, 29% of total consumption, to meet the demand in electricity, cement and steel production. India is the world's second largest producer of coal after the People's Republic of China. The share of coal in both the energy mix and the power mix in India has been increasing since the 1970s and in 2017 coal provided 44% of the total primary energy supply (TPES) and 74% of electricity generation.

Supply and demand

According to the latest Geological Survey of India of April 2018, India holds proven coal reserves of 148.79 Gigatonnes (Gt) and total coal resources of 319.02 Gt. The proven lignite reserves amount to 6.54 Gt, while total lignite resources are 45.66 Gt.

Power generation, the largest consumer of coal, has various characteristics: India has coastal (31 GW) and inland plants (159 GW), which are usually located close to mines. India has 18 GW of power plants that are designed to only use imported coal. Power plants with a total capacity of 32 GW use a blend of domestic and imported coal. Plants using only domestic coal have a total capacity of 140 GW.

The National Thermal Power Corporation (NTPC) is India's largest coal power generator and one of the largest in the world, with 52 GW of installed coal generation capacity. Utilities owned by the state governments hold another 59 GW, while independent power producers (IPPs) account for 75 GW. Different public joint ventures in which NTPC is present account for 5 GW. Additionally, there are captive power plants with a total capacity of 54 GW, which produce electricity for own use in certain industries.

Oil

Oil remains an essential energy source for India. It is the second-largest source in the country's total primary energy supply (TPES) and the largest in its total final consumption (TFC). Oil demand has increased rapidly over the last several decades and India is now the third-largest oil-consuming country in the world.

Oil supply

In 2018 India's domestic oil production stood at 840 kb/d, which is 3% up from a decade ago, but 8% down from its peak of 910 kb/d in 2011. The estimated total volume of India's conventional hydrocarbon resources from 26 sedimentary basins is estimated to be around 47.8 billion tonnes of oil equivalent. According to the 2017/18 Indian Petroleum and Natural Gas Statistics report, India's proven reserves of crude oil and condensate as of April 2018 were around 595 Mt (around 4.4 billion barrels), which could potentially sustain production for about 14 years at current level. Location-wise, oil production in India comes primarily from three onshore states, Assam, Gujarat and Rajasthan, which together account for more than 96% of onshore outputs, and from the aged offshore Mumbai High Field. Some recent discoveries in Rajasthan and in the offshore Krishna-Godavari (KG) basin hold some potential.

Oil demand

Driven by rapid economic growth, oil demand in India has been growing for decades across all sectors. India's oil demand has risen strongly since 2008, with average demand growth close to 160 kb/d per year to reach 4.4 mb/d in 2017, which already represents 5% of global consumption. India's oil demand is expected to reach around 6 mb/d by 2024, representing 3.9% growth per annum, well ahead of the global average of 1.2%. The country is set to overtake China in the mid-2020s as the largest source of global oil

The tamilnadu state's peak power demand on March 19 touched 15,664 which is the maximum till date.

demand.

Natural gas

The present gas based installed capacity for power generation in the country is 24,937 MW and the Central Electricity Authority monitors a capacity of 23,883 MW (all natural gas based plants above 25 MW, excluding liquid fuel). Gas based power generation capacity of 14305 MW (11304 MW commissioned and 3001 MW under construction) is stranded due to non-availability of domestic gas, which is 51.2% of the gas based capacity (installed and under construction). The main reason for stranded gas based capacity is insufficient availability of domestic gas, particularly from Krishna Godavari Dhirubhai - 6 (KG D-6) basin. The supply of gas to power sector from this field is NIL since March, 2013.

Supply and demand

Natural gas supply has been growing more slowly than total energy demand. Hence, the share of natural gas in total primary energy supply (TPES) has fallen during the past decade. In power generation, the share of gas is declining and newly installed gas power capacity remains underutilised. The share of natural gas in total final consumption (TFC) is increasing, as industrial and residential consumption continue to grow.

In 2017 total gas supply was almost 60 bcm. Domestic production accounted for 54% of total supply and imports of LNG for the remaining 43%. With the exception of the period 2009-12, when production peaked at around 50 bcm, India's production has been stable at just above 30 bcm per year since the early 2000s.

Gas imports began in 2003 and have increased stepwise since, as India has expanded its LNG terminal capacity. In 2017 total natural gas imports were 27 bcm, of which 49% came from Qatar (Figure 11.3). India has diversified its supply sources in recent years and imported from more than 13 countries in 2017, including large shares from Nigeria, Equatorial Guinea and Australia.

International energy scenario of renewable sources

The leading countries for installed renewable energy in 2019 were China, the U.S., and Brazil. China was leading in renewable energy installations with a capacity of around 758.6 gigawatts. The U.S., in second place, had a capacity of around 264.5 gigawatts. Renewable energy is an important step in mitigating climate change and reducing the consequences caused by the phenomenon.

Country	Installed capacity in Gw
China	758.63
U.S.	264.5
Brazil	141.93
India	128.23
Germany	125.39
Canada	101
Japan	97.46
Italy	55.32
Russia	55.19
France	52.93

Table: 7. Installed capacity of renewable energy source across globe

Solar

1. Germany

At the end of May 2019, the cumulative solar power capacity of Germany reached 47.72 GW. The country has successfully met over 50% of the nation's daily energy demand from solar power.

2. China

Several centralized solar power projects of 2019 will get benefitted by China's government subsidies, like 1.7 billion Yuan (247.64 million dollars), involving the total installed capacity of 22.79 GW. According to reports from the National Energy Administration (NEA), 3,921 projects in 22 provinces and cities got approvals for these afore said subsidies.

3. Japan

Japan is still among the world's leaders in terms of total solar energy production, roughly around 55.5 GW in early 2019. The country could install nearly 155 GW by 2030 if things go according to their targets.

4. Italy

Likely to go some way to promoting renewable investment and helping Italy reach its 2030 targets are the seven competitive auctions to be held between 2019 and 2021, which include up to 4.8 GW in new PV and wind power plants, as well as 140 megawatts (MW) of hydro, biomass, and geothermal plants.

5. United States

According to the U.S Energy Information Administration, nearly 17% of electricity generation in the United States was hailed with the help of renewable power. All conditions remaining favourable, this perpetual growth might give rise to as much as four million solar installations by the year 2030. The U.S Department of Energy has also forecasted a 10% hike in their solar power generation by end of this year.

6. India

A country with one of the fastest-growing solar plants, India's solar installed capacity reached 28.18 GW in March 2019 and the country became the lowest cost producer of solar power in the world. The government had an initial target of 20 GW capacities for 2022, which was achieved four years ahead of schedule in 2018.

7. United Kingdom

Around 5% of Britain's total electricity generation was provided through solar by early 2019.

8. Australia

PV accounted for 5.2% of Australia's electrical energy production in early 2019, and as of March 2019, the country had over 12,035 MW of installed PV solar power, of which 4,068 MW were installed in the preceding 12 months. 59 solar PV projects with a combined installed capacity of 2,881 MW are also either under construction, constructed or due to start construction having reached financial closure.

9. France

Overall, the country's cumulative installed PV power surpassed an impressive 8.5 GW, with the newly installed PV capacity reaching 479 MW.

10. South Korea

According to the Ministry Of Trade, Industry & Energy, South Korea has successfully exceeded its Annual Deployment Target of 1.63 GW by installing 1.64 GW of Solar PV until July 2019. South Korea has plans to add 30 GW of PV by 2030, sundry of other steps have been undertaken to combat the country's overall former poor renewable performance, with 9% of that capacity to be developed in Saemangeum and 14GW of solar power energy to be installed before 2020.

Wind

1. China – installed capacity 221GW

It boasts the world's largest onshore windfarm in Gansu Province, which currently has a capacity of 7,965MW, five times larger than its nearest rival. The farm is currently only operating at 40% of its capacity, with a further 13,000MW to be installed leading to a grand total of 20,000MW (20GW) in 2020. This expansion is expected to cost $17.5bn.

2. US – installed capacity 96.4GW

The US is in second place with 96.4GW of installed capacity and is particularly strong in onshore wind power. Six of the largest 10 onshore windfarms are based in the US. These include the Alta Wind

Energy Centre in California, the world's second largest onshore wind farm with a capacity of 1,548MW, Shepherd's Flat Wind Farm in Oregon (845MW) and Roscoe Wind Farm in Texas (781.5MW).

3. Germany – installed capacity 59.3GW

Germany has the highest installed wind capacity in Europe with 59.3GW. Its largest offshore windfarms are the Gode Windfarms (phase 1 & 2), which have a combined capacity of 582MW. Germany is also home to the Nordsee One Offshore Wind farm, which has a capacity of 382MW and provides energy for 400,000 homes. According to Wind Europe, Europe installed 11.7GW of wind energy in 2018. Of this, Germany led the way with 29% of this capacity at a total of just under 3.4GW, with 2.4GW of this onshore and just under 1GW offshore.

4. India – installed capacity 35GW

India has the second highest wind capacity in Asia and is the only Asian country apart from China to make the list, with a total capacity of 35GW. The country has the third and fourth largest onshore wind farms in the world, the Muppandal windfarm in Tamil Nadu, Southern India (1,500MW) and the Jaisalmer Wind Park in Rajasthan, Northern India (1,064MW). The Indian government has set a target of installing 60GW of wind energy by 2022, with 25GW to be installed in the next three years.

5. Spain – installed capacity 23GW

Spain is a strong performer in wind energy, with a capacity of 23GW covering 18% of Spain's electricity supply. The country is fifth in the world despite none of its onshore or offshore wind farms being in the top 20 largest by capacity. The Spanish wind industry has actually been in a steep decline over the past few years. Just 104MW was added to its energy mix in 2016-2017 after nothing was added in 2015.

6. United Kingdom – installed capacity 20.7GW

The UK is the third European country on the list, with a total capacity of just over 20.7GW. The UK is particularly noteworthy in offshore wind, with six of the 10 highest-capacity offshore wind projects in the world. One of these is the Walney project off the coast of Cumbria, North West England. This is the largest offshore wind project in the world with Walney 1 & 2 (367MW) and Walney Extension (659MW) forming a grand total of 1,026MW. The Walney installation is set to be overtaken by the 1,218MW Hornsea One project in the North Sea when it is fully completed in 2020.

7. France – installed capacity 15.3GW

France is seventh on the list of top 10 wind energy countries by capacity. It is currently moving away from nuclear power, which previously delivered 75% of the country's energy needs, and will fill the gap by increasing its renewable budget to €71bn for the period 2019-2028. This will allow it to triple its onshore wind capacity by 2030. However, hostility to wind energy is "deeply rooted" in France, as much of the population considers wind turbines to be ugly and noisy.

8. Brazil – installed capacity 14.5GW

Brazil has the largest wind capacity in South America with 14.5GW and is expanding its capacity significantly. The most recent figures show that wind power had increased by 8.9% year-on-year in February 2019. Wind power is fourth place in Brazil's total energy mix, forming about 8% of Brazil's total energy capacity of 162.5GW.

9. Canada – installed capacity 12.8GW

Canada's renewable energy capacity stands at 12.8GW, with 566MW of new installed capacity added in 2018. This energy is generated by a total of 299 wind farms with 6,596 turbines. Ontario has the largest amount of wind energy, with just over 5GW installed. These include the 230MW Niagara Region Windfarm and the 199.5MW Amaranth Windfarm, north of Toronto. The largest wind farm in Canada is the Rivière-du-Moulin project in Quebec, which has a total capacity of 300MW. Wind accounts for about 5% of Canada's renewable energy supply, with hydroelectric way ahead at 67.5%.

10. Italy – installed capacity 10.1GW

In tenth place is Italy, which reached just over 10GW in wind energy capacity in 2018. Italy's wind industry is heavily concentrated in the south and on its islands. All of Italian energy company ERG's onshore wind capacity is based south of Rome for example, with Puglia (248.5MW) and Campania (246.9MW) being its strongest markets.

Geothermal Power

A total of 759 MW were added in 2019. Other countries represent an installed power generation capacity of 1,024 MW, bringing the total installed geothermal power generation capacity at the end of the year 2019 to 15,406 MW. We estimate that this is the largest annual growth to geothermal power generation capacity that we can follow at least back to 2000. It is though close to 2014, when growth the year prior was around 750 MW.

1. United States – 3,676 MW – with an additional 23 MW just added before the year-end
2. Indonesia – 2,133 MW – 185 MW added this year
3. Philippines – 1,918 MW – change of 50 MW is not quite clear, but might depend on work by EDC on existing plants
4. Turkey – 1,526 MW – 179 MW added in 2019, with still existing uncertainties regarding the FIT
5. New Zealand – 1,005 MW – no additions in 2019
6. Mexico – 962.7 MW – one addition of 27 MW, but net only a growth of 11.7 MW due to non-operational capacity.
7. Italy – 944 MW – with the current political climate, this number might not change much soon
8. Kenya – 861 MW – addition of 193.3 MW the largest expansion by country this year
9. Iceland – 755 MW – one addition of 5 MW replacing an old 3 MW plant
10. Japan – 601 MW – continued small-scale development and one larger addition, total 51.6 MW added

Biomass

The global capacity of biomass plants totaled 130 gigawatts.

Sl.No	Country	Biofuels Production - Ktoe (terawatt-hours)
1	North America	4598.07
2	United States	4429.62
3	South & Central America	2963.06
4	Brazil	2485.90
5	Europe	1854.87
6	Asia Pacific	1620.96
7	Indonesia	563.96
8	Germany	400.64
9	China	360.46
10	France	317.16

Table.8. Installed capacity of biomass across globe

Renewable energy scenario in India

Renewable energy (including large hydro) accounted for almost 36% of India's total power capacity mix at the end of the calendar year (CY) 2019, according to data from the Central Electricity Authority (CEA), and the Ministry of New and Renewable Energy (MNRE).

The country's total installed power capacity stood at about 371 GW as of December 31, 2019. Of this, renewables (including large hydro) accounted for about 133.2 GW, up from 122.8 GW last year, an 8.5% rise.

In 2018 the GoI announced an increased ambition of 227 GW renewable capacity by 2022 and 275 GW by 2027. At the United Nations' Climate Summit in New York on 23 September 2019, the Prime Minister of India announced a new target of 450 GW of renewable electricity capacity

Solar

Cumulative solar installations in the country stood at around 35.6 GW at the end of 2019, representing 9.6% of the total installed power capacity mix. It accounted for about 26.7% of all renewable energy in the country.

Wind

Wind power installations in the country have now touched 37.5 GW. This translates to 10.1% of the total installed power capacity.

Hydro

Cumulative hydropower installations moved up to about 50.1 GW and accounted for 13.5% of India's total installed power capacity. Of this, 4.67 GW or 1.26% were small hydropower.

Biomass

Bio power capacity share in the overall power mix was 2.66%. Cumulative installations at the end of 2019 stood at 9.86 GW.

Geothermal energy

Geothermal energy is thermal energy generated and stored in the Earth. India's geothermal energy installed capacity is experimental, and commercial use is insignificant. According to some estimates, India has 10,600 MW of geothermal energy available.

UNIT II - WIND ENERGY

Power in the Wind – Types of Wind Power Plants(WPPs)–Components of WPPs-Working of WPPs- Siting of WPPs-Grid integration issues of WPPs.

Introduction

Wind power or wind energy is the use of wind to provide the mechanical power through wind turbines to operate electric generators. Wind power is a sustainable and renewable energy. Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert it into useful work. The spinning blades, attached to a hub and a low-speed shaft, turn along with the blades. The rotating low-speed shaft is connected to a gearbox that connects to a high-speed shaft on the opposite side of the gearbox. This high-speed shaft connects to an electrical generator that converts the mechanical energy from the rotation of the blades into electrical energy. The key characteristics of a good wind power site are high average wind speed, sufficient separation from noise-sensitive neighbours, good grid connection, good site access, No special environmental or landscape designations. The integration of wind into grid has certain challenges like, Variability, Uncertainty, Location-specificity, Nonsynchronous generation, Low capacity factor.

Wind Energy Basics

Wind energy is a form of solar energy. Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. Mountains, bodies of water and vegetation influence wind flow patterns. Wind speeds vary based on geography, topography and season. As a result, there are some locations better suited for wind energy generation.

Wind power is the conversion of wind energy into electricity or mechanical energy using wind turbines. Wind turbines convert the kinetic energy in the wind into mechanical power. A generator can convert mechanical power into electricity. Mechanical power can also be utilized directly for specific tasks such as pumping water.

The mechanism used to convert air motion into electricity is referred to as a turbine. The power in the wind is extracted by allowing it to blow past moving blades that exert torque on a rotor. The rotor turns the drive shaft, which turns an electric generator. The amount of power transferred is dependent on the rotor size and the wind speed. The types of wind power plants based on capacity are

- **Utility-scale wind:** Wind turbines that range in size from 100 kilowatts to several megawatts, where the electricity is delivered to the power grid and distributed to the end user by electric utilities or power system operators.
- **Distributed or "small" wind:** Single small wind turbines below 100 kilowatts that are used to directly power a home, farm or small business and are not connected to the grid.
- **Offshore wind:** Wind turbines that are erected in large bodies of water, usually on the continental shelf. Offshore wind turbines are larger than land-based turbines and can generate more power.

Windmills: People have been using windmills for centuries to grind grain, pump water, and do other work. Windmills generate mechanical energy, but they do not generate electricity.

Wind Turbines: In contrast to windmills, modern wind turbines are highly evolved machines with more than 8,000 parts that harness wind's kinetic energy and convert it into electricity.

Wind farm: Oftentimes a large number of wind turbines are built close together, which is referred to as a wind project or wind farm. A wind farm functions as a single power plant and sends electricity to the grid.

> *Windmills have been in use since 2000 B.C. and were first developed in Persia and China. Ancient mariners sailed to distant lands by making use of winds. Farmers used wind power to pump water and for grinding grains. Today the most popular use of wind energy is converting it to electrical energy to meet the critical energy needs of the planet.*

Power in the Wind

Wind results from the movement of air due to atmospheric pressure gradients. Wind flows from regions of higher pressure to regions of lower pressure. The larger the atmospheric pressure gradient, the higher the wind speed and thus, the greater the wind power that can be captured from the wind by means of wind energy converting machinery. The generation and movement of wind are complicated due to a number of factors. Among them, the most important factors are uneven solar heating, the Coriolis effect due to the earth‘s self-rotation, and local geographical conditions.

Uneven solar heating

The unevenness of the solar radiation can be attributed to four reasons.

First, the earth is a sphere revolving around the sun in the same plane as its equator. Because the surface of the earth is perpendicular to the path of the sunrays at the equator but parallel to the sunrays at the poles, the equator receives the greatest amount of energy per unit area, with energy dropping off toward the poles. Due to the spatial uneven heating on the earth, it forms a temperature gradient from the equator to the poles and a pressure gradient from the poles to the equator. Thus, hot air with lower air density at the equator rises up to the high atmosphere and moves towards the poles and cold air with higher density flows from the poles towards the equator along the earth‘s surface. Without considering the earth‘s self-rotation and the rotation-induced Coriolis force, the air circulation at each hemisphere forms a single cell, defined as the meridional circulation.

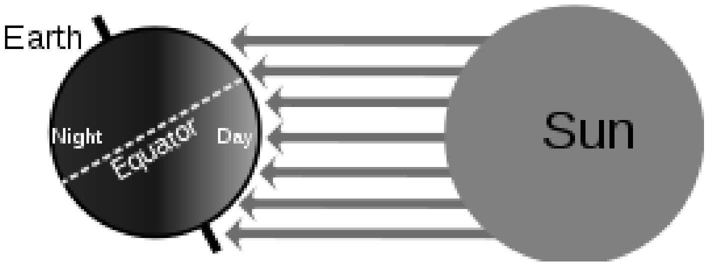


Fig. 1. Uneven solar heating

Second, the earth‘s self-rotating axis has a tilt of about 23.5° with respect to its ecliptic plane. It is the tilt of the earth‘s axis during the revolution around the sun that results in cyclic uneven heating, causing the yearly cycle of seasonal weather changes.

Third, the earth‘s surface is covered with different types of materials such as vegetation, rock, sand, water, ice/snow, etc., Each of these materials has different reflecting and absorbing rates to solar radiation, leading to high temperature on some areas (e.g. deserts) and low temperature on others (e.g. iced lakes), even at the same latitudes.

The fourth reason for uneven heating of solar radiation is due to the earth‘s topographic surface. There are a large number of mountains, valleys, hills, etc. on the earth, resulting in different solar radiation on the sunny and shady sides.

Coriolis effect

The earth‘s self-rotation is another important factor to affect wind direction and speed. The Coriolis force, which is generated from the earth's self-rotation, deflects the direction of atmospheric movements. In the north atmosphere wind is deflected to the right and in the south atmosphere to the left. The Coriolis force depends on the earth‘s latitude; it is zero at the equator and reaches maximum values at the poles. In addition, the amount of deflection on wind also depends on the wind speed; slowly blowing wind is deflected only a small amount, while stronger wind is deflected more.

In large-scale atmospheric movements, the combination of the pressure gradient due to the uneven solar radiation and the Coriolis force due to the earth‘s self rotation causes the single meridional cell to break up into three convectional cells in each hemisphere: the Hadley cell, the Ferrel cell, and the Polar cell as shown in Fig.2. Each cell has its own characteristic circulation pattern. In the Northern Hemisphere, the Hadley cell circulation lies between the equator and north latitude 30°, dominating tropical and sub-tropical climates. The hot air rises at the equator and flows toward the North Pole in the upper atmosphere. This moving air is deflected by Coriolis force to create the northeast trade winds. At approximately north latitude 30°, Coriolis force becomes so strong to balance the pressure gradient force. As a result, the winds are defected to the west.

The air accumulated at the upper atmosphere forms the subtropical high-pressure belt and thus sinks back to the earth's surface, splitting into two components: one returns to the equator to close the loop of the Hadley cell; another moves along the earth's surface toward North Pole to form the Ferrel Cell circulation, which lies between north latitude 30° and 60°. The air circulates towards the North Pole along the earth's surface until it collides with the cold air flowing from the North Pole at approximately north latitude 60°. Under the influence of Coriolis force, the moving air in this zone is deflected to produce westerlies. The Polar cell circulation lies between the North Pole and north latitude 60°. The cold air sinks down at the North Pole and flows along the earth's surface toward the equator. Near north latitude 60°, the Coriolis effect becomes significant to force the airflow to southwest.

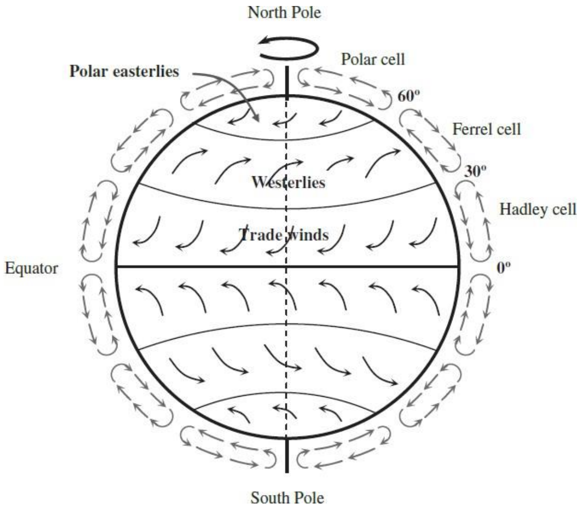


Fig. 2. Idealized atmospheric circulations

Local geography

The roughness on the earth's surface is a result of both natural geography and manmade structures. Frictional drag and obstructions near the earth's surface generally retard with wind speed and induce a phenomenon known as wind shear. The rate at which wind speed increases with height varies on the basis of local conditions of the topography, terrain, and climate, with the greatest rates of increases observed over the roughest terrain. A reliable approximation is that wind speed increases about 10% with each doubling of height. In addition, some special geographic structures can strongly enhance the wind intensity. For instance, wind that blows through mountain passes can form mountain jets with high speeds.

Wind energy characteristics

Wind energy is a special form of kinetic energy in air as it flows. Wind energy can be either converted into electrical energy by power converting machines or directly used for pumping water, sailing ships, or grinding grain. Three key factors affect the amount of energy a turbine can harness from the wind: wind speed, air density, and swept area.

Most of the modern wind turbines have 3 blades which can reach speeds at the tip of over 320 kph (200 mph).

Wind power

Kinetic energy exists whenever an object of a given mass is in motion with a translational or rotational speed. When air is in motion, the kinetic energy in moving air can be determined as

$$E_k = \frac{1}{2} m\bar{u}^2 \quad (1)$$

where m is the air mass and $\bar{u}$ is the mean wind speed over a suitable time period. The wind power can be obtained by differentiating the kinetic energy in wind with respect to time, i.e.:

$$P_w = \frac{dE_k}{dt} = \frac{1}{2} \dot{m}\bar{u}^2 \quad (2)$$

However, only a small portion of wind power can be converted into electrical power. When wind passes through a wind turbine and drives blades to rotate, the corresponding wind mass flowrate is

$$\dot{m} = \rho A \bar{u} \quad (3)$$

where ρ is the air density and A is the swept area of blades, as shown in Fig. 3 . Substituting (3) into (2), the available power in wind P_w can be expressed as

$$P_w = \frac{1}{2} \rho A \bar{u}^3 \quad (4)$$

An examination of eqn (4) reveals that in order to obtain a higher wind power, it requires a higher wind speed, a longer length of blades for gaining a larger swept area, and a higher air density. Because the wind power output is proportional to the cubic power of the mean wind speed, a small variation in wind speed can result in a large change in wind power.

Blade swept area

As shown in Fig. 3, the blade swept area can be calculated from the formula:

$$A = \pi\left[(l+r)^2 - r^2 \right] = \pi l\,(l+2r) \quad (5)$$

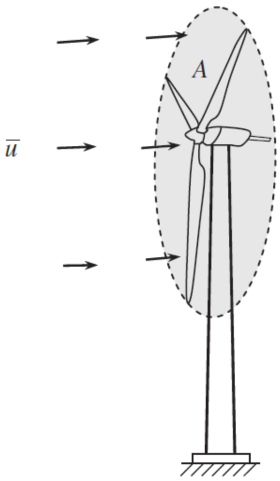


Fig.3. Swept area of wind turbine blades

where l is the length of wind blades and r is the radius of the hub. Thus, by doubling the length of wind blades, the swept area can be increased by the factor up to 4. When $l >> 2r$, $A \approx \pi l^2$.

Air density

Another important parameter that directly affects the wind power generation is the density of air, which can be calculated from the equation of state:

$$\rho = \frac{p}{RT} \quad (6)$$

where p is the local air pressure, R is the gas constant (287 J/kg-K for air), and T is the local air temperature in K.

The hydrostatic equation states that whenever there is no vertical motion, the difference in pressure between two heights is caused by the mass of the air layer:

$$dp = -\rho g\, dz \quad (7)$$

where g is the acceleration of gravity. Combining eqns (6) and (7), yields

$$\frac{dp}{p} = -\frac{g}{RT} dz \quad (8)$$

The acceleration of gravity g decreases with the height above the earth's surface z:

$$g = g_0\left(1 - \frac{4z}{D}\right) \quad (9)$$

where g_0 is the acceleration of gravity at the ground and D is the diameter of the earth. However, for the acceleration of gravity g, the variation in height can be ignored because D is much larger than 4z.
In addition, temperature is inversely proportional to the height. Assume that dT /dz = c, it can be derived that

$$p = p_0\left(\frac{T}{T_0}\right)^{-g/cR} \quad (10)$$

where p_0 and T_0 are the air pressure and temperature at the ground, respectively.
Combining eqns (6) and (10), it gives

$$\rho = \rho_0\left(\frac{T}{T_0}\right)^{-(g/cR+1)} = \rho_0\left(1+\frac{cz}{T_0}\right)^{-(g/cR+1)} \quad (11)$$

This equation indicates that the density of air decreases nonlinearly with the height above the sea level.

The largest wind turbine in the world is located in US in Hawaii. It stands 20 stories tall and has blades the length of a football field.

Wind power density

Wind Power Density (WPD) is a quantitative measure of wind energy available at any location. It is the mean annual power available per square meter of swept area of a turbine, and is calculated for different heights above ground. Some of the wind resource assessments utilize 50m towers with sensors installed at intermediate levels (10 m, 20 m, etc.). For large-scale wind plants, class rating of 4 or higher is preferred. Calculation of wind power density includes the effect of wind velocity and air density.

Wind power parameters

Power coefficient

The conversion of wind energy to electrical energy involves primarily two stages: in the first stage, kinetic energy in wind is converted into mechanical energy to drive the shaft of a wind generator.
The power coefficient C_p deals with the converting efficiency in the first stage, defined as the ratio of the actually captured mechanical power by blades to the available power in wind:

$$C_p = \frac{P_{me,out}}{P_W} = \frac{P_{me,out}}{(1/2)\rho A\bar{u}^3} \quad (12)$$

Because there are various aerodynamic losses in wind turbine systems, for instance, blade-tip, blade-root, profile, and wake rotation losses, etc., the real power coefficient C_p is much lower than its theoretical limit, usually ranging from 30 to 45%.

Total power conversion coefficient and effective power output

In the second stage, mechanical energy captured by wind blades is further converted into electrical energy via wind generators. In this stage, the converting efficiency is determined by several parameters

- Gearbox efficiency η_{gear} – The power losses in a gearbox can be classified as load-dependent and no-load power losses. The load-dependent losses consist of gear tooth friction and bearing losses and no-load losses consist of oil churning, windage, and shaft seal losses. The planetary gearboxes, which are widely used in wind turbines, have higher power transmission efficiencies over traditional gearboxes.
- Generator efficiency η_{gen} – It is related to all electrical and mechanical losses in a wind generator, such as copper, iron, load, windage, friction, and other miscellaneous losses.
- Electric efficiency η_{ele} – It encompasses all combined electric power losses in the converter, switches, controls, and cables.

Therefore, the total power conversion efficiency from wind to electricity η_t is the production of these parameters, i.e.:

$$\eta_t = C_p\,\eta_{gear}\,\eta_{gen}\,\eta_{ele} \quad (13)$$

The effective power output from a wind turbine to feed into a grid becomes

$$P_{eff} = C_p\,\eta_{gear}\,\eta_{gen}\,\eta_{ele}P_w = \eta_t P_w = \frac{1}{2}\left(\eta_t\,\rho A u^3\right) \quad (14)$$

Lanchester–Betz limit

The Betz limit is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919. Betz concluded that this value is 59.3%, meaning that atmost only 59.3% of the kinetic energy from wind can be used to spin the turbine and generate electricity. In reality, turbines cannot reach the Betz limit, and common efficiencies are in the 35-45% range. If a wind turbine was 100% efficient, then all of the wind would have to stop completely upon contact with the turbine which is not practically possible.

Wind Speed – Power curve

Wind speed largely determines the amount of electricity generated by a turbine. Higher wind speeds generate more power because stronger winds allow the blades to rotate faster. Faster rotation translates to more mechanical power and more electrical power from the generator. The relationship between wind speed and power for a typical wind turbine is shown in Fig 2.

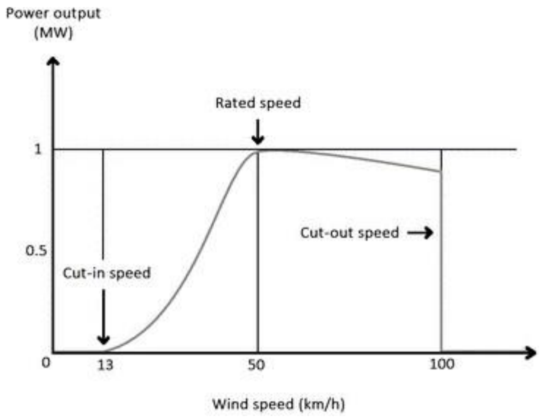


Fig.4 Wind power curve

Turbines are designed to operate within a specific range of wind speeds. The limits of the range are known as the cut-in speed and cut-out speed. The cut-in speed is the point at which the wind turbine is able to generate power. Between the cut-in speed and the rated speed, where the maximum output is reached, the power output will increase cubically with wind speed. For example, if wind speed doubles, the power output will increase 8 times. This cubic relationship is what makes wind speed such an important factor for wind power. This cubic dependence does cut out at the rated wind speed. This leads to the relatively flat part of the curve in Fig. 4, so the cubic dependence is during the speeds below 15 m/s (54 kph).

The cut-out speed is the point at which the turbine must be shut down to avoid damage to the equipment. The cut-in and cut-out speeds are related to the turbine design and size and are decided on prior to construction.

Tip Speed Ratio

The Tip Speed Ratio (often known as the TSR) is of vital importance in the design of wind turbine generators. If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively if the rotor turns too quickly, the blurring blades will appear like a solid wall to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible. The tip speed ratio is given by dividing the speed of the tips of the turbine blades by the speed of the wind – for example if a 20 mph wind is blowing on a wind turbine and the tips of its blades are rotating at 80 mph, then the tip speed ration is 80/20 = 4.

Force on a wind turbine

Airflow over any surface creates two types of aerodynamic forces— drag forces, in the direction of the airflow, and lift forces, perpendicular to the airflow. Either or both of these can be used to generate the forces needed to rotate the blades of a wind turbine.

Drag-based wind turbine

In drag-based wind turbines, the force of the wind pushes against a surface, like an open sail. In fact, the earliest wind turbines, dating back to ancient Persia, used this approach. The Savonius rotor is a simple drag-based windmill that you can make at home. It works because the drag of the open, or concave, face of the cylinder is greater than the drag on the closed or convex section.

Lift-based Wind Turbines

More energy can be extracted from wind using lift rather than drag, but this requires specially shaped airfoil surfaces, like those used on airplane wings. The airfoil shape is designed to create a differential pressure between the upper and lower surfaces, leading to a net force in the direction perpendicular to the wind direction. Rotors of this type must be carefully oriented (the orientation is referred to as the rotor pitch), to maintain their ability to harness the power of the wind as wind speed changes.

Types of Wind Power Plants (WPPs)

A wind power plant is simply a collection of wind turbines in one area. There are several different types of wind power plants. The following classification is based on their construction, size and usage.

Remote Wind Power Plants

Areas which are remote but are blessed with good wind speeds and frequency need a wind turbine which is maintenance free or low-maintenance for long periods of time (just imagine a service technician rushing across mountains and valleys on foot or bullock-cart to repair a turbine time and again). This means that they should have the capability of standing against all odds of climate even if they are relatively smaller in size than their conventional counterparts. These types of turbines are known as remote wind power turbines and are specifically designed with these objectives in view.

Cumulative installed capacity of wind power (as on 31.10.2019) in India is 37,090.03 MW.

Hybrid Wind Power Plants

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

Grid Connected Wind Power Plants

This concept is similar to a hybrid system. The wind power plant is used in conjunction with a main grid which supplies most of the power. The main purpose of the wind turbines is to supplement the energy supply for the grid, whereas the main function in the hybrid system is to complement the energy supply, hence the minor difference in the set up.

Wind Farms

As the name itself suggests, a wind farm is a collection of wind turbines which collectively power a given area or utility harnessing the wind force in a collective manner thereby amplifying the effect of a single unit.

These configurations are used at various locations depending on the conditions of the region and the presence of other sources of electrical supply. An optimum mix would consist of an ingenious combination of the various sources in the best possible manner.

Types of wind turbines

Wind turbines can be separated into two basic types determined by which way the turbine spins. Wind turbines that rotate around a horizontal axis are more common (like a wind mill), while vertical axis wind turbines are less frequently used (Savonius and Darrieus are the most common in the group).

1. Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines (HAWT) are the common style that most of us think of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis

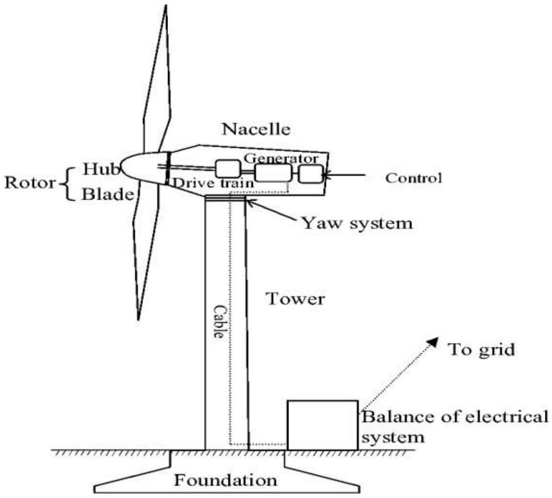


Fig. 5. Horizontal Axis Wind Turbines

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbine are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

Downwind machines have been built, despite the problem of turbulence, because they don‘t need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures and reliability is so important, most HAWTs are upwind machines.

Important point to remember recording HAWT are

- Lift is the main force
- Much lower cyclic stress
- 95% of the existing turbines are HAWTs
- Nacelle is placed at the top of the tower
- Yaw mechanism is required

HAWT Advantage

- The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.
- High efficiency, since the blades always move perpendicular to the wind, receiving power through the whole rotation.

HAWT Disadvantages

- Massive tower construction is required to support the heavy blades, gearbox, and generator.
- Components of horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.
- Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.
- Download variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower‘s wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower).
- HAWTs require an additional yaw control mechanism to turn the blades toward the wind.
- HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.

2. Vertical Axis Wind Turbines (VAWT)

Vertical wind turbines (VAWTs), have the main rotor shaft arranged vertically .The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This makes them suitable in places where the wind direction is highly variable or has turbulent winds. With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT is that, it generally creates drag when rotating into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

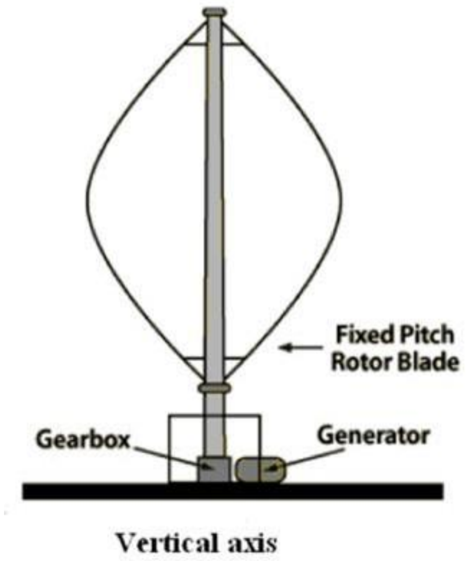


Fig. 6. Vertical Axis Wind Turbines –Darrieus type

Important points to remember for VAWT:

- Nacelle is placed at the bottom.
- Drag is the main force
- Yaw mechanism is not required
- Lower starting torque
- Difficulty in mounting the turbine
- Unwanted fluctuations in the power output

VAWT Advantages

- No yaw mechanisms is needed
- A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
- VAWTs have lower wind startup speeds than the typical HAWTs.
- VAWTs may be built at locations where taller structures are prohibited.
- VAWTs situated close to the ground can take advantage of locations where rooftops, means hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT Disadvantage

- In contrast to HAWT, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to the wind leads to inherently lower efficiency.

- Most VAWTs have an average decreased efficiency from a common HAWT, mainly because of the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.
- Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.
- Because VAWTs are not commonly deployed due mainly to the serious disadvantage mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

Tamil Nadu with 9231.77 MW of installed wind capacity is well ahead of the rest and second positioned Gujarat which has 7203.77 MW of wind generation capacity.

VAWT Subtypes

Darrieus Wind Turbine

Darrieus turbine has long, thin blades in the shape of loops connected to the top and bottom of the axle; it is often called an ―eggbeater windmill‖ as shown in fig. 6. It is named after the French engineer Georges Darrieus who patented the design in 1931. (It was manufactured by the US company FLoWind which went bankrupt in 1997). The Darrieus turbine is characterized by its C-shaped rotor blades which give it its eggbeater appearance. It is normally built with two or three blades.

Darrieus wind turbines are commonly called ―Eggbeater‖ turbines, because they look like a giant eggbeater. They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Also, they generally require some external power source, or an additional savonius rotor, to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area over the rotor area. Newer Darrieus type turbines are not help up by guy-wires but have an external superstructure connected to the top bearing.

The tip speed ratio (TSR) indicates the rotating velocity of the turbines to the velocity of the wind. In this case, the TSR has a higher value than 1, meaning that the velocity rotation here is greater than the velocity of wind and generates less torque. This makes Darrieus turbines excellent electricity generators. The turbine blades have to be reinforced in order to sustain the centrifugal forces generated during rotation, but the generator itself accepts a lower amount of force than the Savorius type. A drawback to the Darrieus wind turbines is the fact that they cannot start rotation on their own. A small motor, or another Savonius turbine, maybe needed to initiate rotation.

Advantages

- The rotor shaft is vertical. Therefore it is possible to place the load, like a generator or a centrifugal pump at ground level. As the generator housing is not rotating, the cable to the load is not twisted and no brushes are requires for large twisting angles.
- The rotor can take wind from every direction.
- The visual acceptation for placing of the windmill on a building might be larger than for an horizontal axis windmill.
- Easily integrates into buildings.

Disadvantages

- Difficult start unlike the Savonius wind turbine.
- Low efficiency.

Savonius wind turbine

The Savonius wind turbine is a type of vertical-axis wind turbine. It is one of the simplest wind turbine designs. It consists of two to three ―scoops‖ that employ a drag action to convert wind energy into torque to drive a turbine. When looked at from above in cross-section, a two scoop Savonius turbine looks like an S-shape. Due to the curvature of the scoops, the turbine encounters less drag when moving against the wind than with it, and this causes the spin in any wind regardless of facing.

Drag type wind turbines such as the Savonius turbine are less efficient at using the wind‘s energy than lift-type wind turbines, which are the ones commonly used in wind farms. A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers. Because they are a drag type turbine they are less efficiency than the common HAWT. Savonius are excellent in areas of turbulent wind and self starting.

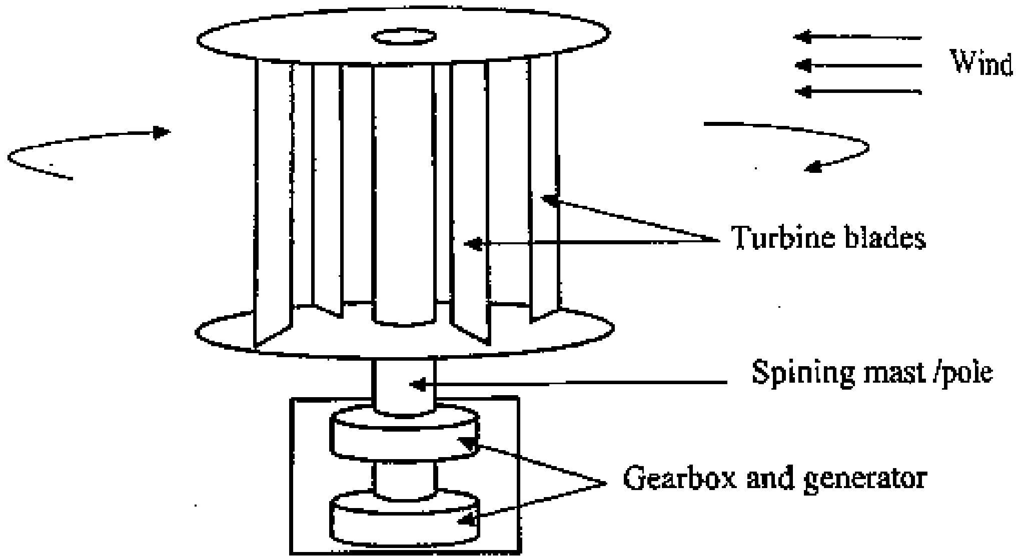


Fig. 7. Savonius wind turbine

Advantages

- Having a vertical axis, the Savonius turbine continues to work effectively even if the wind changes direction.
- Because the Savonius design works well even at low wind speeds, there‘s no need for a tower or other expensive structure to hold it in place, greatly reducing the initial setup cost.
- The device is quiet, easy to build, and relatively small.
- Because the turbine is close to the ground, maintenance is easy.

Disadvantages

- The scoop system used to capture the wind‘s energy is half as efficient as a conventional turbine, resulting in less power generation.

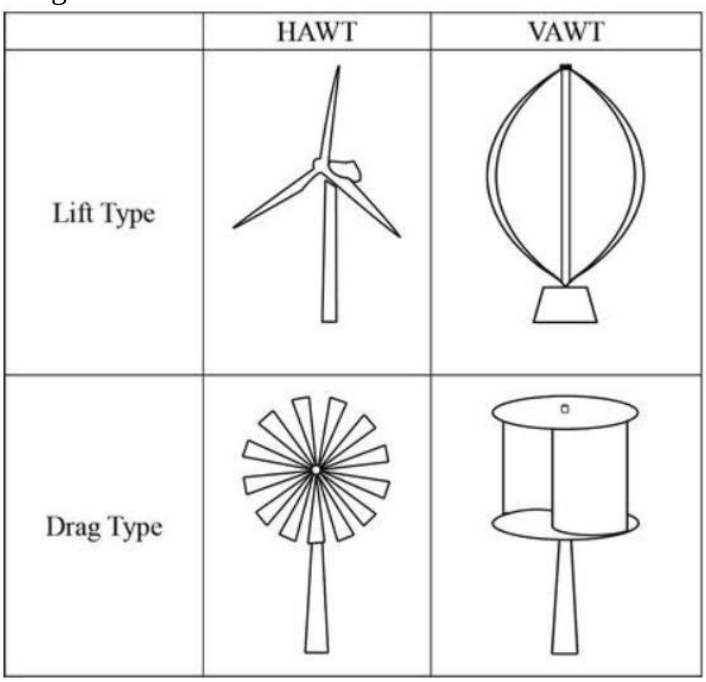


Fig.8. Types of wind turbines

Classification of Wind Energy Conversion Systems

(1) Based on axis
- (a) Horizontal axis machines
- (b) Vertical axis machines

(2) According to size
- (a) Small size machines (upto 2k W)
- (b) Medium size machines (2 to 100k W)
- (c) Large size machines (100k W and above)
  - i. Single generator at single site
  - ii. Multiple generators

(3) Types of output
- (a) DC output
  - i. DC generator
  - ii. Alternator rectifier
- (b) AC output
  - i. Variable frequency, variable or constant voltage AC.
  - ii. Constant frequency, variable or constant voltage AC

(4) According to the rotational speed of the area turbines
- (1) Constant speed and variable pitch blades
- (2) Nearly constant speed with fixed pitch blades
- (3) Variable speed with fixed pitch blades
  - (a) Field modulated system
  - (b) Double output indication generator
  - (c) AC-DC-AC link
  - (d) AC commentator generator
- (4) Variable speed constant frequency generating system.

(5) As per utilization of output
- (a) Battery storage
- (b) Direct conversion to an electro magnetic energy converter
- (c) Thermal potential
- (d) Inter convention with conventional electric utility guides

Mupandal wind farm in Tamilnadu with 3000 turbines and total nominal power of 1,500,000 kW is India's largest Onshore wind farm

Components of WPPs

There are three categories of components: mechanical, electrical, and control. The following is a brief description of the main components:

- **The tower** is the physical structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine equipment. Typical commercial wind towers are usually 50–120 m long and they are constructed from concrete or reinforced steel.
- **Blades** are physical structures, which are aerodynamically optimized to help capture the maximum power from the wind in normal operation with a wind speed in the range of about 3–15 m/s. Each blade is usually 20m or more in length, depending on the power level.
- **The nacelle** is the enclosure of the wind turbine generator, gearbox and internal equipment. It protects the turbine‘s internal components from the surrounding environment.
- **The rotor** is the rotating part of the wind turbine. It transfers the energy in the wind to the shaft. The rotor hub holds the wind turbine blades while connected to the gearbox via the low-speed shaft.
- **Pitch** is the mechanism of adjusting the angle of attack of the rotor blades. Blades are turned in their longitudinal axis to change the angle of attack according to the wind directions.
- **The shaft** is divided into two types: low and high speed. The low-speed shaft transfers mechanical energy from the rotor to the gearbox, while the high-speed shaft transfers mechanical energy from gearbox to generator.

- **Yaw** is the horizontal moving part of the turbine. It turns clockwise or anticlockwise to face the wind. The yaw has two main parts: the yaw motor and the yaw drive. The yaw drive keeps the rotor facing the wind when the wind direction varies. The yaw motor is used to move the yaw.
- **The brake** is a mechanical part connected to the high-speed shaft in order to reduce the rotational speed or stop the wind turbine over speeding or during emergency conditions.
- **Gearbox** is a mechanical component that is used to increase or decrease the rotational speed. In wind turbines, the gearbox is used to control the rotational speed of the generator.
- **The generator** is the component that converts the mechanical energy from the rotor to electrical energy. The most common electrical generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).
- **The controller** is the brain of the wind turbine. It monitors constantly the condition of the wind turbine and controls the pitch and yaw systems to extract optimum power from the wind.
- **Anemometer** is a type of sensor that is used to measure the wind speed. The wind speed information may be necessary for maximum power tracking and protection in emergency cases.
- **The wind vane** is a type of sensor that is used to measure the wind direction. The wind direction information is important for the yaw control system to operate.

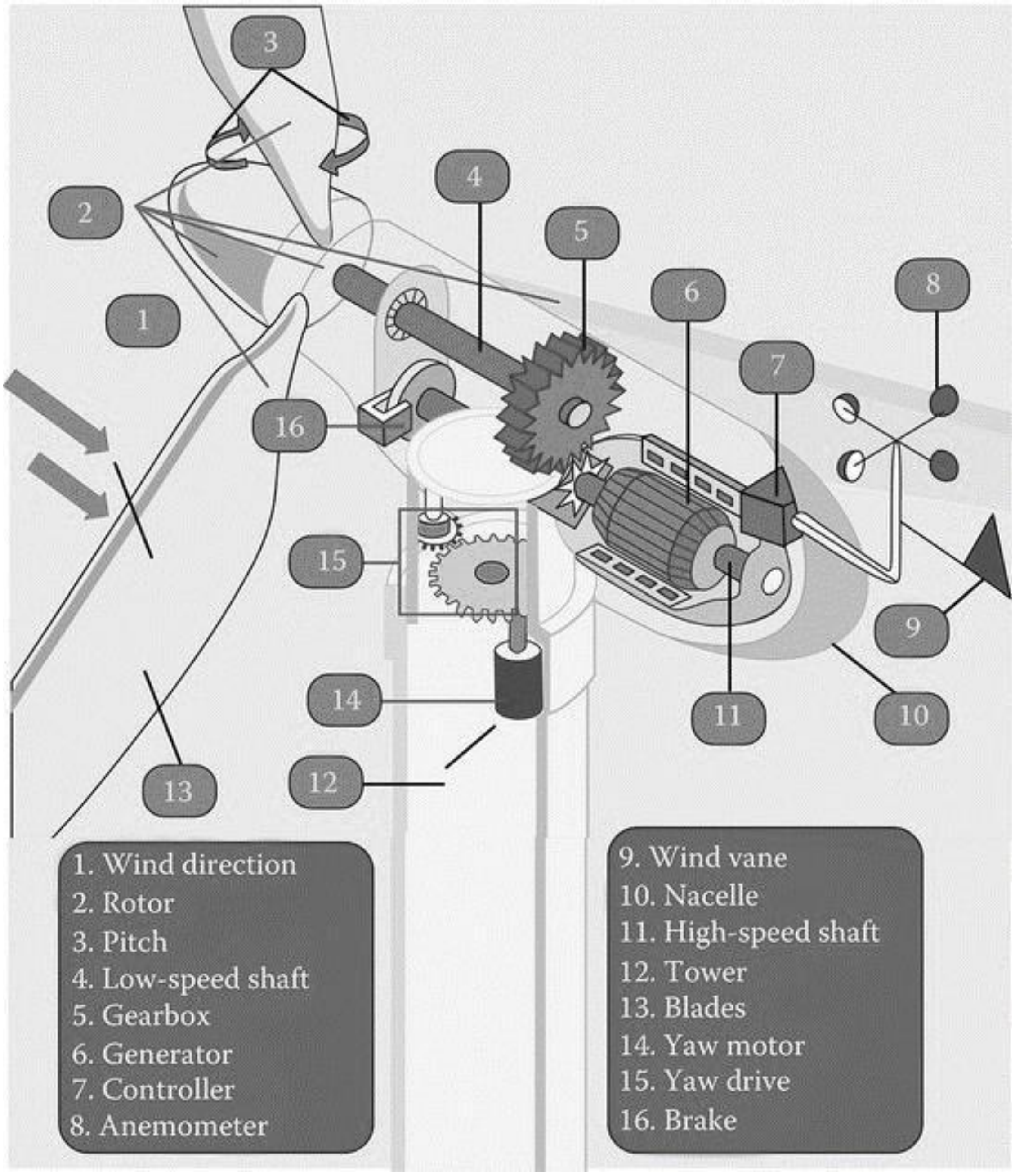


Fig. 9. Components of wind turbine

Working of WPPs (Refer Fig.10 with the following serial no)

1. Wind (moving air that contains kinetic energy) blows toward the turbine's rotor blades.
2. The rotors spin around, capturing some of the kinetic energy from the wind, and turning the central drive shaft that supports them. Although the outer edges of the rotor blades move very fast, the central axle (drive shaft) turns quite slowly.
3. In most large modern turbines, the rotor blades can swivel on the hub at the front so they meet the wind at the best angle (or "pitch") for harvesting energy. This is called the pitch control mechanism. On big turbines, small electric motors or hydraulic rams swivel the blades back and forth under precise electronic control. On smaller turbines, the pitch control is often completely mechanical. However, many turbines have fixed rotors and no pitch control at all.
4. Inside the nacelle (the main body of the turbine sitting on top of the tower and behind the blades), the gearbox converts the low-speed rotation of the drive shaft (perhaps, 16 revolutions per minute, rpm) into high-speed (perhaps, 1600 rpm) rotation fast enough to drive the generator efficiently.
5. The generator, immediately behind the gearbox, takes kinetic energy from the spinning drive shaft and turns it into electrical energy. Running at maximum capacity, a typical 2MW turbine generator will produce 2 million watts of power at about 700 volts.
6. Anemometers (automatic speed measuring devices) and wind vanes on the back of the nacelle provide measurements of the wind speed and direction.
7. Using these measurements, the entire top part of the turbine (the rotors and nacelle) can be rotated by a yaw motor, mounted between the nacelle and the tower, so it faces directly into the oncoming wind and captures the maximum amount of energy. If it is too windy or turbulent, brakes are applied to stop the rotors from turning (for safety reasons). The brakes are also applied during routine maintenance.
8. The electric current produced by the generator flows through a cable running down through the inside of the turbine tower.
9. A step-up transformer converts the electricity to about 50 times higher voltage so it can be transmitted efficiently to the power grid (or to nearby buildings or communities). If the electricity is flowing to the grid, it is converted to an even higher voltage by a substation nearby.
10. The consumer enjoy clean, green energy: the turbine has produced no greenhouse gas emissions or pollution as it operates.
11. Wind carries on blowing past the turbine, but with less speed and energy and more turbulence (since the turbine has disrupted its flow).

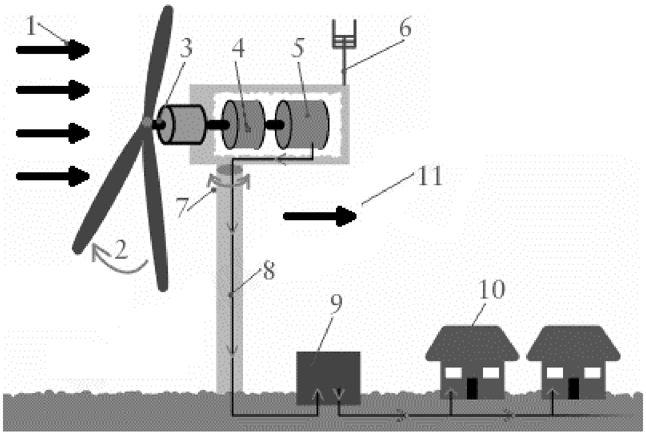


Fig. 10. Working of wind power plant

Pitch control and yaw control

Suzlon Energy Limited, Regen Powertech private limited, Inox Wind limited, Orient Green Power Limited, Vestas India, Enercon India Pvt limited, Gamesa wind turbines private limited.

Different control methods are used either to 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.

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. This maintains the turbine‘s safety in the event of high winds, loss of electrical load, or other catastrophic events.

Fig. 11. Pitch control

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.

Fig. 12. Yaw control

Stall control

(Passive) stall controlled wind turbines have the rotor blades bolted onto the hub at a fixed angle. The geometry of the rotor blade profile, however has been aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade which is not facing the wind. This stall prevents the lifting force of the rotor blade from acting on the rotor. In other words, as the actual wind speed in the area increases, the angle of attack of the rotor blade will increase, until at some point it starts to stall.

If you look closely at a rotor blade for a stall controlled wind turbine you will notice that the blade is twisted slightly as you move along its longitudinal axis. This is partly done in order to ensure that the rotor blade stalls gradually rather than abruptly when the wind speed reaches its critical value (other reasons for twisting the blade are mentioned in the previous section on aerodynamics).

The basic advantage of stall control is that one avoids moving parts in the rotor itself, and a complex control system. On the other hand, stall control represents a very complex aerodynamic design problem, and related design challenges in the structural dynamics of the whole wind turbine, e.g. to avoid stall-induced vibrations. Around two thirds of the wind turbines currently being installed in the world are stall controlled machines.

Siting of WPPs

The power available in the wind increases rapidly with the speed, hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent. Although daily winds at a given site may be highly variable, the monthly and especially annual average are remarkably constant from year to year.

The major contribution to the wind power available at a given site is actually made by winds with speeds above the average. Nevertheless, the most suitable sites for wind turbines would be found in areas where the annual average wind speeds are known to be moderately high or high.

The site choice for a single or a spatial array of WECS is an important matter when wind electrics is looked at from the systems point of view of aero turbine generators feeding power into a conventional electric grid. If the WECS sites are wrongly or poorly chosen the net wind electrics generated energy per year may be sub optimal with resulting high capital cost for the WECS apparatus, high costs for wind generated electric energy, and low Returns on Investment. Even if the WECS is to be a small generator not tied to the electric grid, the siting must be carefully chosen if inordinately long break even times are to be avoided. Technical, economic, environmental, social and other factors are examined before a decision is made to erect a generating plant on a specific site. Some of the main site selection consideration are given below:

1. High annual average wind speed
2. Availability of anemometry data
3. Availability of wind V(t) Curve at the proposed site
4. Wind structure at the proposed site
5. Altitude of the proposed site
6. Terrain and its aerodynamic
7. Local Ecology
8. Distance to road or railways
9. Nearness of site to local centre/users
10. Nature of ground
11. Favourable land cost

1. **High annual average wind speed:** The speed generated by the wind mill depends on cubic values of velocity of wind, the small increases in velocity markedly affect the power in the wind. For example, Doubling the velocity, increases power by a factor of 8. It is obviously desirable to select a site for WECS with high wind velocity. Thus a high average wind velocity is the principle fundamental parameter of concern in initially appraising WESCS site. For more detailed estimate value, one would like to have the average of the velocity cubed.
2. **Availability of anemometry data:** It is another improvement sitting factor. The anemometry data should be available over some time period at the precise spot where any proposed WECS is to be built and that this should be accomplished before a sitting decision is made.
3. **Availability of wind V(t) Curve at the proposed site:** This important curve determines the maximum energy in the wind and hence is the principle initially controlling factor in predicting the electrical output and hence revenue return o the WECS machines.

   It is desirable to have average wind speed ‗V‘ such that V>=12-16 km/hr (3.5 – 4.5 m/sec) which is about the lower limit at which present large scale WECS generators ‗cut in‘ i.e., start turning. The V(t) Curve also determines the reliability of the delivered WECS generator power, for if the V(t) curve goes to zero there be no generated power during that time.

   If there are long periods of calm the WECS reliability will be lower than if the calm periods are short. In making such reliability estimates it is desirable to have measured V(t) Curve over about a 5 year period for the highest confidence level in the reliability estimate.
4. **Wind structure at the proposed site:** The ideal case for the WECS would be a site such that the V(t) Curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal. Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity. This departure from homogeneous flow is collectively referred to as ―the structure of the wind‖.
5. **Altitude of the proposed site:** It affects the air density and thus the power in the wind and hence the useful WECS electric power output. Also, as is well known, the wind tend to have higher velocities at

higher altitudes. One must be carefully to distinguish altitude from height above ground. They are not the same except for a sea level WECS site.

6. **Terrain and its aerodynamic:** One should know about terrain of the site to be chosen. If the WECS is to be placed near the top but not on the top of a not too blunt hill facing the prevailing wind, then it may be possible to obtain a ‗speed-up' of the wind velocity over what it would otherwise be. Also the wind here may not flow horizontal making it necessary to tip the axis of the rotor so that the aeroturbine is always perpendicular to the actual wind flow.
   It may be possible to make use of hills or mountains which channel the prevailing wind into a pass region, thereby obtaining higher wind power.
7. **Local Ecology:** If the surface is base rock it may mean lower hub height hence lower structure cost. If trees or grass or vegetation are present, all of which tend to destructure the wind, the higher hub heights will be needed resulting in larges system costs that the bare ground case.
8. **Distance to road or railways:** This is another factor the system engineer must consider for heavy machinery, structure, materials, blades and other apparatus will have to be moved into any choosen WECS site.
9. **Nearness of site to local centre/users:** This obvious criterion minimizes transmission line length and hence losses and cost. After applying all the previous string criteria, hopefully as one narrows the proposed WECS sites to one or two they would be relatively near to the user of the generated electric energy.
10. **Nature of ground:** Ground condition should be such that the foundation for a WECS are secured. Ground surface should be stable. Erosion problem should not be there, as it could possibly later wash out the foundation of a WECS, destroying the whole system.
11. **Favourable land cost:** Land cost should be favourable as this along with other siting costs, enters into the total WECS system cost.
12. **Other conditions such as icing problem, salt spray or blowing dust should not present at the site, as they** may affect aeroturbine blades or environmental is generally adverse to machinery and electrical apparatus.

Grid integration issues of WPPs.

The electrical grid is the electrical power system network comprised of the generating plant, the transmission lines, the substation, transformers, the distribution lines and the consumer. Ideally the electric grid is aimed to operate at constant voltage and frequency. However, the grid can take some fluctuation in voltage and electrical equipment is designed for maximum and minimum allowable voltage levels, usually about +/- 10%.

Wind power generation varies depending on how wind fluctuates. However, the variations in output are smoothed when many wind power plants are aggregated over an area in a power system. To deal with uncertainty, wind power output can be forecasted minutes, hours, and even days ahead. Aggregating wind power plants over a wider geographic area will improve the forecast accuracy at all time frames.

Wind power as a generation source has specific characteristics, including variability, geographical distribution, favourable economics. Large-scale integration of both onshore and offshore wind raises challenges for the various stakeholders involved, ranging from generation, transmission and distribution to power trading and consumers.

In order to integrate wind power successfully, a number of issues need to be addressed in the following areas:

- **Variability:** Power plants that run on fuel (along with some hydro and geothermal plants) can be ramped up and down on command. They are, in the jargon, "dispatchable." But Variable Renewable Energy (VRE) plants produce power only when the wind is blowing or the sun is shining. Grid operators don't control VRE, they accommodate it, which requires some agility.
- **Uncertainty:** The output of VRE plants cannot be predicted with perfect accuracy in day-ahead and day-of forecasts, so grid operators have to keep excess reserve running just in case.
- **Location-specificity:** Sun and wind are stronger (and thus more economical) in some places than in others — and not always in places that have the necessary transmission infrastructure to get the power to where it's needed.

- **Nonsynchronous generation:** Conventional generators provide voltage support and frequency control to the grid. VRE generators can too, potentially, but it's an additional capital investment.
- **Low capacity factor:** VRE plants only run when sun or wind cooperates. According to the Energy Information Administration, in 2014 the average capacity factor — production relative to potential — for utility-scale solar PV was around 28 percent; for wind, 34 percent. (By way of comparison, the average capacity factor of US nuclear power was 92 percent; those plants are almost always producing power.) Because of the low capacity factor of VRE, conventional plants are needed to take up the slack, but because of the high output of VRE in peak hours, conventional plants sometimes don't get to run as often as needed to recover costs.
- **Design and operation of the power system:** Reserve capacities and balance management, short-term forecasting of wind power, demand side management and storage and optimisation of system flexibility;
- **Grid infrastructure issues:** Optimisation of present infrastructure, extensions and reinforcements, offshore grids and improved interconnection;
- **Grid connection of wind power:** Grid codes and power quality and wind power plant capabilities;
- **Market redesign issues:** Market aggregation and adapted market rules increase the market flexibility particularly for cross-border exchange and operating the system closer to the delivery hour;
- **Institutional issues:** Stakeholder incentives, non-discriminatory third party grid access and socialisation of costs

The cost of a single 225 KW or 250 KW which is widely preferred is about Rs. 1 Crore.

Steps to integrate wind power to grid

Despite these issues, there are solutions for integrating solar and wind into the grid

- **Improved planning and coordination:** This is the first step, making sure that VRE is matched up with appropriately flexible dispatchable plants and transmission access so that energy can be shared more fluidly within and between grid regions.
- **Flexible rules and markets:** Most grids are physically capable of more flexibility than they exhibit. Changes to the rules and markets that govern how plants are scheduled and dispatched, how reliability is assured and how customers are billed, says NREL(National Renewable Energy Laboratory), —can allow access to significant existing flexibility, often at lower economic costs than options requiring new sources of physical flexibility." This is the low-hanging fruit of grid flexibility. Recent research from the Regulatory Assistance Project offers an overview of the changes needed in "market rules, market design, and market operations." A new Department of Energy study describes utility best practices in "time-of-use pricing," which varies the price of electricity throughout the day to encourage demand shifting. In New York, utility regulations are being fundamentally rewritten to optimize the management of distributed energy resources (DERs).
- **Flexible demand and storage:** To some extent, demand can be managed like supply. "Demand response" programs aggregate customers willing to let their load be ramped up and down or shifted in time. The result is equivalent, from the grid operator's perspective, to dispatchable supply. There is a whole range of demand-management tools available and more coming online all the time. Similarly, energy storage, by absorbing excess VRE at times when it is cheap and sharing it when it is more valuable, can help even out VRE's variable supply. It can even make VRE dispatchable, within limits.
- **Flexible conventional generation:** Though older coal and nuclear plants are fairly inflexible, with extended shut-down, cool-off, and ramp-up times, lots of newer and retrofitted conventional plants are more nimble — and can be made more so by a combination of technology and improved practices. Grid planners can favor more flexible non-VRE options like natural gas and small-scale combined heat and power (CHP) plants. Cycling conventional plants up and down more often does come with a cost, but the cost is typically smaller than the fuel savings from increased VRE.

- **Flexible VRE:** New technology enables wind turbines to "provide the full spectrum of balancing services (synthetic inertial control, primary frequency control, and automatic generation control)," and both wind turbines and solar panels can now offer voltage control.
- **Interconnected transmission networks:** Wind and solar resources become less variable if aggregated across a broader region. The bigger the geographical area linked up by power lines, the more likely it is that the sun is shining or the wind is blowing somewhere within that area.

Grid Integration of wind farms and Power Quality Issues

The issue of power quality is of great importance to the wind turbines. The critical power quality issues related to integration of wind farms are discussed below.

1. **Issue of voltage variation:** If a large proportion of the grid load is supplied by wind turbines, the output variations due to wind speed changes can cause voltage variation, flicker effects in normal operation. The voltage variation can occur in specific situation, as a result of load changes, and power produce from turbine.
2. **Issue of voltage dips:** It is a sudden reduction in the voltage to a value between 1% & 90 % of the nominal value after a short period of time, conventionally 1ms to 1min. This problem is considered in the power quality and wind turbine generating system operation and computed according to the rule given in IEC 61400-3-7 standard, ―Assessment of emission limit for fluctuating load‖.
3. **Switching operation of wind turbine on the grid:** Switching operations of wind turbine generating system can cause voltage fluctuations and thus voltage sag, voltage swell that may cause significant voltage variation. The acceptances of switching operation depend not only on grid voltage but also on how often this may occur. The maximum number of above specified switching operation within 10-minute period and 2-hr period are defined in IEC 61400-3-7 Standard.
4. **Harmonics:** The harmonics voltage and current should be limited to acceptable level at the point of wind turbine connection in the system. This fact has lead to more stringent requirements regarding power quality, such as Standard IEC 61000-3-2 or IEEE-519.
5. **Flickers:** Flicker is the one of the important power quality aspects in wind turbine generating system. Flicker has widely been considered as a serious drawback and may limit for the maximum amount of wind power generation that can be connected to the grid. Flicker is induced by voltage fluctuations, which are caused by load flow changes in the grid. The flicker emission produced by grid-connected variable-speed wind turbines with full-scale back-to-back converters during continuous operation and mainly caused by fluctuations in the output power due to wind speed variations, the wind shear, and the tower shadow effects.
6. **Reactive power:** Traditional wind turbines are equipped with induction generators. Induction generator is preferred because they are inexpensive, rugged and requires little maintenance. Unfortunately induction generators require reactive power from the grid to operate. The interactions between wind turbine and power system network are important aspect of wind generation system.
7. **Location of wind turbine:** The way of connecting wind turbine into the electric power system highly influences the impact of the wind turbine generating system on the power quality. As a rule, the impact on power quality at the consumer‘s terminal for the wind turbine generating system (WTGS) located close to the load is higher than WTGS connected away, that is connected to H.V. or EHV system.
8. **Low voltage ride through capability:** The impact of the wind generation on the power system will no longer be negligible if high penetration levels are going to be reached. The extent to which wind power can be integrated into the power system without affecting the overall stable operation depends on the technology available to mitigate the possible negative impacts such as loss of generation for frequency support, voltage flicker, voltage and power variation due to the variable speed of the wind and the risk of instability due to lower degree of controllability.
9. **IEC recommendation:** For consistent and replicable documentation of power quality characteristic of wind turbine, the international Electro-technical Commission IEC-61400-21 was developed and today, most of the large wind turbine manufactures provide power quality characteristic data accordingly. IEC 61400-21 describe the procedures for determine the power quality characteristics of wind turbines.

Grid code for wind farms

Parameter	Allowable limit
Voltage Rise	< 2%

Voltage dips	≤ 3 %
Flicker	≤ 0.4, for average time of 2 hours
Grid frequency	47.5-51.5 Hz

UNIT III - SOLAR PV AND THERMAL SYSTEMS

Solar Radiation, Radiation Measurement, Solar Thermal Power Plant, Central Receiver Power Plants, Solar Ponds - Thermal Energy storage system with PCM- Solar Photovoltaic systems: Basic Principle of SPV conversion – Types of PV Systems- Types of Solar Cells, Photovoltaic cell concepts: Cell, module, array, PV Module I-V Characteristics, Efficiency & Quality of the Cell, series and parallel connections, maximum power point tracking, Applications.

Introduction

The basic principle behind both solar panel – solar photovoltaic (PV) and solar thermal – is the same. They absorb raw energy from the sun and use it to create usable energy. In solar PV systems this is through the creation of electricity, whereas thermal systems are used directly for heating water or air. The amount of solar radiation on the earth surface can be instrumentally measured using Pyrheliometer, Pyranometer, Photoelectric sunshine recorder and many instruments. Solar thermal power plants collect and concentrate sunlight to produce the high temperature heat needed to generate electricity. Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. A photovoltaic module consists of multiple PV cells connected in series to provide a higher voltage output. A photovoltaic array is a system composed of multiple PV modules. They can be connected in one or more series circuits, which are connected to a combiner box to provide a single direct-current output.

Solar Radiation

Solar radiation, often called the solar resource, is a general term for the electromagnetic radiation emitted by the sun. The sun emits electromagnetic radiations as a black body having a surface temperature of about 6000 K. This is because of the nuclear reaction running in it, where the sun is converting hydrogen into helium. The radius of the sun amounts to 1.39×10^9 m. The total radiation power received from the sun on a unit area perpendicular to the sun rays at the mean earth sun distance, termed an astronomical unit, is called the solar constant (SC), where 1 astronomical unit = 1AU = 1.496×10^{11}m.

The solar radiation intensity at other distances is expressed in terms of SC with SC = 1.353 kW/m^2. Like a black body radiation, the sun‘s radiation covers a wide spectrum of wavelengths from deep ultraviolet to far infrared. The power spectral distribution of the sunlight is shown in Fig. 1. The vertical axis represents the spectral irradiance $I(\lambda)$ while the horizontal axis represents the wavelength in mm. The irradiance $I(\lambda)$ is equal to the incident solar power/$m^2/\delta\lambda$ = [W/m^2/mm], where $\delta\lambda$ is the respective wavelength range in µm. It is clear from this figure that the maximum spectral irradiance lies at $\lambda = 0.5$µm. The spectral irradiance decreases because of the presence of air in the atmosphere. The air molecules scatter and absorb the solar radiation. There are multiple absorption bands for O_2, H_2O, and CO_2. It is important to notice that the solar irradiance resembles the black body radiation at ~ 6000 K represented by the dashed line.

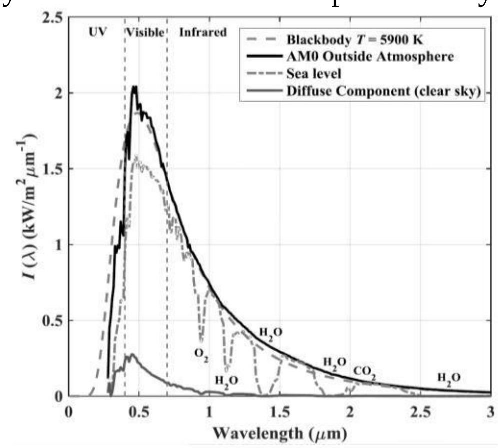


Fig.1. The power spectral distribution of the sunlight

The solar power intensity without the effect of the atmosphere or ground surface is called the Air Mass Zero where one AM0 = 1 SC = 135.3 mW/cm^2. The solar power intensity after crossing one air mass perpendicular to the earth is called the air mass 1, AM1. It represents the area under the spectral irradiance curve and amounts to 92.5 mW/cm^2. If θ is the angle of incidence with normal to the earth surface, then the optical path in units of the air mass will be larger. The air mass AM = $1/(\cos\theta)$.

As the solar radiation passes through the atmosphere, it gets absorbed, scattered, reflected, or transmitted. All these processes result in reduction of the energy flux density. Actually, the solar flux density is reduced by about 30% compared to extraterrestrial radiation flux on a sunny day and is reduced by as much as 90% on a cloudy day. The following main losses should be noted:

- absorbed by particles and molecules in the atmosphere - 10-30%
- reflected and scattered back to space - 2-11%
- scattered to earth (direct radiation becomes diffuse) - 5-26%

- As a result, the direct radiation reaching the earth surface (or a device installed on the earth surface) never exceeds 83% of the original extraterrestrial energy flux. This radiation that comes directly from the solar disk is defined as beam radiation.
- The scattered and reflected radiation that is sent to the earth surface from all directions (reflected from other bodies, molecules, particles, droplets, etc.) is defined as diffuse radiation. The sum of the beam and diffuse components is defined as total (or global) radiation. The beam radiation can be concentrated, while the diffuse radiation, in many cases, cannot be concentrated.
- Short-wave radiation, in the wavelength range from 0.3 to 3 μm, comes directly from the sun. It includes both beam and diffuse components.
- Long-wave radiation, with wavelength 3 μm or longer, originates from the sources at near-ambient temperatures - atmosphere, earth surface, light collectors, other bodies.
- The solar radiation reaching the earth is highly variable and depends on the state of the atmosphere at a specific locality. Two atmospheric processes can significantly affect the incident irradiation: scattering and absorption.

Scattering is caused by interaction of the radiation with molecules, water and dust particles in the air. The amount of light scattered depends on the number of particles in the atmosphere, particle size and the total air mass the radiation comes through.

Absorption occurs upon interaction of the radiation with certain molecules, such as ozone (absorption of short-wave radiation - ultraviolet), water vapour, and carbon dioxide (absorption of long-wave radiation - infrared).

Due to these processes, out of the whole spectrum of solar radiation, only a small portion reaches the earth surface. Thus most of x-rays and other short-wave radiation is absorbed by atmospheric components in the ionosphere, ultraviolet is absorbed by ozone and not-so abundant long-wave radiation is absorbed by CO_2. As a result, the main wavelength range to be considered for solar applications is from 0.29 to 2.5 μm.

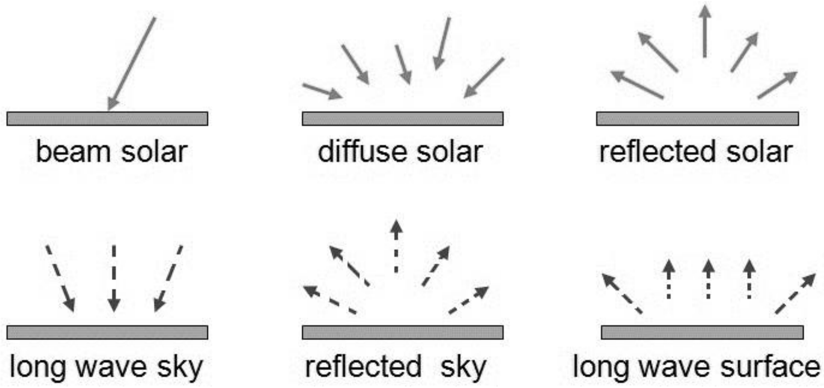


Fig.2.Different types of radiation at the earth surface: — short wave; ----long wave

India's solar installed capacity reached 34.404 GW as of 29 February 2020.

Insolation is the incident solar radiation onto some object. Specifically, it is a measure of the solar energy that is incident on a specified area over a set period of time. Generally insolation is expressed in two ways. One unit is kilowatt-hours per square meter (kWh/m^2) per day which represents the average amount of energy hitting an area each day. Another form is watts per square meter (W/m^2) which represents the average amount of power hitting an area over an entire year.

It is important to have values for insolation at certain positions on the Earth as these figures are used to help determine the size and output of solar power systems. Values for insolation can help to determine the expected output for solar panels and determine where on Earth solar panels would be most effective.

Radiation Measurement

The amount of solar radiation on the earth surface can be instrumentally measured, and precise measurements are important for providing background solar data for solar energy conversion applications. There are two important types of instruments to measure solar radiation:

1) Pyrheliometer 2) Pyranometer

Pyrheliometer is a device used for measuring direct beam radiation at normal incidence. Its outer structure looks like a long tube, projecting the image of a telescope and we have to point the lens to the sun to measure the radiance.

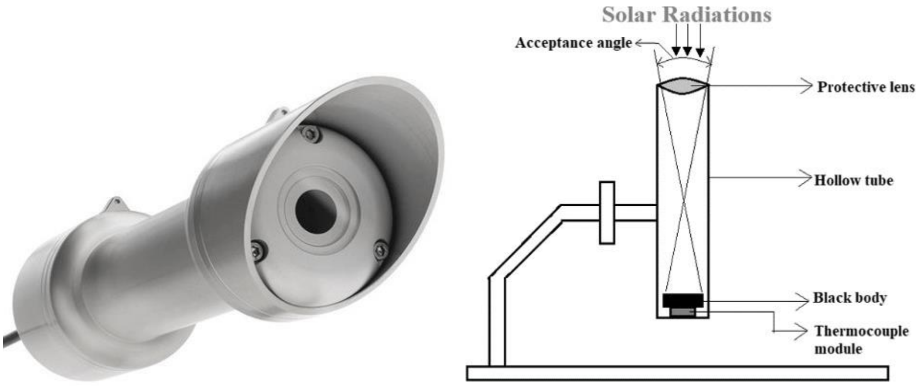


Fig. 3. Construction of Pyrheliometer

The lens is pointed towards the sun and the radiation will pass through the lens, tube and at the end falls on to the black object present at the bottom. A simpler diagram is shown in the Fig.4

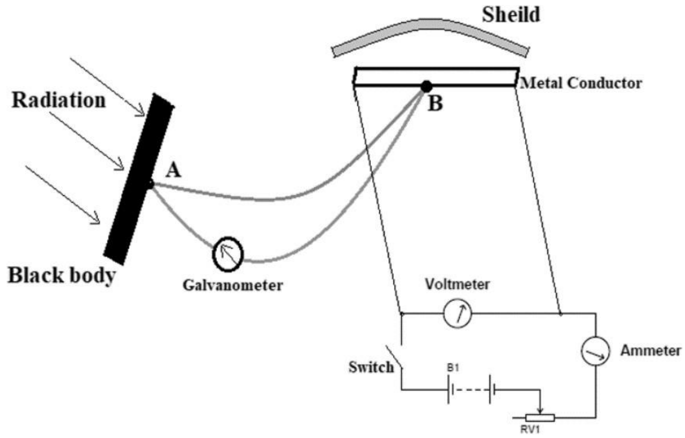


Fig.4. Simple diagram of Pyrheliometer

In the circuit, it can be seen that the black body absorbs the radiation falling from the lens and a perfect black body completely absorbs any radiation falling on it, so the radiation falling into the tube gets absorbed by the black object entirely. Once the radiation gets absorbed the atoms in the body gets excited because of the increasing temperature of the entire body. This temperature increase will also be experienced by the thermocouple junction ‗A‘. Now with junction ‗A‘ of the thermocouple at high temperature and junction ‗B‘ at low temperature, a current flow takes place in its loop.(Thermocouple action) This current in the loop will also flow through the galvanometer which is in series and thereby causing a deviation in it. This deviation is proportional to current, which in turn is proportional to temperature difference at junctions.

The deviation in the galvanometer can be reduced by adjusting the rheostat to change the current in the Metal conductor. Now by adjusting the rheostat until the galvanometer deviation becomes completely void. Once this happens we can obtain voltage and current readings from the meters and do a simple calculation to determine the heat absorbed by the black body. This calculated value can be used to determine the radiation, as heat generated by the black body is directly proportional to the radiation.

-Top 5 Largest Solar Power Plants in India-
1. Pavagada Solar Park, Karnataka 2. Kurnool Ultra Mega Solar Park, Andhra Pradesh 3. Kamuthi Solar Power Project, Tamil Nadu 4. Bhadla Solar Park, Rajasthan 5. Charanka Solar Park, Gujarat

Pyranometer working and Construction

Pyranometer is a device that can be used to measure both beam radiation and diffused radiation. In other words, it is used to measure total hemispherical radiation (beam plus diffuse on a horizontal surface). The device looks like a saucer which is the best shape suited for its purpose. This device is more popular than the others and most of the solar resource data nowadays are measured using it. The original picture and internal structure of the Pyranometer is shown in Fig.5.

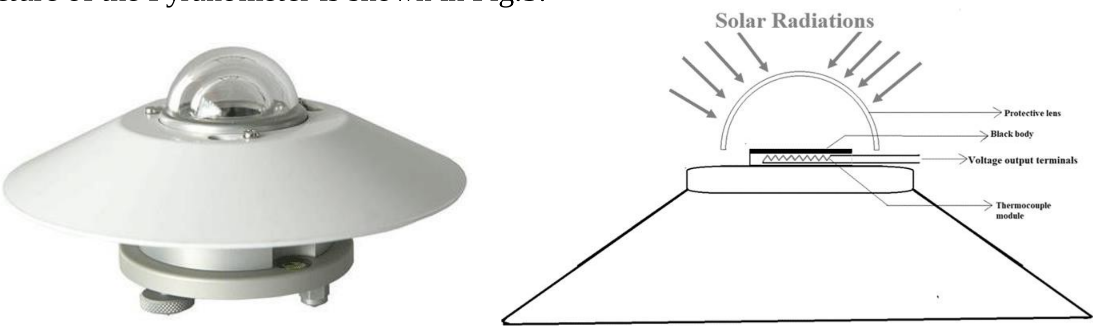


Fig.5. Pyranometer

Here the radiation from the surrounding atmosphere passes through the glass dome and falls onto the blackbody situated at the centre of the instrument. The temperature of the body rises after absorbing all the radiation and this rise will also be experienced by the Thermocouple chain or Thermocouple module present directly beneath the blackbody. So one side of the module will be hot and another will be cold because of the heat sink. The thermocouple module generates a voltage and this can be seen at the output terminals. This voltage received at the output terminals is directly proportional to temperature difference according to the principle of a thermocouple.

Since we know that the temperature difference is related to radiation absorbed by the black body, we can say the output voltage is linearly proportional to the radiation. Similar to the previous calculation, the value of total radiation can be easily obtained from this voltage value. Also by using the shade and following the same procedure, we can also obtain the diffused radiation. With total radiation and diffused radiation value, beam radiation value can also be calculated.

Quantum Sensors

Quantum sensors are specialized devices which measure the quantity of photosynthetically active radiation, or the portion of the visible spectrum which can be used by photosynthetic organisms, within a band of solar radiation. Specifically, quantum sensors measure the photosynthetic photon flux density (PPFD) of sunlight. This measurement is useful in agriculture for choosing productive farmland locations or maintaining growhouses and is also used in oceanography to calculate the boundaries of an ocean's sunlight zone. (For the latter reason, quantum sensors are often built with waterproof housing.) Quantum sensors typically use photovoltaic technology to generate a potential output.

Fig. 6. Quantum sensors

Solar Thermal Power Plant

Solar thermal power plant is a combination of solar energy and thermal energy. The sun‘s radiations is used as fuel in the power plant. Solar energy is converted into heat or thermal energy which is further converted to mechanical energy using turbine and electrical energy using generators. Further categories are based upon the power cycles i.e. low, medium and high temperature cycles. These cycles are based upon the solar radiations and type of collectors used for collecting the solar radiations. In low temperature cycles the temperature is limited to about 100⁰ C in medium temperature, range varies from 150⁰ C to 300⁰ C whereas in high temperature cycles temperature may go above 300⁰ C.

For different temperature cycle different thermodynamic cycles are used in the power plant. Generally, for low and medium temperature ranges, Rankine cycle is preferred whereas for high temperature range Brayton cycle is used. The cycle operation and different components of the solar thermal power plant are discussed here;

- Solar pond
- Solar energy collectors
- Working fluid
- Evaporator Boiler
- Turbine and Generator
- Condenser and Cooling tower

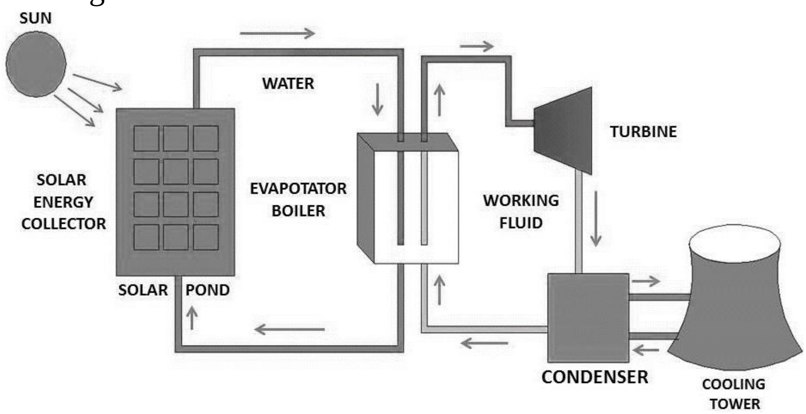


Fig.7. Solar thermal power plant

Solar pond: The solar energy coming from the sun is firstly absorbed by the solar pond. Solar pond is a reservoir of water where sun‘s rays directly focus by using solar energy collectors. After that, solar energy increases the internal energy and raises the temperature of solar pond. The fluid in the solar pond may be directly used as the working fluid if its temperature reaches up to evaporating temperature or other way is to use a secondary fluid known as working fluid. The fluid from the solar pond goes into cyclic process. The detailed operation of solar pond is as follows.

Solar pond, also called solar ‗salt pond‘, is an artificially designed pond, filled with salty water, maintaining a definite concentration gradient. It combines solar energy radiation and sensible heat storage, and as such, it is utilised for collecting and storing solar energy. A solar pond reduces the convective and evaporative heat losses by reversing the temperature gradient with the help of non-uniform vertical concentration of salts.

The vertical configuration of ―salt gradient solar pond‖ normally consists of the following three zones:

1. ―Surface (homogeneous) convective zone (SCZ)‖- It is adjacent to the surface and serves as a buffer zone between environmental fluctuations at the surface and conductive heat transport from the layer below. It is about 10 to 20 cm thick with a low uniform concentration at nearly the ambient air temperature.
2. ―Lower connective zone (LCZ)‖- It is at the bottom of the pond and this is the layer with highest salt concentration, where high temperatures are built up.
3. ―Concentration/Intermediate gradient zone (CGZ)‖- This zone keeps the two convective zones (SCZ and LCZ) apart and gives the solar pond its unique thermal performance. It provides excellent insulation for the storage layer, while transmitting the solar radiation. To maintain a solar pond in this non-equilibrium stationary state it is necessary to replace the amount of salt that is transported by molecular diffusion from the LCZ to SCZ. This means that salt must be added to the LCZ, and fresh water to the

SCG whilst brine is removed. The brine can be recycled, divided into water and salt (by solar distillation) and returned to the pond.

The major heat loss occurs from the surface of the solar pond. This heat loss can be prevented by spreading a plastic grid over the pond's surface to prevent disturbance by the wind. Disturbed water tends to lose heat transfer faster than when calm.

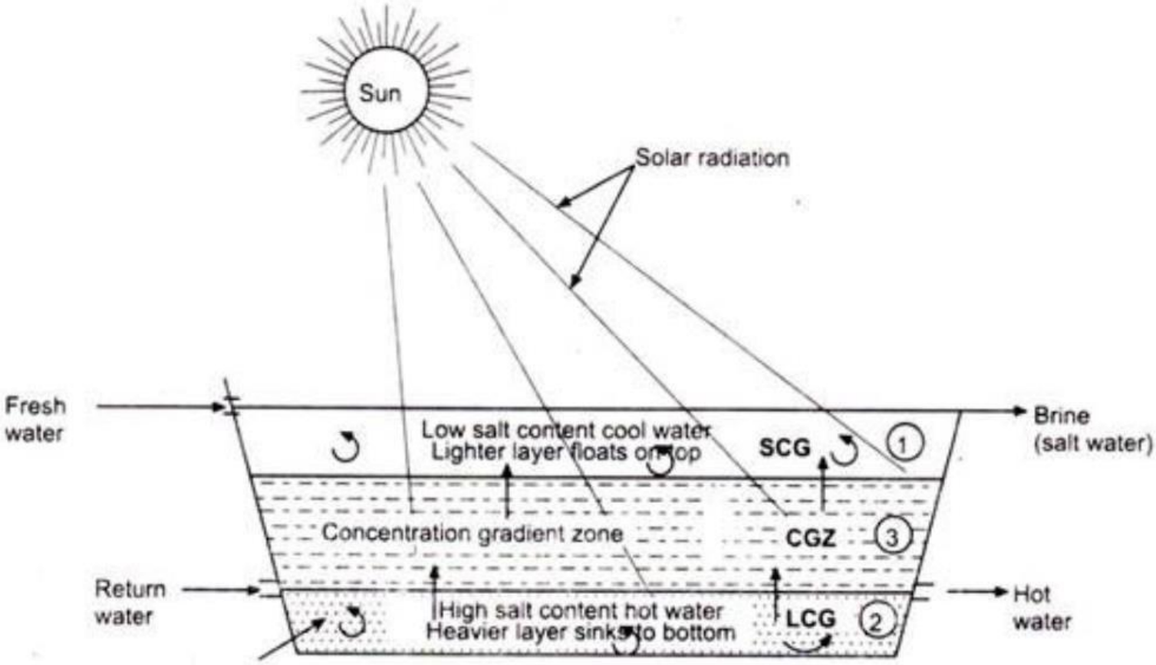


Fig.8. Principle of Solar Pond

Principle of Solar Pond

Due to the excessively high salt concentration of the LCZ, a plastic liner or impermeable soil must be used to prevent infiltration into the nearby ground water or soil. The liner is a factor that increases the cost of a solar pond. A site where the soil is naturally impermeable, such as the base of a natural pond or lake, or can be made impermeable by compaction or other means, will allow considerably lower power costs.

The optical transmission properties and related collection efficiency vary greatly and depend on the following factors:

i. Salt concentration.
ii. The quantity of suspended dust or other particles.
iii. Surface impurities like leaves or debris, biological material like bacteria and algae.
iv. The type of salt.

It becomes obvious that much higher efficiencies and storage can be achieved through the utilization of refined or pure salt whenever possible, as this maximizes optical transmission.

The solar pond is an effective collector of diffuse, as well as direct radiation, and will gather useful heat even on cloudy or overcast days. Under ideal conditions, the pond's absorption efficiency can reach 50% of incoming solar radiation, although actual efficiencies average about 20% due to heat losses.

Applications of Solar Ponds:

1. Power generation.
2. Space heating and cooling.
3. Crop drying.
4. Desalination.
5. Process heat.

Limitations of Solar Ponds:

1. Sunny climate is required
2. Need for large land area.
3. Availability of salt.
4. Availability of water.

Solar energy is a completely free source of energy and it is found in abundance. Though the sun is 90 million miles from the earth, it takes less than 10 minutes for light to travel from that much of distance.

Solar energy collectors: Solar energy collectors are the device used for collecting the solar radiations and focus the solar radiations at particular location to transfer the heat energy into the solar ponds or fluid. Generally, two types of collectors are used first is non-concentrating or flat plate type solar collector which is used for low temperature cycle and second one is concentrating or focusing type solar collector which are used for medium and high temperature applications. Collectors make the solar energy more useful. Flat plate collectors are very simple, the collecting area is equal to absorbing area where as focusing type collector have several arrangements of mirrors and lenses for proper concentration of sun light. Due to this by using focus type collectors we can capture 100 times solar radiation as compared to flat plate collector keeping the area same. By using focusing type collector we can directly generate medium pressure steam.

Solar collectors are classified as

1. Non concentrating type
   - i) Flat-Plate Collectors
   - ii) Evacuated-Tube Collector
2. Concentrating type
   - i) Parabolic trough collector.
   - ii) Power tower receiver.
   - iii) Parabolic dish collector.
   - iv) Fresnel lens collector.

Flat-Plate Collectors

Flat-plate solar collectors are the most common ones. They consist of an absorber, a transparent cover and insulation. The main use of the technology is usually in residential buildings where the demand for hot water is big and affects bills. Commercial application of flat-plate collectors is usually seen in car washes, laundromats, military laundry facilities or restaurants.

The parts of a flat plate collectors are

- Black surface - absorbent of the incident solar energy
- Glazing cover - a transparent layer that transmits radiation to the absorber, but prevents radiative and convective heat loss from the surface
- Tubes containing heating fluid to transfer the heat from the collector
- Support structure to protect the components and hold them in place
- Insulation covering sides and bottom of the collector to reduce heat losses

Flat-plate solar collectors show a good price-performance ratio and also give a lot of mounting options.

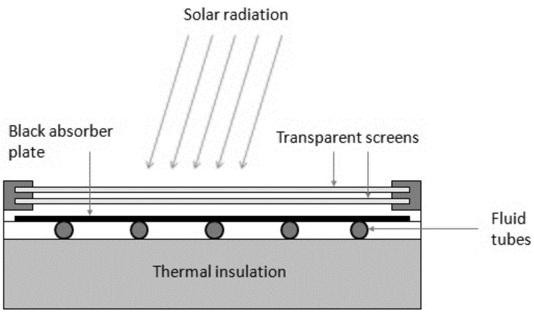


Fig. 9. Flat plate collectors

-Top 10 Solar Companies in India-
Adani Power, Tata Solar, Jinko Solar, Trina Solar, ACME Solar, Vikram Solar, Waaree Energies, EMMVEE, Goldi Solar, Canadian Solar

Evacuated-Tube Collector

This is a type of a vacuum collector. Its absorber strip is placed in an evacuated and pressure proof glass tube. The heat transfer fluid flows directly the absorber into a U-tube or in a tube-in-tube system. The heat pipe collector integrates a special fluid, which evaporates even at low temperatures, thus the steam rises in the individual heat pipes and warms up the fluid in the main pipe, generating heat. Thermodynamic panels are also based on such a refrigerant fluid but are exploiting the heat in the ambient air, and, therefore, are only suitable for hot water.

The technology is very reliable as it has an estimated lifespan of 25 years. The vacuum that surrounds the outside of the tubes greatly reduces the risk of heat loss, therefore efficiency is greater than it is with flat-plate collectors.

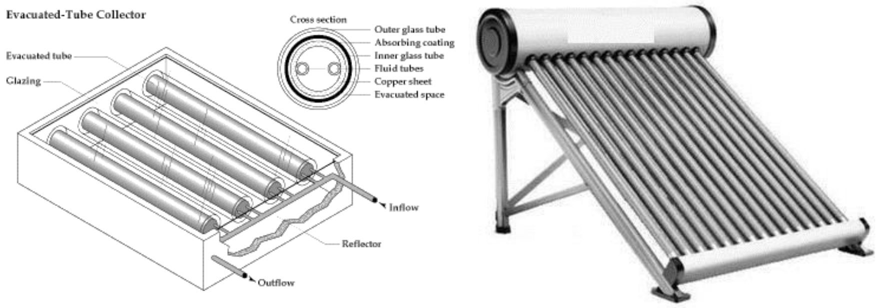


Fig. 10. Evacuated-Tube Collector

Parabolic Trough Collector

- It is a line focusing type collector. In this type of collector, the solar radiations falling on the area of the parabolic reflector are concentrated at the focus of the parabola.
- When the reflector is manufactured in the form of a trough with the parabolic cross-section, the solar radiations gets focused along a line. An absorber pipe is placed along this line and a working fluid (usually synthetic oil or water) flows through it.
- When the focused solar radiations fall on the absorber pipe, it heats the fluid to a high temperature. Then the heat absorbed by the working fluid is transferred to water for producing steam.
- The focus of solar radiations changes with the change in sun‘s elevation. In order to focus the solar radiations on the absorber pipe, either the trough or the collector pipe is rotated continuously about the axis of the absorber pipe.

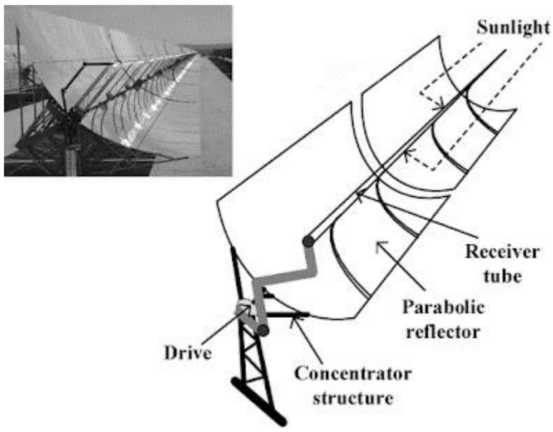


Fig.11. Parabolic Trough Collector

Power Tower Receiver

In this collector, the receiver is located at the top of the tower. It has a large number of independently-moving flat mirrors (heliostats) spread over a large area of ground to focus the reflected solar radiations on the receiver. The heliostats are installed all around the central tower. Each heliostat is rotated into two directions so as to track the sun. The solar radiations reflected from heliostats are absorbed by the receiver mounted on a tower of about 500 m height. The tower supports a bundle of vertical tubes containing the working fluid. The working fluid in the absorber receiver is converted into the high-temperature steam of about 600ºC – 700ºC. This steam is supplied to a conventional steam power plant coupled to an electric generator to generate electric power.

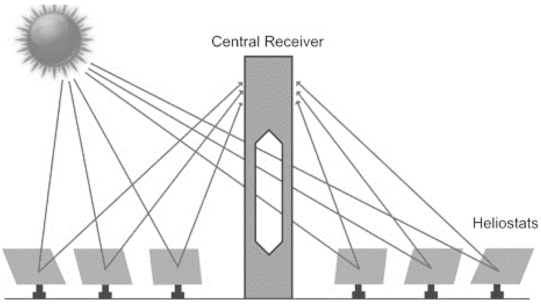
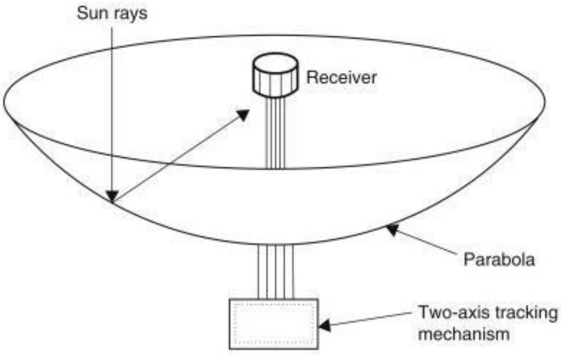


Fig.12. Power tower receiver

Parabolic Dish Collector

- In these collectors, the receiver is placed at the focal point of the concentrator. The solar beam radiations are focused at a point where the receiver (absorber) is placed. The solar radiations are collected in the receiver.
- A small volume of fluid is heated in the receiver to a high temperature. This heat is used to run a prime mover coupled with a generator.
- A typical parabolic dish collector has a dish of 6 m diameter. This collector requires two-axis tracking. It can yield temperatures up to 3000⁰ C.
- Due to the limitations of size and the small quantity of fluid, dish type solar collectors are suitable for only small power generation (up to few kW).



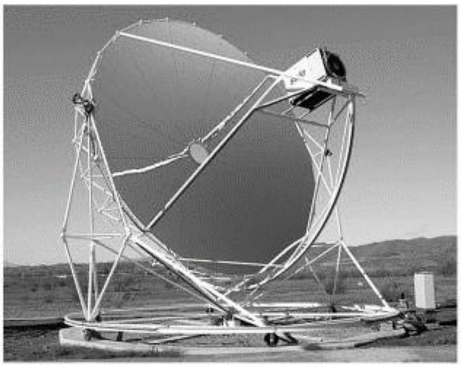


Fig.13. Parabolic Dish Collector

Fresnel Lens Concentrating Collector

- In this collector, a Fresnel lens which consists of fine, linear grooves on the surface of refracting material of optical quality on one side and flat on the other side is used.
- The angle of each groove is so designed that the optical behaviour of the Fresnel lens is similar to that of a common lens.
- The solar radiations which fall normally to the lens are refracted by the lens and are focused on a line where the absorber tube (receiver) is placed to absorb solar radiations.

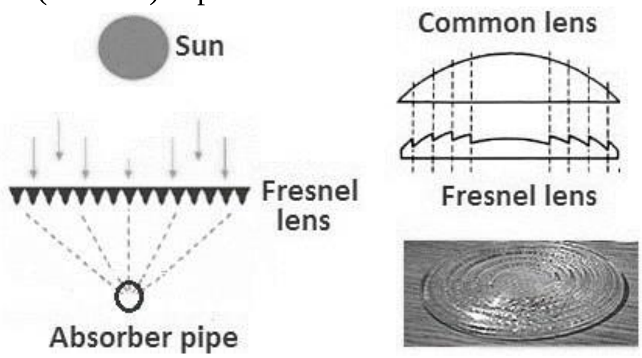


Fig.14. Fresnel Lens Concentrating Collector

Working Fluid: It is the fluid used in the cyclic operation. We use some other fluid as a working fluid because sometimes solar energy is not capable to evaporate the water. We use working fluid which gains energy from the solar pond and evaporate easily or having evaporation temperature less as compare to water. Generally, brine or some organic fluids are used as the working fluid. After evaporation working fluid goes through cyclic operations in turbine and then through condenser it goes again into the evaporator boiler. The cycle is continuously repeated.

Evaporator Boiler: In this device, working fluid is kept and gains latent heat of vaporisation from the sun's radiations or by solar pond. Working fluid is circulating throughout the cycle by evaporating boiler.

Turbine and Generator: Turbine and generators are the essential part of the power generation system. Working fluid goes through the cyclic operation and runs the turbine which is connected to the generator. Generator generates electricity which is transferred to the required location.

Condenser and cooling tower: After turbine, the working fluid goes into the condenser and cooling tower condenses the working fluid and sends back to the evaporator boiler with the help of pump.

Working of solar power plant

The working is very simple almost similar to any thermal power plant. Solar power plant also works on Rankine cycle and Brayton cycle as per the requirements. With the help of construction, we can easily predict the cycle of operation and working. Working fluid gains latent heat of vaporisation from the direct solar radiations or by means of solar ponds in the evaporator boiling and converts it into vapour form. After that it runs the turbine which is connected to the generator. Then the turbine working fluid goes into the condenser and loses heat and again sends back to the evaporator boiler with the help of pump. This whole cycle repeats continuously until the sun remains in the sky and radiation falls on the earth surface.

Advantages:

- Solar power plants work on solar energy which is available in abundant on the earth surface at most of the places.
- Solar power plants produce negligible pollution as compared to thermal power plant.
- The energy produced is renewable energy with negligible cost.
- Quantity of water used in solar power plants is very less as compare to other power plants.

Disadvantages:

- The major drawback is the availability of the sun. Sun's radiation of desired intensity is not available whole day.
- For collecting the sun radiations at useful rate large area is required.
- Initial setup cost of Solar plant is quite high.

It would cost anywhere between Rs 70,000 to Rs 1,20,000 per kW depending on the panels and inverter

Central Receiver Power Plants

Unlike linear concentrating systems (troughs), which reflect light onto a focal line, the central receiver systems send concentrated light onto a remote central receiver. A typical example of such a system is a solar power tower system, which consists of multiple tracking mirrors (heliostats) positioned in the field around a main external receiver installed on a tower. Such systems are capable of reaching of much higher levels of concentration than linear systems. Concentrated radiation is further used as heat to produce steam and convert it to electricity (like in a regular power plant), or the generated thermal energy can be stored in a molten salt storage.

Central receiver systems are typically large-scale plants that are usually built to power a steam cycle. The central position of the receiver offers a universal advantage to collect all energy at one location and save on transport networks. Central receiver systems use a field of distributed, circular array of mirrors that is, heliostats which individually track the sun and focus the sunlight on the top of a tower. By concentrating the sunlight 600 – 1000 times, they achieve temperatures from 800°C to well over 1000°C. Solar energy is absorbed by a working fluid and then used to generate steam to power a conventional turbine. The high temperatures available in solar towers can be used not only to drive steam cycles, but also for gas turbines and combined cycle systems. Such systems can achieve up to 35% peak and 25% annual solar electric efficiency when coupled to a combined cycle power plant.

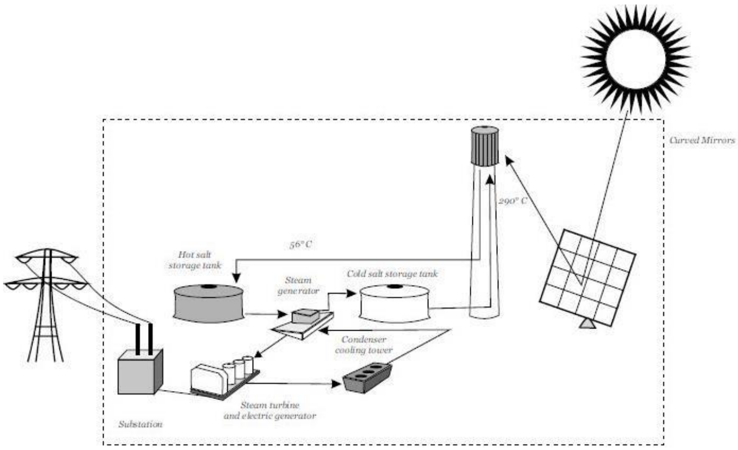


Fig.15. Operation of Central Receiver Power Plants

Major sub-components of central receiver system

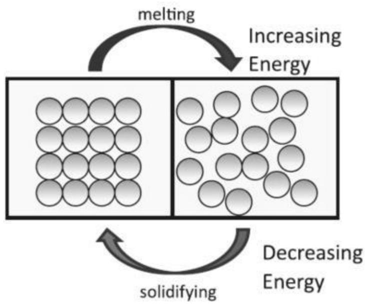
- **Heliostat field:** The heliostat field comprises a large heliostat, structure, and control/tracking. The heliostat typically utilizes a mirror, which can be oriented throughout the day to redirect sunlight along a fixed axis toward a stationary target or receiver. The reflecting element of a heliostat is typically a thin, back (second) surface, low-iron glass mirror. This heliostat is composed of several mirror module panels rather than a single large mirror. The thin glass mirrors are supported by a substrate backing to form a slightly concave mirror surface. Individual panels on the heliostat are also canted toward a point on the receiver. The heliostat focal length is approximately equal to the distance from the receiver to the farthest heliostat. Subsequent ―tuning‖ of the closer mirrors is possible.
- **Storage:** Central tower based systems typically use Molten salt, hot concrete storage, phase change materials, saturated steam or pressurized air as storage media.
  - Nitrate salt mixtures can be used as both a heat transfer fluid and a storage medium at temperatures of up to 565°C. However, most mixtures currently being considered freeze at temperatures around 140 to 220°C and thus must be heated when the system is shutdown. They have a good storage potential because of their high volumetric heat capacity.
  - Liquid sodium can also be used as both a heat transfer fluid and storage medium, with a maximum operating temperature of 600°C. Because sodium is liquid at this temperature, its vapour pressure is low. However, it solidifies at 98°C thereby requiring heating on shutdown. The cost of sodium-based systems is higher than the nitrate salt systems.
  - For high-temperature applications such as Brayton cycles, it is proposed to use air or helium as the heat transfer fluid. Operating temperatures of around 850°C at 12 atm pressure are being proposed. Although the cost of these gases would be low, they cannot be used for storage and require very large diameter piping to transport them through the system.
- **Receivers/absorber and power block:** This includes the receivers, absorbers including heat collection elements, and Power Block. The receiver, placed at the top of a tower, is located at a point where reflected energy from the heliostats can be intercepted most efficiently. The receiver absorbs the energy being reflected from the heliostat field and transfers it into a heat transfer fluid. There are two basic types of receivers: external and cavity.
  - **External Receivers.** These normally consist of panels of many small (20-56 mm) vertical tubes welded side by side to approximate a cylinder. The bottoms and tops of the vertical tubes are connected to headers that supply heat transfer fluid to the bottom of each tube and collect the heated fluid from the top of the tubes.
  - **Cavity Receivers.** In an attempt to reduce heat loss from the receiver, some designs propose to place the flux absorbing surface inside of an insulated cavity, thereby reducing the convective heat losses from the absorber. The flux from the heliostat field is reflected through an aperture onto absorbing surfaces forming the walls of the cavity. Typical designs have an aperture area of about one-third to one-half of the internal absorbing surface area. Cavity receivers are limited to an acceptance angle of 60 to 120 degrees. Therefore, either multiple cavities are placed adjacent to each other, or the heliostat field is limited to the view of the cavity aperture.

The solar field which consists of solar collectors, balance of system and tracking constitutes 36% of the cost followed by the power block at 24% which comprises the turbine, generator, heat exchangers etc. The receiver is also a major component of this technology comprising 15% of the cost.

Thermal Energy storage system with PCM

Phase change materials (PCMs) are materials that undergo the solid-liquid phase transformation, more commonly known as the melting-solidification cycle, at a temperature within the operating range of a selected thermal application. As a material changes phase from a solid to a liquid, it absorbs energy from its surroundings while remaining at a constant or nearly constant temperature. The energy that is absorbed by the material acts to increase the energy of the constituent atoms or molecules, increasing their vibrational state. At the melt temperature the atomic bonds loosen and the materials transitions from a solid to a liquid.

Solidification is the reverse of this process, during which the material transfers energy to its surroundings and the molecules lose energy and order themselves into their solid phase. This can be seen in Fig. 16.a. The energy that is either absorbed or released during the melting-solidification cycle is known as the latent heat of fusion. Latent heat is unique in that it is heat that is absorbed into a material without the material itself increasing in temperature.



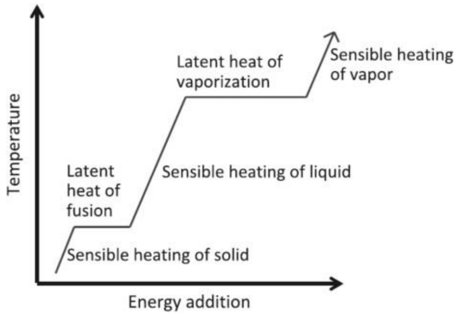


Fig. 16.a. The melting solidification process **b. Standard heating curve**

It is easy to picture this process by considering the melting of an ice cube. You can heat the ice cube by exposing it to ambient room temperature conditions, by heating it with a hair dryer, or by blasting it with a blow torch, but no matter how much heat flux is supplied to it, that ice cube will not increase in temperature until the melting process is complete. The latent heat absorbed during the melting process is referred to as the latent heat of fusion, in order to distinguish it from the other form of latent heat, the latent heat of vaporization, which characterizes the change in phase from a liquid to a gas. In contrast to latent heat, which does not increase the temperature of a material, sensible heat is that heat which does result in a change in temperature within the material.

A standard continuous heating process may begin with a subcooled solid, which is heated to the melting point through sensible heating. As the heating process continues the solid transitions to a liquid through the latent of heat fusion, and sensible heat then increases its temperature to the boiling point. Once the boiling point is reached, the liquid transitions to a vapour through the latent heat of vaporization until the phase change process is complete. Any additional heating is now in the form of sensible heat which acts to superheat the vapour. It can be seen in Fig. 16.b that the latent heat of vaporization is a higher energy process than the latent heat of fusion.

It is true that in general that the boiling/condensation process absorbs/and releases more energy, but the density change from a liquid to a vapour is large, and working with boilers and condensers often requires a significant amount of support equipment which is not always convenient. There are of course many applications for boiling heat transfer, but here we will concentrate on the applications for which a solid-liquid phase change process is most advantageous. The amount of energy absorption or release during the melting-solidification cycle is governed by the value of that material‘s latent heat of fusion. The latent heat of fusion is commonly expressed in units of J/g or kJ/kg. Thus the process is a mass-based process. The amount of energy absorbed by the material during melting depends solely on the mass of material present in the design.

Advantages of PCMs

- The use of PCMs for transient thermal management has the advantage of maintaining a constant system temperature throughout the melt process regardless of applied heat flux.
- PCMs are lightweight, portable and highly reliable depending only on the characteristics of the material itself, and do not depend on an external flow source such as a fan or pump.
- The main options available for thermal energy storage include sensible heat storage and thermochemical storage.
- Latent heat storage has a much higher energy density than sensible heat storage, resulting in less required material mass and/or smaller storage tank volumes.
- Latent heat storage systems are also easier to work with than thermochemical storage.
- The solid-liquid transition results in only a small density change, resulting in smaller system size and less support equipment than when attempting to store thermal energy for long term use through the liquid vapour phase change process.

Limitations

PCMs, however, are far from perfect solutions. The detriment most commonly cited to their greater utilization is that many PCMs do not have high thermal conductivities or diffusivities, preventing rapid system transients.

Application of PCM in Concentrating Solar Power Plants

The use of phase change materials for thermal energy storage (TES) in solar applications can extend the usefulness of the technology so that benefits can be provided even where there is low or no direct insolation. Commercial solar power plants are designed using the concept of Concentrating Solar Power (CSP). In these plants, sunlight is reflected and concentrated using mirrors and then used to heat a carrier fluid. An example of parabolic trough technology is shown in Fig. 17. In this image, the thermal receiver is supported above the concentrating mirrors. The receiver is a black pipe encased in a vacuum tube to reduce convective losses.

A high temperature, high pressure heat transfer fluid (HTF) circulates through the receiver pipes. Depending on the design of the system, the HTF fluid may serve as the heat source in an evaporator, creating steam which powers a stream turbine which drives a generator, or the HTF may directly vaporize as it passes through the solar field and then pass straight through the turbine without an intermediate heat exchanger (known as Direct Steam Generation—DSG). In either design, during periods of high insolation, it is possible to absorb more solar thermal energy into the HTF than is necessary to power the turbine. This ―excess‖ solar thermal energy can be stored using sensible or latent heat in storage tanks as shown in Fig. 17.

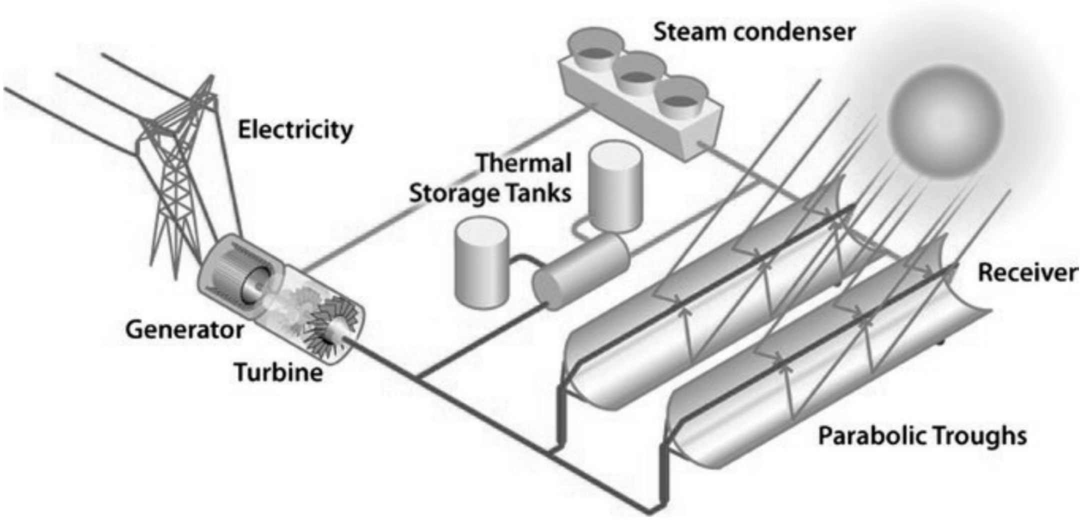


Fig. 17. Direct steam generation concentrating solar power plant with thermal energy storage

In the two-tank molten system a heat exchanger is located between the two tanks with the HTF flowing on one side of the exchanger and the storage medium (molten salt) on the other side. During the energy storage cycle, some of the HTF from the solar is diverted to this exchanger where it transfers energy to the molten salt. In this case, the salt flow originates in the ―cold‖ tank and flows through the heat exchanger where it absorbs solar thermal energy and then into the ―hot‖ tank where it is stored. During the energy discharge cycle, the HTF and molten salt flow paths are reversed.

The salt gives up its energy to the HTF as it moves from the hot tank through the heat exchanger into the cold tank, and the now hot HTF is used in the power cycle. While these systems have seen success, there is significant cost inherent in using two storage tanks, and the energy density of these storage systems is low as the salt remains in the liquid phase at all times. The use of PCMs in these applications can thus reduce tank number (to one), size and installation costs, creating an economic benefit. Molten salts are commonly used in these applications because of their high operating points. These materials have melting points from around 300 °C to over 800 °C. The HTF in parabolic trough and linear Fresnel system can reach around 300–400 °C in the receiver, while heliostats receivers can operate in excess of 2000 °C. Salts are well suited for these operational ranges, but suffer from a few drawbacks including high corrosiveness and low thermal conductivity. The primary issue with low thermal conductivity is the need for quick charge and discharge of energy as the HTF flows through the storage medium. In a few cases, liquid metal alloys may be used instead of molten salts.

The PCM used in the Rankine cycle system was 60 % $NaNO_3$/40 % KNO_3, known as solar salt while the PCM used with the s-CO2 power cycle was $KCl/MgCl_2$. The typical PCMs used in these applications are inorganic salts which melt in the range from 300–800 °C. These PCMs tend to be corrosive and have low thermal conductivities but it was shown that this can be offset with the use of embedded heat pipes or thermosyphons. In certain applications liquid metals may be used instead.

Domestic Solar Applications

While the large CSP plants certainly have significant technical and economic incentives to implement PCM thermal energy storage systems, smaller scale solar systems can also reap some benefits from TES. For example, solar thermal systems can be used by small businesses and homes for hot water production and for heating systems. A small scale solar hot water system with energy storage can be seen in Fig. 18. These systems feature a flat plate solar collector, typically mounted on the roof, which features a heat transfer fluid passing through the receiver tubes.

The receiver tubes are isolated within an enclosure with a glass cover plate. The enclosure may be evacuated to prevent convective losses. In many ways this is similar to the CSP solar field, but without the concentrators. The lack of concentrators means that the HTF will not reach the high temperatures characteristic of CSP. As such the fluid can‘t be used to create vapour and drive a power system, but is hot enough to provide the heat source for a domestic hot water tank. As with CSP, the effectiveness of the system is limited to daylight hours, but the solar thermal system can be designed to store extra heat using PCM in the storage tanks for the overnight hours, greatly reducing dependence on supplemental natural gas or electrical heating.

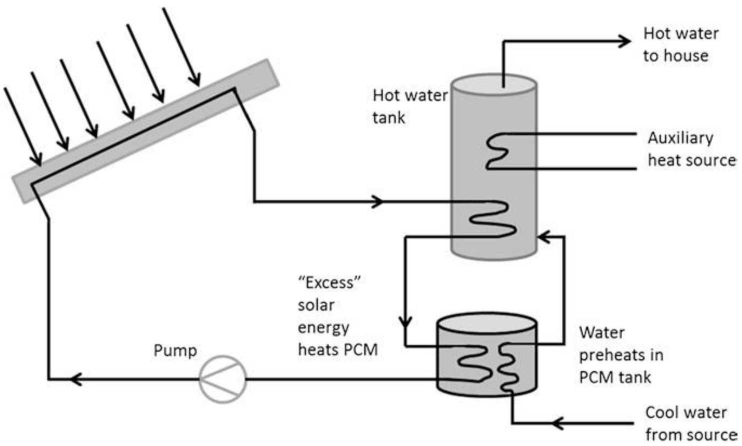


Fig.18. Domestic solar hot water heating system with PCM thermal storage

The average cost of installation of rooftop PV system without subsidy is around Rs 60,000 – 70,000. After availing 30 per cent subsidy, people just have to pay Rs 42,000 – 49,000 for installing a rooftop PV system.

Solar Photovoltaic systems: Basic Principle of SPV conversion

A photovoltaic (PV) cell is an energy harvesting technology that converts solar energy into useful electricity (DC) through a process called the photovoltaic effect. It is made up of semiconductor materials such as silicon, gallium arsenide and cadmium telluride, etc. These cells vary in size ranging from about 0.5 inches to 4 inches. There are different types of PV cells which all use semiconductors to interact with incoming photons from the Sun in order to generate an electric current.

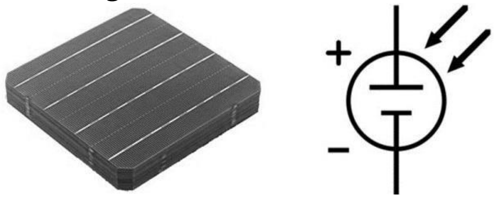


Fig. 19 PV cell and PV Cell symbol

Photovoltaic cell concepts: Cell

Layers of a PV Cell

A photovoltaic cell is comprised of many layers of materials, each with a specific purpose. The most important layer of a photovoltaic cell is the specially treated semiconductor layer. It is comprised of two distinct layers of p-type and n-type, and is what actually converts the Sun's energy into useful electricity through a process called the photovoltaic effect. On either side of the semiconductor is a layer of conducting material which "collects" the electricity produced. Note that the backside or shaded side of the cell can afford to be completely covered in the conductor, whereas the front or illuminated side must use the conductors sparingly to avoid blocking too much of the Sun's radiation from reaching the semiconductor.

The final layer which is applied only to the illuminated side of the cell is the anti-reflection coating. Since all semiconductors are naturally reflective, reflection loss can be significant. The solution is to use one or several layers of an anti-reflection coating (similar to those used for eyeglasses and cameras) to reduce the amount of solar radiation that is reflected off the surface of the cell.

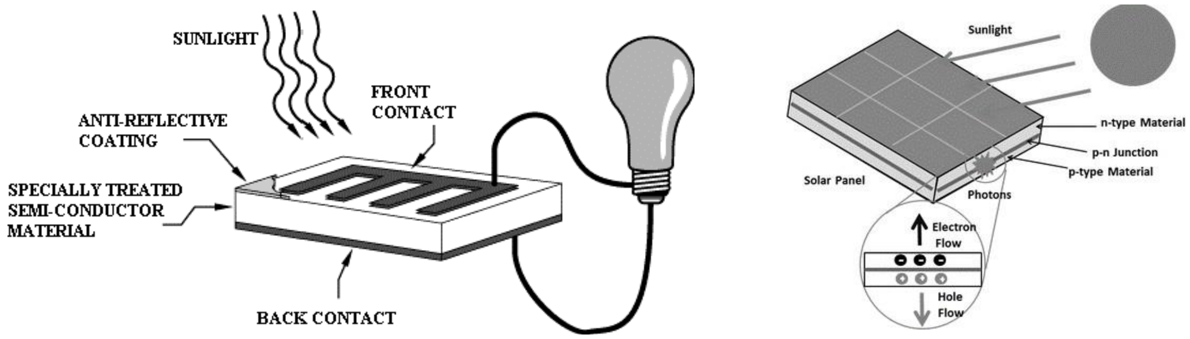


Fig. 20. A diagram showing the photovoltaic effect.

Photovoltaic Effect

The photovoltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight. These solar cells are composed of two different types of semiconductors—a p-type and an n-type that are joined together to create a p-n junction. By joining these two types of semiconductors, an electric field is formed in the region of the junction as electrons move to the positive p-side and holes move to the negative n-side. This field causes negatively charged particles to move in one direction and positively charged particles in the other direction.

Light is composed of photons, which are simply small bundles of electromagnetic radiation or energy. When light of a suitable wavelength is incident on these cells, energy from the photon is transferred to an electron of the semiconducting material, causing it to jump to a higher energy state known as the conduction band. In their excited state in the conduction band, these electrons are free to move through the material, and it is this motion of the electron that creates an electric current in the cell.

- **Cell:** A photovoltaic cell is the most basic unit of a solar PV system - solar cells can be either monocrystalline or polycrystalline, and their key characteristic is that they produce a voltage output when exposed to light. It is important to note that although they are normally called "solar cells", they can respond to any type of light. Each cell produces approximately 1/2 a volt and a solar module can have any number of solar cells.

- **Module:** A photovoltaic module consists of multiple PV cells connected in series to provide a higher voltage output. PV modules are manufactured in standard sizes. A solar module designed for charging a 12 volt battery will typically have 36 solar cells while the typical residential grid connected system uses solar modules with 60 solar cells. For large commercial and utility scale solar systems, solar modules will have typically 72 solar cells. By increasing the number of solar cells the module voltage and wattage increases. The term solar panel is sometimes used interchangeably with solar module. The main difference is that some solar panels models are composed of multiple modules mounted together.
- **Array:** A photovoltaic array is a system composed of multiple PV modules. They can be connected in one or more series circuits, which are connected to a combiner box to provide a single direct-current output. This output can be used to charge batteries, power DC loads, or fed to an inverter to provide an AC voltage for home appliances or exporting to the electric grid.

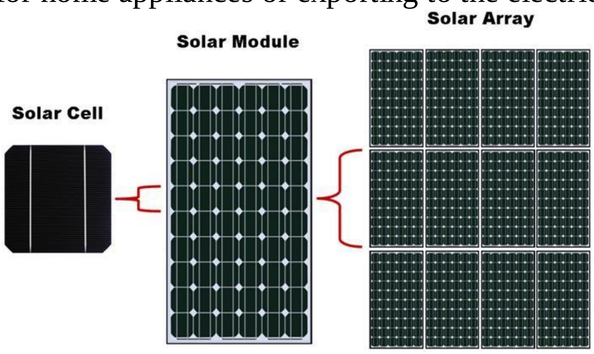


Fig.21. Cell module and array

Operation of PV Systems

Solar cells produce direct current (DC), therefore they are only used for DC equipments. If alternating current (AC) is needed for AC equipment or backup energy is needed, solar photovoltaic systems require other components in addition to solar modules. These components are specially designed to integrate into solar PV system. The components of solar photovoltaic system are shown in the figure.

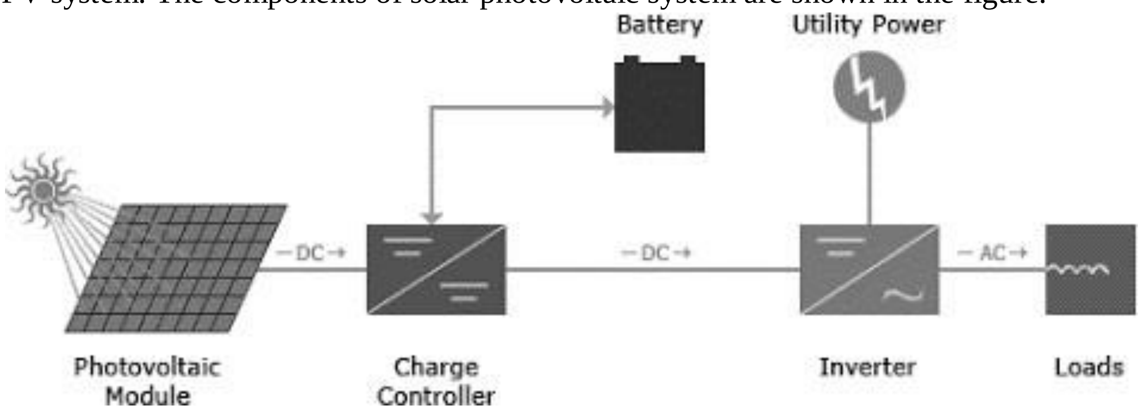


Fig. 22. Components of Photovoltaic system

1. **Solar or Photovoltaic Module** is the essential component of any solar PV system that converts sunlight directly into DC electricity.
2. **Solar Charge Controller** regulates voltage and current from solar arrays, charges the battery, prevents battery from overcharging and also performs controlled over discharges.
3. **Battery** stores the energy produced from solar arrays for using when sunlight is not visible, night time or other purposes.
4. **Inverter** is a critical component of any solar PV system that converts DC power output of solar arrays into AC for AC appliances.
5. **Lightning protection** prevents electrical equipment from damages caused by lightning or induction of high voltage surge. It is required for the large size and critical solar PV systems, which include efficient grounding.

Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid.

Types of PV Systems

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principle classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.

PV Direct System

These are the simple most type of solar PV systems, with the fewest components; the Solar Panels and the load. Because they don‘t have batteries and are not hooked up to the grid, they only power the loads when the sun is shining. They are appropriate for a few applications e.g. water pumping or attic ventilation fan.

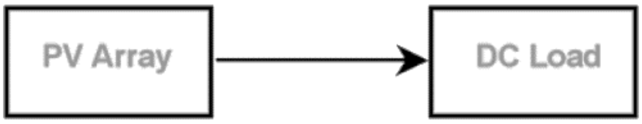


Fig. 23. Direct PV System

Solar Off Grid System

Also referred to as stand-alone systems, it is designed to be independent of the power grid. Batteries are used to store energy when the sun is not available during cloudy days or at night. This type of system will require regular attention to battery electrolyte levels and terminal corrosion.

- Independence from the utility grid
- Not subject to the terms/policies of the utility company
- Rate increases, blackouts, or brownouts do not apply
- In remote areas, it is cost effective than extending a grid
- Encourages energy efficiency
- Batteries require maintenance and has limited life
- More components means more complexity
- Batteries decrease system efficiency
- It is more expensive than a grid-direct system
- When the batteries are fully charged, potential power from the PV array is not utilized
- If the PV system fails, back-up electricity is required to run load
- Most off-grid systems use a backup generator for non-sunny days. They are expensive, noisy, dirty, and require fuel and regular maintenance

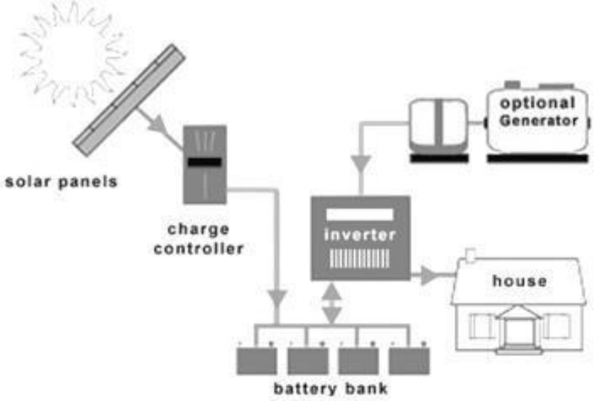


Fig. 24. Off grid solar PV system

Solar Grid Tied System without Battery backup

These are most common type of PV systems. They are also known as on-grid, grid-tied, grid-intertied, or grid-direct systems. They generate solar electricity and route it to the loads and to the grid, offsetting some of electricity usage. System components comprises of the PV array and inverter. Grid-connected system is similar to regular electric powered system except that some or all of the electricity comes from the sun. The drawback of these battery less systems is that they provide no outage protection when the utility grid fails, these systems cannot operate.

- grid-tied-system
- Increased design flexibility because the system does not have to power all of the home‘s loads
- It is less expensive compared to stand-alone or grid-tied with battery backup systems
- It requires the least amount of maintenance
- If the system produces more than the loads need, then the extra energy is exchanged with the grid
- Grid-direct systems have a higher efficiency because batteries are not part of the system
- Higher voltage means smaller wire size
- Electricity costs are fixed for the life of your system
- There is no power to the home when the grid goes down
- Paperwork requirements for interconnection, incentives, and rebates

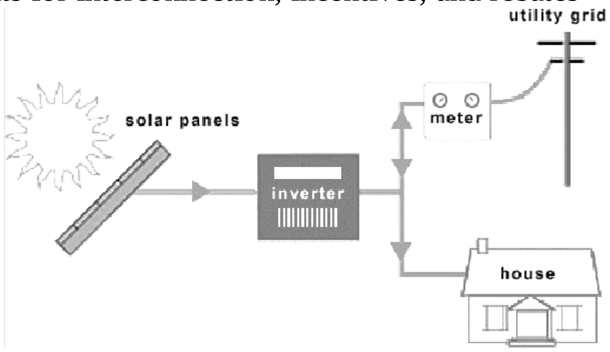


Fig. 25. Grid tied system without battery back up

Solar Grid Tied with Battery Backup System

This type is very similar to an off-grid system in design and components, but adds the utility grid, which reduces the need for the system to provide all the energy all the time.

- grid-tied-with-battery-backup
- Designated loads have power when the grid goes down
- If the system produces more than the home needs, then the extra energy is sold back to the utility- not lost as in a stand-alone systems after the batteries get full on a sunny day
- Batteries require maintenance
- Requires rewiring circuits from main service panel to a separate subpanel
- More components mean more complexity
- Batteries decrease system performance because of their efficiency losses
- More expensive than a grid-direct system
- Typically only provides modest backup – usually not all of the loads are backed up
- Requires paperwork for interconnection, incentives, and rebates

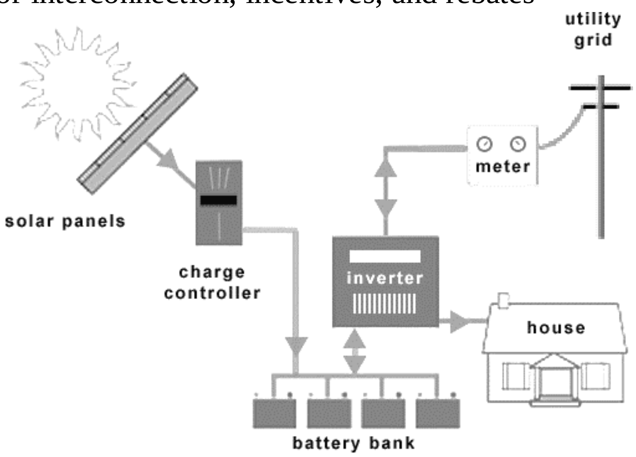


Fig. 26. Gird tied solar system with battery back up

Hybrid system

Hybrid system tries to combine multiple sources of power to maximize availability of power. It may source energy from sun, wind or diesel generator and back it up with battery.

- Multiple sources of generation allows for complementary sources and backup. For instance, when it is sunny out the PV array will charge the battery; if it is cloudy and windy, a wind turbine can charge the batteries.
- Array size and battery bank capacity can typically be reduced and not having to oversize for periods of no sun
- More complex system design and installation
- Multiple power sources can increase upfront expenses
- Wind turbines and generators require regular maintenance.

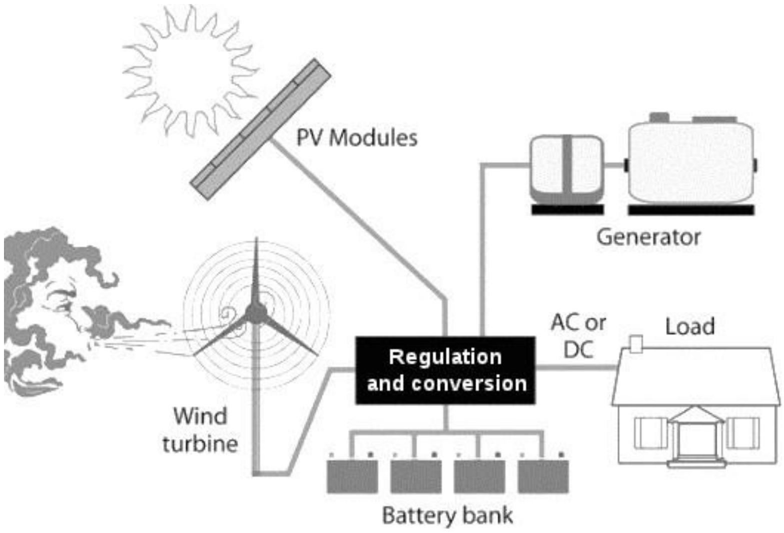


Fig. 27. Hybrid power systems

Types of Solar Cells

There are different types of photovoltaic cells available to buy, but mainly they are manufactured from silicon (Si). The use of silicon in the manufacture of photovoltaic cells produces the stereo typical uniform blue coloured PV cell which we see on roof tops and the sides of buildings.

The two major types of photovoltaic cell materials used are crystalline silicon and thin film deposits, which vary from each other in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production. Crystalline silicon PV cells are the most common type of photovoltaic cell in use today and are also one of the earliest successful PV devices.

The three general types of photovoltaic cells made from silicon are:

1. Mono-crystalline Silicon – also known as single-crystal silicon
2. Poly-crystalline Silicon – also known as multi-crystal silicon
3. Thin Film Silicon

Noor Complex is the world's largest concentrated solar power (CSP) plant, located in the Sahara Desert. The project has a 580-megawatt capacity.

Crystalline Silicon (c-Si)

This is the most common technology used to produce photovoltaic cells representing about 90% of the market today. Crystalline photovoltaic cells are made from silicon which is first melted, and then crystallised into ingots or casting‘s of pure silicon. Thin slices of silicon called wafers, are cut from a single crystal of silicon (Mono-crystalline) or from a block of silicon crystals (Poly-crystalline) to make individual cells. The conversion efficiency for these types of photovoltaic cell ranges between 10% and 20%.

Mono-crystalline Silicon is a type of photovoltaic cell material manufactured from a single-crystal silicon structure which is uniform in shape because the entire structure is grown from the same crystal. High purity silicon is melted in a crucible. A single-crystal silicon seed is dipped into this molten silicon and is slowly pulled out from the liquid producing a single-crystal ingot. The ingot is then cut into very thin wafers or slices which are then polished, doped, coated, interconnected and assembled into modules and arrays. These types of photovoltaic cells are also widely used in photovoltaic panel construction.

Compared to non-crystalline cells, the uniform molecular structure of the silicon wafer makes it ideal for transferring loose electrons through the material resulting in a high energy conversion efficiency. The conversion efficiency for a mono-crystalline cell ranges between 15 to 20%.

Not only are they energy efficient, mono-crystalline photovoltaic cells are highly reliable for outdoor power applications due to their wafer thickness. However, to make an effective PV cell, the silicon has to be ―doped‖ with other elements to make the required N-type and P-type conductive layers.

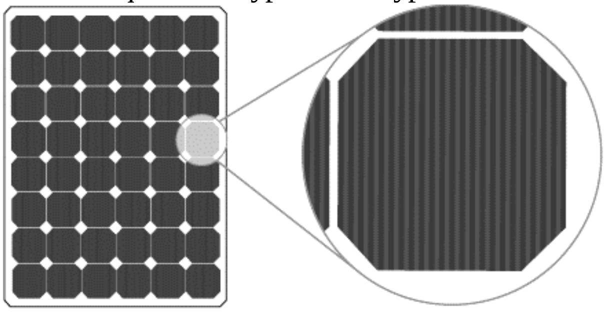


Fig. 28. Monocrystalline solar panels

Poly-crystalline Silicon also known as multi-crystalline silicon, is cast to produce a silicon ingot. The silicon molecular structure consists of several smaller groups or grains of crystals, which introduce boundaries between them. Poly-crystalline PV cells are less energy efficient than the previous mono-crystalline silicon PV cells because these boundaries restrict the flow of electrons through it by encouraging the negative electrons to recombine with the positive holes reducing the power output of the cell.

The result of this means that a poly-crystalline PV cell only has an energy conversion efficiency of between 10 to 14%. However, these types of photovoltaic cell are much less expensive to produce than the equivalent single mono-crystalline silicon due to their lower manufacturing costs.

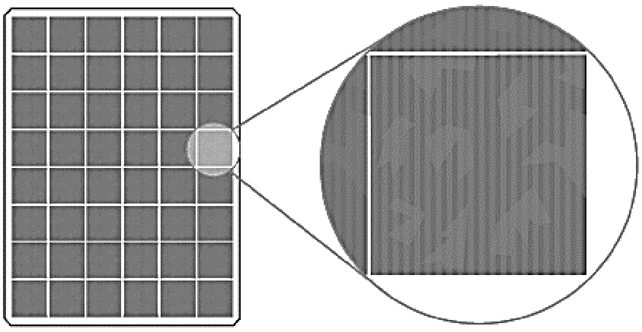


Fig. 29. Polycrystalline solar panels

Thin Film Solar Cell

Thin Film Solar Cells are another type of photovoltaic cell which were originally developed for space applications with a better power-to-size and weight ratio compared to the previous crystalline silicon devices. Thin film photovoltaics are produced by printing or spraying a thin semiconductor layer of PV material onto a glass, metal or plastic foil substrate. By applying these materials in thin layers, the overall thickness of each photovoltaic cell is substantially smaller than an equivalent cut crystalline cell, hence the name ―thin film‖. As the PV materials used in these types of photovoltaic cells are sprayed directly onto a glass or metal substrate, the manufacturing process is therefore faster are cheaper making thin film PV technology more viable for use in a home solar system as their payback time is shorter.

However, although thin film materials have higher light absorption than equivalent crystalline materials, thin film PV cells suffer from poor cell conversion efficiency due to their non-single crystal structure, requiring larger sized cells. Semiconductor materials used for the thin film types of photovoltaic cell include: Cadmium Telluride, Amorphous Silicon and Copper Indium diSelenide or CIS.

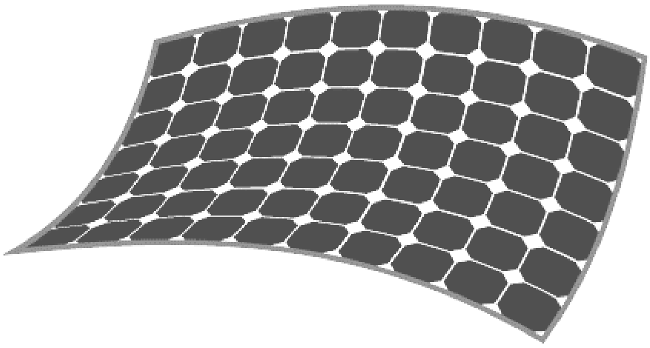


Fig. 30. Thinfilm solar panels

Cadmium Telluride, (CdTe) is a poly-crystalline semiconductor material made from cadmium and tellurium. Thin film cadmium telluride has a high light absorption level so the amount of CdTe required can be quite minimal with less than 1.0 microns of semiconductor material is needed to effectively absorb sunlight for the solar device to perform.

Although the process of spraying or printing the thin film is relatively easy making it cheap to manufacture these types of photovoltaic cell, the main material, cadmium is a toxic heavy metal can pollute the environment if the cell is damaged or broken. Another disadvantage of these types of photovoltaic cells is that the conversion efficiency for a cadmium telluride PV cell can be low at less than 10%.

Amorphous Silicon, (a-Si) is a non-crystalline form of silicon that is widely used in calculators, consumer electronics and solar garden products that require a small current at a low voltage. Of the different types of photovoltaic cell available, amorphous silicon has the highest light absorption of over 40 times higher than crystalline silicon. The advantage of this is that a much thinner layer of amorphous silicon material is required to make a thin film PV cell reducing manufacturing costs and price.

Amorphous silicon cells have various advantages and disadvantages. On the plus side, amorphous silicon can be deposited on a variety of low cost rigid and flexible substrates such as polymers, thin metals and plastics as well as tinted glass for building integration. However, on the minus side, two of the main disadvantages of amorphous silicon (a-Si) is its very low conversion efficiency ranging from between 7 to 9% when new, degrading down within a few months of exposure to sunlight to less than 5%.

Copper Indium diSelenide, (CIS) is another type of poly-crystalline semiconductor material composed of Copper, Indium and Selenium, ($CuInSe2$). Thin film CIS types of photovoltaic cell can produce conversion efficiencies of nearly 10%, almost double that of amorphous silicon without suffering from the same outdoor degradation problems due to their thicker film. Also CIS cells are one of the most light-absorbent semiconductor compounds absorbing up to 90% of the solar spectrum.

Although Copper Indium diSelenide, CIS cells are efficient, the complexity of the formulation of the semiconductor compound makes them difficult to manufacture and expensive. Also, Indium is a relatively expensive material due to its limited availability with manufacturing safety issues a concern as hydrogen selenide is an extremely toxic gas.

Copper Indium Gallium diSelenide, (CIGS) is another type of photovoltaic cell. It is basically a P-type poly-crystalline thin film material based on the previous copper indium diselenide (CIS) semiconductor material. The addition of small amounts of the compound Gallium (Ga) produces a photovoltaic cell with a higher conversion efficiency of around 12% from the same amount of sunlight with an open circuit voltage of about 0.7 volts. This is because Gallium, which is a liquid similar to mercury at room temperatures, increases the light-absorbing band gap of the cell, which matches more closely the solar spectrum, thereby improving its conductivity allowing electrons to freely move through the cell to the electrodes.

Other Types of Photovoltaic Cell

Apart from the commonly used types of photovoltaic cell mentioned above, and which account for about 95% of the commercial market, other types of photovoltaic cell currently being developed include:

Multijunction PV Cells – These are types of photovoltaic cell designed to maximise the overall conversion efficiency of the cell by creating a multi-layered design in which two or more PV junctions are layered one on top of the other. The cell is made up of various semiconductor materials in thin-film form for each individual layer.

The advantage of this is that each layer extracts energy from each photon from a particular portion of the light spectrum that is bombarding the cell. This layering of the PV materials increases the overall efficiency and reduces the degradation in efficiency that occurs with standard amorphous silicon cells.

Dye-Sensitive PV Cells – This type of technology is considered to be the 3rd generation of solar cells. Instead of using solid-state PN-junction technology to convert photon energy into electrical energy, an electrolyte, liquid, gel or solid is used to produce a photo-electrochemical PV cell. These types of photovoltaic cells are manufactured using microscopic molecules of photosensitive dye on a nano-crystalline or polymer film. The photon light energy being absorbed by the dye releases electrons into the conduction band causing a flow of the electricity through the semiconductor. The advantage of a dye-sensitive nano-crystalline photo-electrochemical photovoltaic cell is that the dye can be screen printed onto any surface producing conversion efficiencies of around 10%.

3D Photovoltaic Cells – This type of photovoltaic cell uses a unique three-dimensional structure to absorb the photon light energy from all directions and not just from the top as in convectional flat PV cells. The cell uses a 3D array of miniature molecular structures which capture as much sunlight as possible boosting its efficiency and voltage output while reducing its size, weight and complexity.

Solar panel type	Advantages	Disadvantages
Monocrystalline	• High efficiency/performance • Aesthetics	• Higher costs
Polycrystalline	• Low cost	• Lower efficiency/performance
Thin-film	• Portable and flexible • Lightweight • Aesthetics	• Lowest efficiency/performance

Table: Comparison of types of Solar cells

China is the world's largest manufacturer of solar panels.

PV Module I-V Characteristics

Solar Cell I-V Characteristic Curves show the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array giving a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device‘s output performance and solar efficiency.

The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve. The intensity of the solar radiation (insolation) that hits the cell controls the current (I), while the increases in the temperature of the solar cell reduces its voltage (V).

Solar cells produce direct current (DC) electricity and current times voltage equals power, so we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device.

Solar Cell I-V Characteristics Curves are basically a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible.

Solar Cell I-V Characteristic Curve

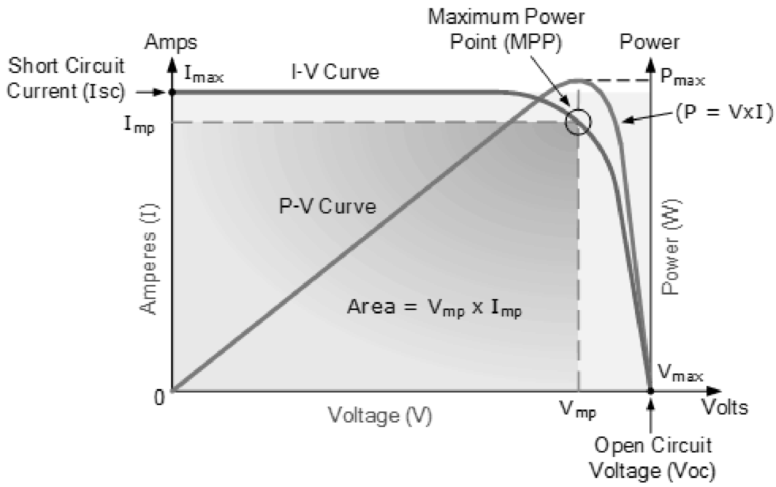


Fig. 31. Solar Cell I-V Characteristic Curve

The above graph shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a solar cell is the product of current and voltage (I × V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

With the solar cell open-circuited, that is not connected to any load, the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells open circuit voltage, or V_{oc}. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells short circuit current, or I_{sc}.

Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (I_{sc}) at zero output volts, to zero current at the full open circuit voltage (V_{oc}). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between were the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and V_{mp}. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the ―maximum power point‖ or MPP. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

The maximum power point (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: $V_{mp} \cong (0.8–0.90)V_{oc}$ and $I_{mp} \cong (0.85–0.95)I_{sc}$. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.

Solar Panel I-V Characteristic Curves

Photovoltaic panels can be wired or connected together in either series or parallel combinations, or both to increase the voltage or current capacity of the solar array. If the array panels are connected together in a series combination, then the voltage increases and if connected together in parallel then the current increases. The electrical power in Watts, generated by these different photovoltaic combinations will still be the product of the voltage times the current, (P = V × I). However the solar panels are connected together, the upper right hand corner will always be the maximum power point (MPP) of the array.

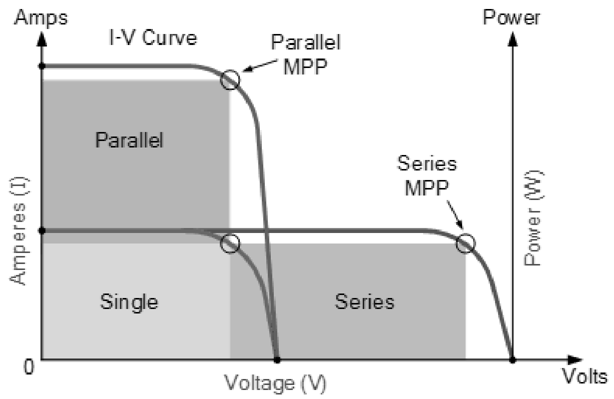


Fig. 32. Solar Panel I-V Characteristic Curves

The Electrical Characteristics of a Photovoltaic Array

The electrical characteristics of a photovoltaic array are summarised in the relationship between the output current and voltage. The amount and intensity of solar insolation (solar irradiance) controls the amount of output current (I), and the operating temperature of the solar cells affects the output voltage (V) of the PV array. Solar cell I-V characteristic curves that summarise the relationship between the current and voltage are generally provided by the panels manufacturer and are given as:

Solar Array Parameters

- V_{OC} = open-circuit voltage: – This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition). This value is much higher than V_{mp} which relates to the operation of the PV array which is fixed by the load. This value depends upon the number of PV panels connected together in series.
- I_{SC} = short-circuit current – The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). This value is much higher than I_{mp} which relates to the normal operating circuit current.
- MPP = maximum power point – This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where MPP = $I_{mp} \times V_{mp}$. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp).
- FF = fill factor – The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions and the product of the open-circuit voltage times the short-circuit current, ($V_{oc} \times I_{sc}$) This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8.
- % eff = percent efficiency – The efficiency of a photovoltaic array is the ratio between the maximum electrical power that the array can produce compared to the amount of solar irradiance hitting the array. The efficiency of a typical solar array is normally low at around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film) being used.

Photovoltaic I-V characteristics curves provide the information needed for us to configure a solar power array so that it can operate as close as possible to its maximum peak power point. The peak power point is measured as the PV module produces its maximum amount of power when exposed to solar radiation equivalent to 1000 watts per square metre, 1000 W/m^2 or $1kW/m^2$.

Efficiency & Quality of the Cell

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. Terrestrial solar cells are measured under AM1.5 conditions and at a temperature of 25°C. Solar cells intended for space use are measured under AM0 conditions.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{OC}\, I_{SC}\, FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where, V_{oc} is the open-circuit voltage;
I_{sc} is the short-circuit current;
FF is the fill factor and
η is the efficiency.

Factors affecting conversion efficiency

- **Wavelength:** The sunlight that reaches the earth's surface has wavelengths from ultraviolet, through the visible range, to infrared. When light strikes the surface of a solar cell, some photons are reflected, while others pass right through. Some of the absorbed photons have their energy turned into heat. The remainder have the right amount of energy to separate electrons from their atomic bonds to produce charge carriers and electric current.
- **Recombination:** It is one of the fundamental factors that limits efficiency. Indirect recombination is a process in which the electrons or holes encounter an impurity, a defect in the crystal structure, or interface that makes it easier for them to recombine and release their energy as heat.
- **Temperature:** Solar cells generally work best at low temperatures. Higher temperatures cause the semiconductor properties to shift, resulting in a slight increase in current, but a much larger decrease in voltage. Extreme increases in temperature can also damage the cell and other module materials, leading to shorter operating lifetimes.
- **Reflection:** A cell's efficiency can be increased by minimizing the amount of light reflected away from the cell's surface. For example, untreated silicon reflects more than 30% of incident light. Anti-reflection coatings and textured surfaces help decrease reflection. A high-efficiency cell will appear dark blue or black.

Quality of solar cell

The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power that would be output at both the open circuit voltage and short circuit current together. The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}. A larger fill factor is desirable, and corresponds to an I-V sweep that is more square-like. Typical fill factors range from 0.5 to 0.82.

Most solar panels are between 15% and 20% efficient, with outliers on either side of the range. High-quality solar panels can exceed 22% efficiency in some cases (and almost reach 23%), but the majority of photovoltaic panels available are not above 20% efficiency.

Increasing efficiency of solar cell

There are ways to improve the efficiency of PV cells, all of which come with an increased cost.

- One way is to decrease the number of semiconductor impurities and crystal structure deformations. This can be achieved through the production of monocrystalline, or "single-crystal" cells. A more pure and uniform cell has a higher chance of interacting with incoming photons.
- Another method is to use a more efficient semiconducting material such as Gallium Arsenide. Although it's much more rare and expensive than silicon, gallium arsenide has an optimal band-gap of 1.4 electron volts, allowing for a higher percentage of the Sun's energy to be harnessed.
- Multiple layers of semiconductor material called p-n junctions can also be used to increase cell efficiency. These multi-junction cells harness energy from multiple sections of the solar spectrum as each junction has a different band gap energy.

- Efficiency can also be increased through concentrated photovoltaics. This method involves concentrating the Sun's energy through various methods to increase the intensity of energy hitting the solar cell.

Regulations for quality

The manufacture of photovoltaic modules is governed by several standards required by the IEC (International Electrotechnical Commission) in order to be marketed on the international market.

These standards are as follows:

- The standard IEC 61215 (crystalline) or IEC 61646 (amorph) certifies a guarantee of quality in terms of respect for electrical parameters and mechanical stability. The requirements of this standard refer to the qualification of the design and approval of photovoltaic modules for land application and for long-term use.
- The standard IEC 61730 specifically addresses the topics of prevention against electric shock, fire hazard and bodily injury due to mechanical and environmental constraints.
- This standard, whose specificities concern the safety aspects of the modules, complements the IEC 61215 standard, which fixes the electrical performance.

At the end of May 2019, the cumulative solar power capacity of Germany reached 47.72 GW.

Series and parallel connections

Depending on the equipment that the system uses and the size of the system, your solar installer may decide to wire your solar panels in series, in parallel, or in a combination of the two. Here are the fundamental differences between wiring solar panels in series vs. in parallel:

Wiring solar panels in series

When a solar installer wires your solar panels in a series, each panel is connected to the next in a ―string.‖ The total voltage of each solar panel is summed together, but the amps of electrical current stay the same. When you wire in series, there is just a single wire leading from the roof for each string of solar panels.

Wiring solar panels in parallel

When an installer wires your solar panels in parallel, each panel‘s wires are connected to a centralized wire leading from the roof. The amps of electrical current for each solar panel are summed together, but the system voltage stays the same. Wiring your solar panels in parallel results in more wires running from your solar panel system.

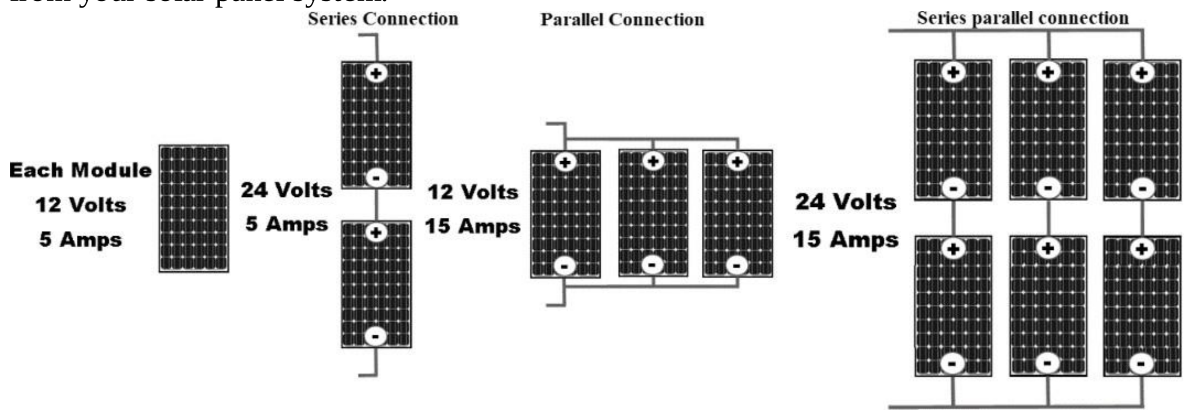


Fig. 33. Series, parallel Series parallel connections

In theory, parallel wiring is a better option for many electrical applications because it allows for continuous operation of the panels that are not malfunctioning. But, it is not always the best choice for all applications. When designing your solar system, your installer might decide that series wiring is better suited for your application or he might choose a hybrid approach by series wiring some panels and parallel wiring others.

Maximum power point tracking

MPPT or Maximum Power Point Tracking is an algorithm that is included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which

PV module can produce maximum power is called maximum power point (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature.

Typical PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day.

The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery.

MPPT is most effective under these conditions:

- Cold weather, cloudy or hazy days: Normally, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.
- When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers.

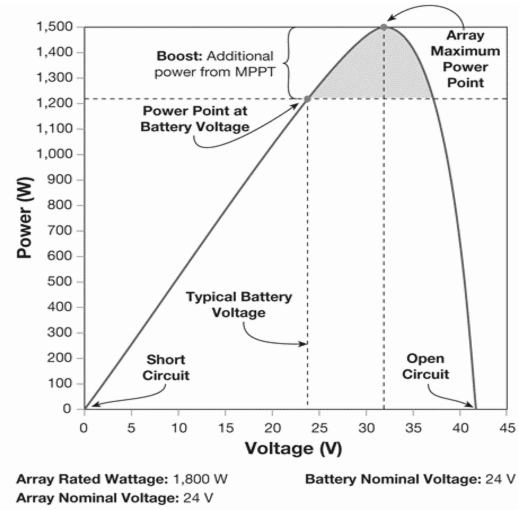


Fig.34. Comparison of MPPT Vs Non MPPT IV Curve

Example: MPPT On a Cold Winter Day

- If the outside temperature is 20°F (-7°C) and the wind is blowing a bit, the PV cell temperature rises to only around 32°F (0°C). The Vpp = 18V. Batteries are a bit low, and loads are on, so the battery voltage = 12.0.
- The ratio of Vpp to battery voltage is 18:12 = 1.5:1.
- Under these conditions, a theoretically perfect MPPT (with no voltage drop in the array circuit) would deliver a 50% increase in charge current. In reality, there are losses in the conversion just as there is friction in a car‘s transmission. Reports from the field indicate that increases of 20 to 30% are typically observed.

MPPT solar charge controller

- A MPPT solar charge controller is the charge controller embedded with MPPT algorithm to maximize the amount of current going into the battery from PV module.
- MPPT is DC to DC converter which operates by taking DC input from PV module, changing it to AC and converting it back to a different DC voltage and current to exactly match the PV module to the battery.

Smart Grids can integrate solar sourced electricity such as Rooftop solar PV along with traditional power generation allowing higher flexibility to have localized and right sized power plants with reduced transmission loss, zero environmental concerns and higher efficiency.

Examples of DC to DC converter are

- Boost converter is power converter which DC input voltage is less than DC output voltage. That means PV input voltage is less than the battery voltage in system.

- Buck converter is power converter which DC input voltage is greater than DC output voltage. That means PV input voltage is greater than the battery voltage in system.
- MPPT algorithm can be applied to both of them depending on system design. Normally, for battery system voltage is equal or less than 48 V, buck converter is useful. On the other hand, if battery system voltage is greater than 48 V, boost converter should be chosen.
- MPPT solar charge controllers are useful for off-grid solar power systems such as stand-alone solar power system, solar home system and solar water pump system, etc.

Main features of MPPT solar charge controller

- In any applications which PV module is energy source, MPPT solar charge controller is used to correct for detecting the variations in the current-voltage characteristics of solar cell and shown by I-V curve.
- MPPT solar charge controller is necessary for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.
- MPPT solar charge controller allows users to use PV module with a higher voltage output than operating voltage of battery system.
- For example, if PV module has to be placed far away from charge controller and battery, its wire size must be very large to reduce voltage drop. With a MPPT solar charge controller, users can wire PV module for 24 or 48 V (depending on charge controller and PV modules) and bring power into 12 or 24 V battery system. This means it reduces the wire size needed while retaining full output of PV module.
- MPPT solar charge controller reduces complexity of system while output of system is high efficiency. Additionally, it can be applied to use with more energy sources. Since PV output power is used to control DC-DC converter directly.
- MPPT solar charge controller can be applied to other renewable energy sources such as small water turbines, wind-power turbines, etc.

Conditions That Limits the Effectiveness of MPPT

The V_{mp} of a solar module decreases as the temperature of the module increases. In very hot weather, the V_{mp} may be close or even less than battery voltage. In this situation, there will be very little or no MPPT gain compared to traditional controllers. However, systems with modules of higher nominal voltage than the battery bank will always have an array V_{mp} greater than battery voltage. Additionally, the savings in wiring due to reduced solar current make MPPT worthwhile even in hot climates.

Applications.

- **Residential Application:** Use of solar energy for homes has number of advantages. The solar energy is used in residential homes for heating the water with the help of solar heater. The photovoltaic cell installed on the roof of the house collects the solar energy and is used to warm the water. Solar energy can also be used to generate electricity. Batteries store energy captured in day time and supply power throughout the day. The use of solar appliances is one of the best ways to cut the expenditure on energy.
- **Industrial Application:** Sun‘s thermal energy is used in office, warehouse and industry to supply power. Solar energy is used to power radio and TV stations. It is also used to supply power to lighthouse and warning light for aircraft.
- **Remote Application:** Solar energy can be used for power generation in remotely situated places like schools, homes, clinics and buildings. Water pumps run on solar energy in remote areas. Large scale desalination plant also use power generated from solar energy instead of electricity.
- **Transportation:** Solar energy is also used for public transportation such as trolleys, buses and light-rails.
- **Pool heating:** Solar heating system can be used to heat up water in pool during cold seasons.

- **Solar Green Houses:** A green house is a structure covered with transparent material (glass or plastic) that acts as a solar collector and utilises solar radiant energy to grow plants. It has heating, cooling and ventilating devices for controlling the temperature inside the green house.
- **Solar Cooking:** The solar cooker requires neither fuel nor attention while cooking food and there is no pollution, no charring or overflowing of food and the most important advantage is that nutritional value of the cooked food is very high as the vita-mins and natural tastes of the food are not destroyed.
- **Solar furnace:** In a Solar furnace, high temperature is obtained by concentrating the solar radiations onto a specimen using a number of heliostats (turn-able mirrors) ar-ranged on a sloping surface.
- **Solar Drying of Agricultural and Animal Products:** Solar drying, especially of fruits improves fruit quality as the sugar concentra-tion increases on drying. Other agricultural products commonly solar-dried are potato-chips, berseem, grains of maize and paddy, ginger, peas, pepper, cashew-nuts, timber drying and tobacco curing. Spray drying of milk and fish drying are examples of solar dried animal products.
- **Solar-pumping:** In solar pumping, the power generated by solar-energy is utilized for pumping water for irrigation purposes.
- **Solar-distillation:** In arid semi and or coastal areas there is scarcity of potable water. The abundant sunlight in these areas can be used for converting saline water into portable distilled water by the method of solar distillation.

UNIT IV - BIOMASS ENERGY

Introduction-Bio mass resources –Energy from Bio mass: conversion processes-Biomass Cogeneration-Environmental Benefits. Geothermal Energy: Basics, Direct Use, Geothermal Electricity. Mini/micro hydro power: Classification of hydropower schemes, Classification of water turbine, Turbine theory, Essential components of hydroelectric system.

Introduction

Biomass refers to the organic material that is used for the production of energy referred to as Bioenergy. Biomass is primarily found in the form of living or recently living plants and biological wastes from industrial and domestic use. The process of energy conversion from biomass includes thermal conversion, chemical conversion, biochemical conversion and electrochemical conversion. A geothermal power plant works by tapping the steam or hot water reservoirs underground the earth and the heat is used to drive an electrical generator. Hydroelectric energy is a form of energy that harnesses the power of water in motion such as water flowing over a waterfall to generate electricity. A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. The conversion efficiency of a hydroelectric power plant depends mainly on the type of water turbine employed and can be as high as 95% for large installations.

Bio mass resources

Biomass resources, sometimes referred to as bio-renewable resources are all forms of organic materials, including plant matter both living and in waste form, as well as animal matter and their waste products. Biomass resources are generally classified as being either waste materials or dedicated energy crops.

A waste material can be any municipal solid waste and industrial waste material that has been discarded because it no longer has any apparent value to the user or which represents a nuisance or even a potential pollutant to the local environment. If the organic waste products from one process, was used as primary source of feedstock in another process, for example, waste cardboard, wood and paper recycled into newspapers, books and magazines, then if these waste materials were economically converted into electricity, heat, liquid biofuels, or chemicals, then they could be considered as a biomass resource rather than an unwanted waste stream. Waste materials that would qualify as a bio-renewable resource include agricultural residues, yard and garden waste, municipal solid waste, food processing waste, animal manure, etc.,

Solid Biomass Resources

- **Agricultural Residues** are the non-edible stalk type materials that remain after the harvest of the edible portions of the crops, such as corn, wheat, grain and sugar cane. Agricultural residues also includes plant leaves, husks, some roots and stems. The residues of dedicated bioenergy non-food crops are grown for their starches, sugars, or oils for the conversion into bioethanol and bio-lubricants. The advantage of agricultural residues is that they do not require the use of additional land space because they are grown together with the food crops.
- **Food Processing Waste** is the effluent wastes from a wide variety of industrial processes ranging from breakfast and cereal bar manufacturers to fresh and frozen vegetable manufacturers to alcohol breweries. These residues and wastes can be in the form of either dry solids or watery liquids. Fermentation of liquid wastes and oils from food processing can produce Ethanol.
- **Municipal Solid Waste** is the items that are thrown away in the garbage and trash and is collected by the dustbin men or sent to the recycling centre. Municipal solid waste such as particularly paper, cardboard, and discarded food products, is an attractive source of endless biomass feedstock. However, not all municipal waste is suitable as a biomass resource, especially metallic and plastic waste.
- **Animal Waste** from farms, ranches, slaughterhouses, fisheries and dairies or any concentration of animals into giant livestock farming facilities produces large amounts of manure and sewage sludge. Liquid sewage, animal wastes, and also human waste from urban areas, provides a constant source of chemical energy and gases which can be converted into electrical power at wastewater treatment

plants. The treatment of animal waste produces combustible methane and biogas which can then be used for heating and transportation.

- **Dedicated Biomass Energy Crops** can be grown specifically as an energy source. These dedicated energy crops are not only greener and cleaner with respect to solid waste materials, but their use represents a closed and balanced carbon cycle with regards to atmospheric carbon dioxide.

  Energy crops are defined as plants and crops grown specifically as an energy resource. The current production of biomass resources includes primarily agricultural byproducts, (Herbaceous crops) and forestry byproducts, (woody biomass crops). But when agricultural crops are grown solely for their energy production, either as a biomass resource or as a biofuel, than the plant species that offers the highest efficiency and the least pollution potentials are usually selected. Energy crops grown specifically as biomass resources include energy cane, sorghum, sugar cane, eucalyptus trees, switch grass, miscanthus, giant reeds, and leauceana lucacephala, etc., which are then planted and harvested periodically. Dedicated energy crops contain significant quantities of one or more of four important energy-rich components: oils, sugars, starches, and fibre.
- **Herbaceous Energy Crops** that have little or no woody tissue such as grasses and legumes grown on grasslands. Generally, food crops, such as maize, wheat, rice and sugarcane represent good sources of herbaceous biomass. Some byproducts or residues of crop cultivation, such as stalks and stems, can also be considered as herbaceous biomass.

  Switchgrass and miscanthus form the primary production of herbaceous crops as these tropical grasses tend to grow faster than woody trees and can produce higher amounts of biomass feedstock in a much shorter period. Generally the growth of these herbaceous plants usually lives for only a single growing season.
- **Woody Energy Crops** include hardwoods and softwoods form the basis of most biomass resources. The primary source of woody energy crops comes from fast growing trees and plantations, but woody biomass can also be a residue from forestry activities (timber waste), from wood processing (industrial wood, sawdust, wood shavings), and end-of-life wood products (bulky waste, demolition, pallets). Woody biomass is cut into uniform, small pieces called wood chips. Highly efficient and non-polluting burners and stoves can be designed to burn these chips for cooking and heating.
- **Lipids** are water insoluble oils and fats obtained from recently living biomass. For example, soya bean oil, palm oil, rapeseed oil, waxes and animal fats and greases, etc. Renewable lipid feedstock also includes algae, bacteria's and other such micro-organisms. Algae are among the fastest growing types organisms in the world, with about half of their weight being oil. The liquid biofuel, usually in the form of alcohol or ethanol, can be used to produce biodiesel to power cars, trucks, and even aeroplanes.

  Biomass Resources available for energy production encompasses a wide range of plants and materials ranging from agricultural and forest crops specifically grown for energy purposes, agricultural and forest wastes and residues, wastes from food processing and fisheries, municipal waste including sewage sludge, as well as aquatic plants and algae.

Biomass provides 32% of all the primary energy use in the country at present.

Energy from Bio mass: conversion processes

There are five fundamental forms of biomass energy use.

(1) The "traditional domestic" use in developing countries (fuelwood, charcoal and agricultural residues) for household cooking (e.g. the "three stone fire"), lighting and space-heating. In this role-the efficiency of conversion of the biomass to useful energy generally lies between 5% and 15%.

(2) The "traditional industrial" use of biomass for the processing of tobacco, tea, pig iron, bricks & tiles, etc, where the biomass feedstock is often regarded as a "free" energy source. There is generally little incentive to use the biomass efficiently so conversion of the feedstock to useful energy commonly occurs at an efficiency of 15% or less.

(3) ―Modern Industries‖ are experimenting with technologically advanced thermal conversion technologies. Expected conversion efficiencies are between 30 and 55%.

(4) Newer "chemical conversion" technologies ("fuel cell") which are capable of by-passing the entropy-dictated Carnot limit which describes the maximum theoretical conversion efficiencies of thermal units.

(5) "Biological conversion" techniques, including anaerobic digestion for biogas production and fermentation for alcohol.

In general, biomass-to-energy conversion technologies have to deal with a feedstock which can be highly variable in mass and energy density, size, moisture content, and intermittent supply. Therefore, modern industrial technologies are often hybrid fossil-fuel/biomass technologies which use the fossil fuel for drying, preheating and maintaining fuel supply when the biomass supply is interrupted.

Biomass can be converted into useful forms of energy using a number of different processes. Factors that influence the choice of conversion process are: the type and quantity of biomass feedstock, the desired form of the energy, i.e. end-use requirements, environmental standards, economic conditions, and project specific factors. In many situations the form in which the energy is required determines the process route followed by the available types and quantities of biomass. The conversion technologies to utilize biomass can be classified into three basic categories

- Direct combustion processes.
- Thermochemical processes.
- Biochemical processes.

Direct combustion processes.

Feedstocks used are often residues such as woodchips, sawdust, bark, hogfuel, black liquor, bagasse, straw, municipal solid waste (MSW), and wastes from the food industry.

Direct combustion furnaces can be divided into two broad categories and are used for producing either direct heat or steam. Dutch ovens, spreader-stoker and fuel cell furnaces employ two-stages. The first stage is for drying and possible partial gasification, and the second for complete combustion. More advanced versions of these systems use rotating or vibrating grates to facilitate ash removal, with some requiring water cooling.

The second group, include suspension and fluidised bed furnaces which are generally used with fine particle biomass feedstocks and liquids. In suspension furnaces the particles are burnt whilst being kept in suspension by the injection of turbulent preheated air which may already have the biomass particles mixed in it. In fluidised bed combustors, a boiling bed of pre-heated sand (at temperatures of 500 to 900°C) provides the combustion medium, into which the biomass fuel is either dropped (if it is dense enough to sink into the boiling sand) or injected if particulate or fluid. These systems obviate the need for grates, but require methods of preheating the air or sand, and may require water cooled injection systems for less bulky biomass feedstocks and liquids.

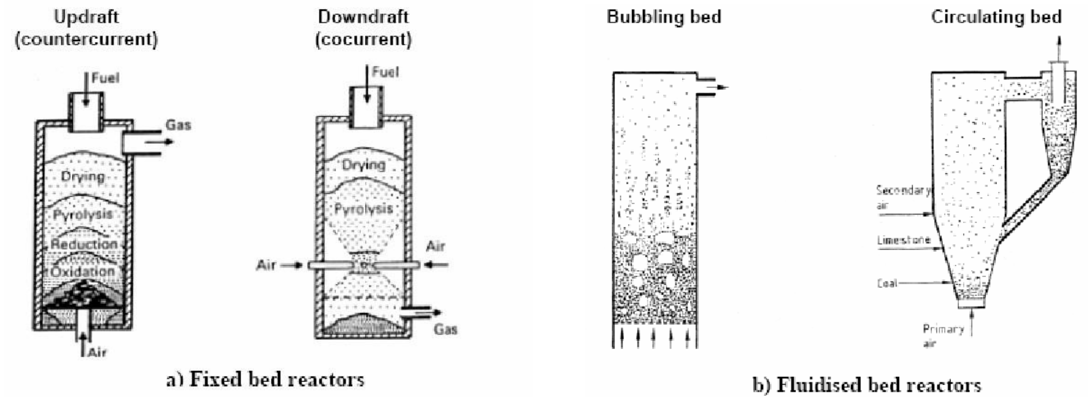


Fig.1. Direct combustion process

Co-firing.

A modern practice which has allowed biomass feedstocks an early and cheap entry point into the energy market is the practice of co-firing a fossil-fuel (usually coal) with a biomass feedstock. Co-firing has a number of advantages, especially where electricity production is an output.

There are three different concepts for co-firing biomass in coal boilers.

- **Direct co-firing** – The biomass and the coal are burned in the same furnace. The mills for the grinding of the fuel and the burners may be separate. This depends on the biomass used and its fuel properties. This concept is most commonly used, because it is the easiest to implement and most cost-effective.
- **Indirect co-firing** – In this concept, the solid biomass is converted to a clean fuel gas, using a biomass gasifier. The gas can be burnt in the same furnace as the coal. For this reason, it is also possible to use biomass, which, for example is difficult to grind. The gas can be cleaned and filtered before use, to remove impurities .
- **Parallel co-firing** – It is also possible to install a completely separate biomass boiler for increasing the steam parameters, like pressure or temperature, in the steam system of the coal power plant. This method allows a high amount of biomass.

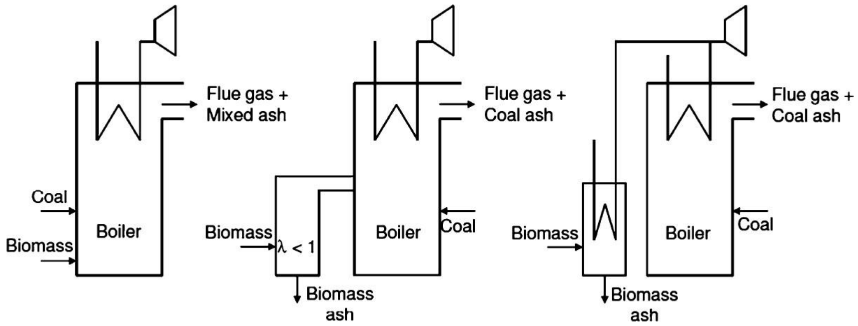


Fig.2. Cofiring

India has ~5+ GW capacity biomass powered plants: 83% are grid connected, 17% are off-grid plants. More than 70% of the country's population depends upon biomass for its energy needs.

Thermochemical processes.

- Pyrolysis.
- Carbonisation.
- Gasification.
- Catalytic Liquefaction.

These processes do not necessarily produce useful energy directly, but under controlled temperature and oxygen conditions are used to convert the original biomass feedstock into more convenient forms of energy carriers, such as producer gas, oils or methanol. These carriers are either more energy dense and therefore reduce transport costs, or have more predictable and convenient combustion characteristics allowing them to be used in internal combustion engines and gas turbines.

Pyrolysis

Pyrolysis is the technique of applying high heat to organic matter (lignocellulosic materials) in the absence of air or in reduced air. The process can produce charcoal, condensable organic liquids (pyrolytic fuel oil), non-condensable gasses, acetic acid, acetone, and methanol. The process can be adjusted to favour charcoal, pyrolytic oil, gas, or methanol production with a 95.5% fuel-to-feed efficiency.

Sixty-eight percent of the energy in the raw biomass is contained in the charcoal and fuel oils made at the facility. The charcoal has the same heating value in Btu(British thermal Unit) as coal, with virtually no sulphur to pollute the atmosphere. The remaining energy is in non-condensable gases that are used to co-generate steam and electricity. Every ton of biomass converted to fuels in this manner produces approximately 27% charcoal, 14% pyrolytic fuel oil, and 59% intermediate-Btu gas.

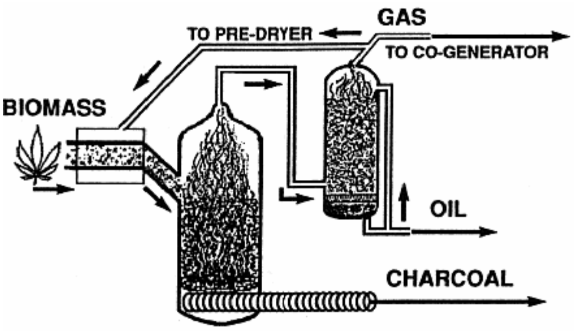


Fig. 3. Pyrolysis

The biomass feedstock is subjected to high temperatures at low oxygen levels, thus inhibiting complete combustion, and may be carried out under pressure. Biomass is degraded to single carbon molecules (CH_4 and CO) and H_2 producing a gaseous mixture called "producer gas." Carbon dioxide may be produced as well, but under the pyrolytic conditions of the reactor it is reduced back to CO and H_2O; this water further aids the reaction.

Carbonisation

This is an age old pyrolytic process optimised for the production of charcoal. Traditional methods of charcoal production have centred on the use of earth mounds or covered pits into which the wood is piled. Control of the reaction conditions is often crude and relies heavily on experience. The conversion efficiency using these traditional techniques is believed to be very low.

During carbonisation most of the volatile components of the wood are eliminated; this process is also called "dry wood distillation." Carbon accumulates mainly due to a reduction in the levels of hydrogen and oxygen in the wood.

The modernisation of charcoal production has lead to large increases in production efficiencies with large-scale industrial production achieving efficiencies of over 30% (by weight).

There are three basic types of charcoal-making:

a) internally heated (by controlled combustion of the raw material),

b) externally heated (using fuelwood or fossil fuels), and

c) hot circulating gas (retort or converter gas, used for the production of chemicals).

Externally heated reactors allow oxygen to be completely excluded, and thus provide better quality charcoal on a larger scale. They do, however, require the use of an external fuel source, which may be provided from the "producer gas" once pyrolysis is initiated. Recirculating heated gas systems offer the potential to generate large quantities of charcoal and associated by-products, but are presently limited by high investment costs for large scale plant.

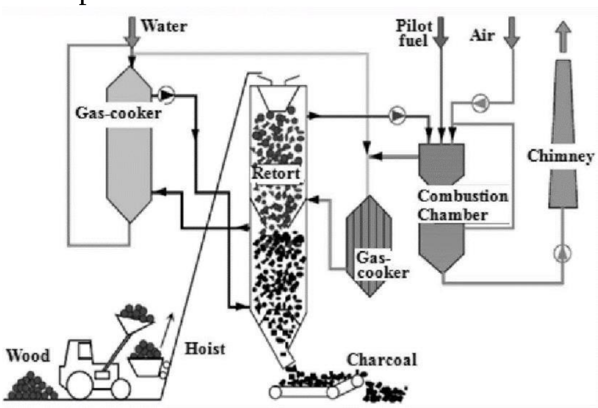


Fig. 4. Carbonisation

The United States is the world's largest producer of ethanol, having produced nearly 16 billion gallons in 2017 alone. Together, the U.S. and Brazil produce 85% of the world's ethanol.

Gasification

Biomass gasification is a thermal process which converts organic carbonaceous materials (such as wood waste, shells, pellets, agricultural waste, energy crops) into a combustible gas comprised of carbon monoxide (CO), hydrogen (H) and carbon dioxide (CO_2). This is achieved by reacting the material at high temperatures, without fully combusting it, using a controlled oxygen (O) inlet. The resulting gas mixture is called syngas. At temperatures of approximately 600 to 1000°C, solid biomass undergoes thermal decomposition to form gas-phase products which typically include CO, H, CH_4, CO_2, and H_2O.

There are four stages involved in gasification process:

- **Drying:** In the drying zone, moisture in the feedstock is evaporated by the heat from the lower zones at a temperature of between 150 and 200°C. Vapours move down and mix with vapours originating in the oxidation zone. A part of the vapour is converted into oxygen with the remainder being retained in the producer gas.
- **Pyrolysis:** This is the thermal decomposition of biomass in low oxygen conditions at temperatures ranging from 200 to 600°C.
- **Combustion:** Oxidation occurs in the presence of a reactive gas (air or pure oxygen) which affect the calorific value of the gas leaving the gasifier. The use of air as reactive gas is the more common.
- **Reduction:** The products of the oxidation zone, hot gases and glowing char, move into the reduction zone. Since there is insufficient O_2 in this high- temperature zone for continued oxidation, a number of reduction reactions take place between the hot gases (CO, H_2O, CO_2, and H_2) and char.

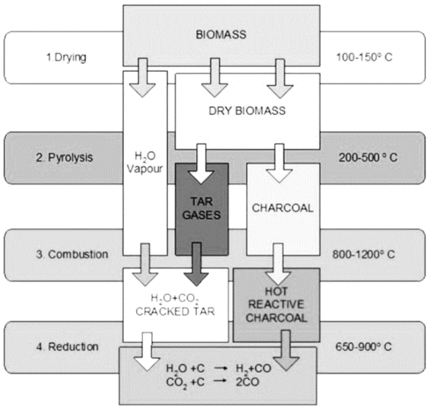


Fig.5. Gasification

Catalytic Liquefaction

This technology has the potential to produce higher quality products of greater energy density. These products also require less processing to produce marketable products. Catalytic liquefaction is a low temperature, high pressure thermochemical conversion process carried out in the liquid phase. It requires either a catalyst or a high hydrogen partial pressure. A homogeneous hydrotreating catalyst is added directly to the reaction mixture to facilitate hydrogenation. As in the case with non-catalytic liquefaction, a hydrogen-donor solvent is employed to stabilise the cracked products by hydrogen transfer, but additionally, the feed, cracked products and the dehydrogenated solvent are hydrogenated in situ with molecular hydrogen (H_2). The solvent is usually recovered and recycled in the process.

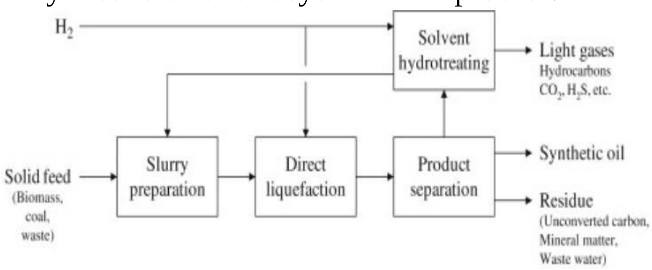


Fig.6. Catalytic liquefaction

Biochemical processes.

- Anaerobic Fermentation.
- Methane Production in Landfills.
- Ethanol Fermentation.
- Biodiesel.

Micro organisms have become regarded as biochemical "factories" for the treatment and conversion of most forms of human generated organic waste. Microbial engineering has encouraged the use of fermentation technologies (aerobic and anaerobic) for use in the production of energy (biogas) and fertiliser, and for the use in the removal of unwanted products from water and waste streams.

Anaerobic Fermentation.

Anaerobic reactors are generally used for the production of methane rich biogas from manure (human and animal) and crop residues. They utilise mixed methanogenic bacterial cultures which are characterised by defined optimal temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide temperature range i.e. above 0°C up to 60°C.

When functioning well, the bacteria convert about 90% of the feedstock energy content into biogas (containing about 55% methane), which is a readily useable energy source for cooking and lighting. The sludge produced after the manure has passed through the digester is non-toxic and odourless. Also, it has lost relatively little of its nitrogen or other nutrients during the digestion process thus, making a good fertiliser. In fact, compared to cattle manure left to dry in the field the digester sludge has a higher nitrogen content; many of the nitrogen compounds in fresh manure become volatised while drying in the sun. On the other hand, in the digested sludge little of the nitrogen is volatilised, and some of the nitrogen is converted into urea. Urea is more readily accessible by plants than many of the nitrogen compounds found in dung, and thus the fertiliser value of the sludge may actually be higher than that of fresh dung.

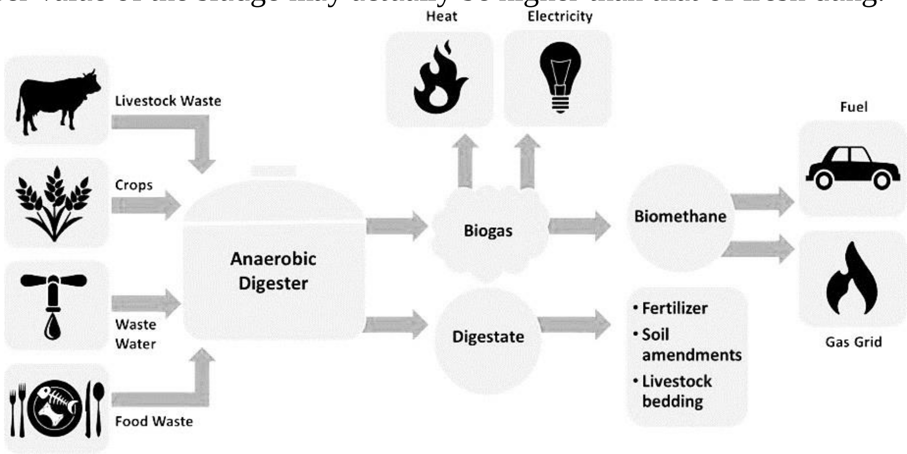


Fig. 7. Anaerobic Fermentation

Methane Production in Landfills

Landfills for municipal solid waste are a source of biogas. Biogas is produced naturally by anaerobic bacteria in municipal-solid-waste landfills and is called landfill gas. Some landfills reduce landfill gas emissions by capturing and burning or flaring the landfill gas. Burning the methane in landfill gas produces CO_2, but CO_2 is not as strong a greenhouse gas as methane. Many landfills collect landfill gas, treat it to remove CO_2, water vapour, and hydrogen sulphide, and then sell the methane. Some landfills use the methane gas to generate electricity.

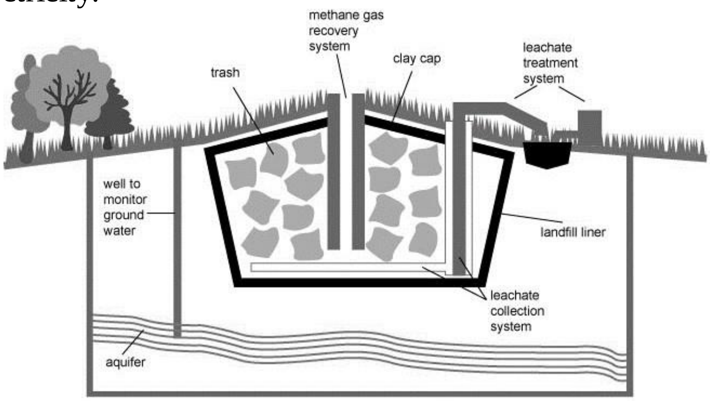


Fig. 8. Methane Production in Landfills

US is leading producer of biofuel in the world on 2018 with production of 1,190.2 thousand barrels/day

Ethanol Fermentation.

Ethanol is mainly used as a substitute for imported oil in order to reduce their dependence on imported energy supplies. The substantial gains made in fermentation technologies now make the production of ethanol for use as a petroleum substitute and fuel enhancer, both economically competitive (given certain assumptions) and environmentally beneficial.

The most commonly used feedstock in developing countries is sugarcane, due to its high productivity when supplied with sufficient water. Where water availability is limited, sweet sorghum or cassava may become the preferred feedstocks. Other advantages of sugarcane feedstock include the high residue energy potential and modern management practices which make sustainable and environmentally benign production possible while at the same time allowing continued production of sugar. Other feedstocks include saccharide-rich sugarbeet, and carbohydrate rich potatoes, wheat and maize.

Conversion of biomass to ethanol includes (1) pretreatment, (2) enzymatic hydrolysis, (3) fermentation, and (4) distillation. Pretreatment sometimes includes mechanical size reduction which must be followed by a strong thermochemical pretreatment to break up lignocellulosic structure solubilizing hemicellulose and/or lignin to make cellulose more accessible to hydrolytic enzymes. Enzymatic hydrolysis releases glucose from cellulose for ethanol fermentation. The two steps can be done together in a single step called simultaneous saccharification and fermentation (SSF). In order to obtain high ethanol concentration for distillation in lignocellulosic biorefinery process, steps such as enzymatic hydrolysis or SSF need to be operated at high solid loading.

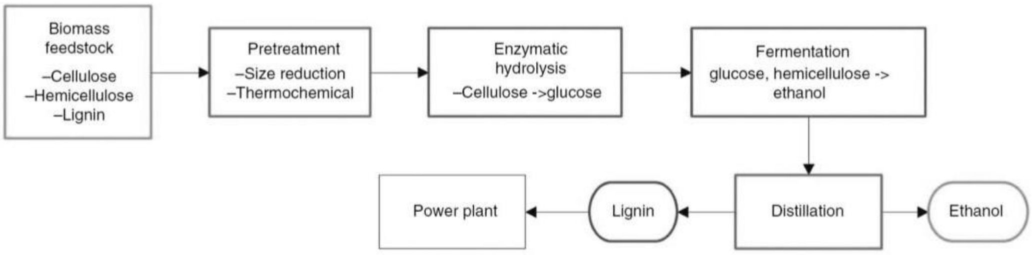


Fig. 9. Ethanol Fermentation

Biodiesel

The use of vegetable oils for combustion in diesel engines has occurred for over 100 years. The raw oil can be obtained from a variety of annual and perennial plant species. Perennials include, oil palms, coconut palms, physica nut and Chinese Tallow Tree. Annuals include, sunflower, groundnut, soybean and rapeseed. Many of these plants can produce high yields of oil, with positive energy and carbon balances.

Transformation of the raw oil is necessary to avoid problems associated with variations in feedstock. The oil can undergo thermal or catalytic cracking, Kolbe electrolysis, or transesterification processes in order to obtain better characteristics. Untreated oil causes problems through incomplete combustion, resulting in the build up of sooty residues, waxes, gums etc. Also, incorrect viscosities can result in poor atomization of the oil also resulting in poor combustion. Oil polymerisation can lead to deposition on the cylinder walls.

Biodiesel is produced from vegetable oils, yellow grease, used cooking oils, or animal fats. The fuel is produced by transesterification; a process that converts fats and oils into biodiesel and glycerin (a coproduct). Approximately 100 pounds of oil or fat are reacted with 10 pounds of a short-chain alcohol (usually methanol) in the presence of a catalyst (usually sodium hydroxide [NaOH] or potassium hydroxide [KOH]) to form 100 pounds of biodiesel and 10 pounds of glycerin (or glycerol). Glycerin, a co-product, is a sugar commonly used in the manufacture of pharmaceuticals and cosmetics.

Raw or refined plant oil, or recycled greases that have not been processed into biodiesel, are not biodiesel and should not be used as vehicle fuel. Fats and oils (triglycerides) are much more viscous than biodiesel, and low-level vegetable oil blends can cause long-term engine deposits, ring sticking, lube-oil gelling, and other maintenance problems that can reduce engine life.

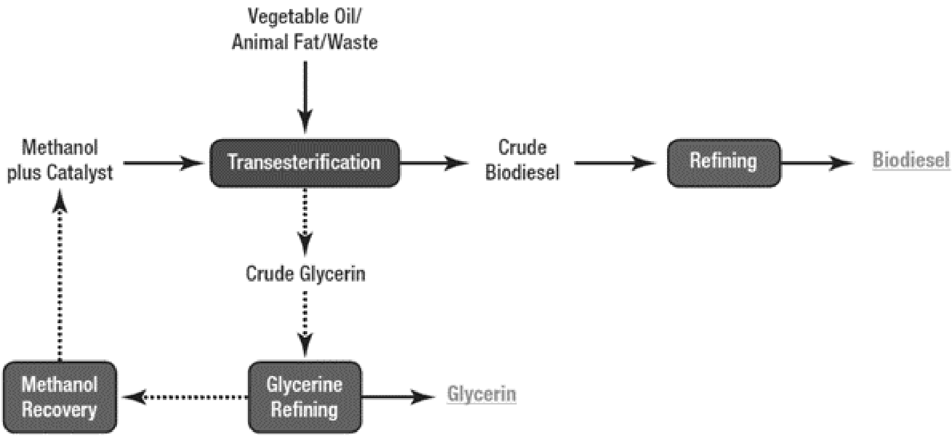


Fig.10. Biodiesel

Biomass Cogeneration

Cogeneration is a combined production of heat and electricity, suitable for fossil fuel or biofuel (biomass) combustion systems. Cogeneration is the best solution for energy saving and environmental preservation. Cogeneration requires a heat exchanger to absorb and recover exhaust heat. Biomass cogeneration is considered an effective alternative to reduce greenhouse gas emissions due to their low CO_2 emission. Many researches have been conducted in recent years to improve the economic and environmental efficiency and effectiveness of biomass cogeneration systems. Biomass cogeneration systems are becoming increasingly popular. Several cogeneration technology and systems have been developed in recent years, some of which are suitable for large power plants and other for medium power and micro-cogeneration.

Steam Cycle

The operating principle is in line with the classic Clausius-Rankin process. High temperature, high pressure steam generated in the boiler and then enters the steam turbine. In the steam turbine, the thermal energy of the steam is converted into mechanical work. The low-pressure steam leaving the turbine enters the condenser housing and condenses on the condenser tubes. The condensate is transported by the water supply system to the boiler, where it is reused in a new cycle.

The process of producing electricity and heat from steam includes the following components: a biomass combustion system (combustion chamber), a steam system (boiler plus distribution systems), a steam turbine, an electricity generator and the heat distribution system for heating from the condenser. At present, electricity and heat generation in biomass power plants with a steam cycle remains the most developed technology, adapted to high temperatures and high power; however, this technology is not suitable for cogeneration systems with a power of less than 100 kW compared to its low electrical efficiency and high investment costs.

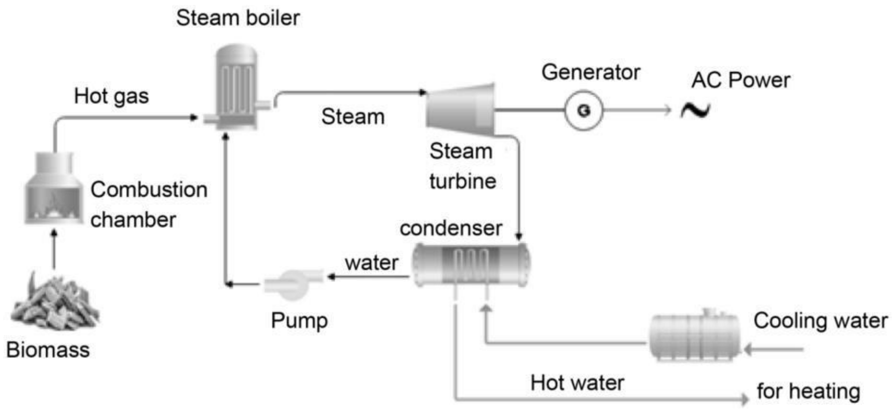


Fig. 11. Principle of operation of a steam turbine biomass cogeneration plant.

Biomass cogeneration plants generally use grid combustion systems with a thermal combustion capacity of 20 to 30 MW. In the case where chemically untreated wood biomass is used, the steam temperature reaches 540˚C. The achievable annual electrical efficiency depends on the steam parameters (temperature and pressure) and the temperature level required for the heating process. Annual electricity efficiencies generally range from 18% to 30% for biomass cogeneration plants between 2 and 25 MW. Below are the advantages of the use of steam cycle:

- The use of water as a heat transfer fluid has great advantages, such as its high availability, non-toxic, non-flammable, chemical stability, low viscosity (less friction losses);
- Thermal efficiency greater than 30%;
- Low pump consumption.

Major pollutant produced from burning biomass is most dangerous: particle pollution, known as soot

Environmental Benefits

Biomass benefits are still subject of many debates when compared with other renewable energy sources. However, biomass has many advantages over fossil fuels due to reduction of the amount of carbon emissions. The main benefits of biomass are:

- **Biomass is a renewable energy source:** The benefit of biomass energy is that biomass is renewable source of energy and it cannot be depleted. Biomass mostly derived from plants, that means as long as plants are going on this planet, biomass will be available as renewable energy source.
- **Biomass helps climate change by reducing GHG:** Biomass indeed helps reduce the amount of greenhouse gas emissions that give more impact to global warming and climate change. Though biomass is connected with certain level of emissions this level is far smaller compared to currently dominant energy sources, fossil fuels. The basic difference between biomass and fossil fuels when it comes to amount of carbon emissions is that all the CO_2 which has been absorbed by plant for its growth is going back in the atmosphere during its burning for the production of biomass energy while the CO_2 produced from fossil fuels is only going to atmosphere where it increases Earth's greenhouse effect and adds to global warming.
- **Cleaner environment:** The third main benefit of biomass energy is that biomass can help clean our environment. World population is constantly increasing, and with the increase in population there is also a problem of increased waste which needs to be properly disposed. Many of the garbage ends up in rivers, water streams, oceans harming nearby ecosystems and having negative impact on human health. Instead of pollution our planet with all this garbage we could use it for the production of this energy and it helps cleaning our environment from many different form of pollution.
- **Biomass is widely available source of energy:** Biomass is widely available energy source. The sources are from agriculture, forestry, fisheries, aquaculture, algae and waste. Many energy experts agree that when you combine economic and environmental character of energy sources biomass is on top of the list as one of the best energy sources.
- **GHG emission balances for biomass-fuelled electricity and heat applications:** Some biomass systems show net GHG emissions savings of more than 40% of the substituted fossil alternatives, while some others only score 4%. Thus, the span of the environmental benefit is wide, and the effective value will depend on the particular application situation (technology, scale etc). The total GHG emissions from contaminated biomass fuels (non-tradables) are set at 0, since these fuels are available anyway. There existence cannot be avoided, and all GHG emissions associated with their production should be allocated to the products from which they are the unavoidable result.
- **Biomass Power is Carbon Neutral:** Biomass power is carbon neutral. Any carbon that is released into the atmosphere during combustion of biomass is absorbed from the atmosphere at one point in the tree's life – so what it took out ends up going back. In many cases, the carbon released is re-absorbed by another plant so it never reaches the atmosphere in the first place. With fossil fuels, the carbon released during combustion has been inaccessible to the atmosphere for millennia and therefore adds additional carbon to the atmosphere.
- **Reduces amount of waste in landfills:** Most waste produced in homes is either plant matter or biodegradable. This kind of waste can be channeled to more profitable use. Biomass energy generation utilizes any waste that would have otherwise found way into landfills. This minimizes the impacts of waste in landfills to the environment. This impact may be compounded by contamination of local habitats and destruction of wildlife ecosystems. Minimized waste means reduction of land intended for landfills, hence, more space for human habitats.

Geothermal Energy: Basics

The word geothermal comes from the Greek words geo (earth) and therme (heat). So, geothermal energy is heat from within the Earth. We can recover this heat as steam or hot water and use it to heat buildings or generate electricity. Geothermal energy is a renewable energy source because the heat is continuously produced inside the Earth.

Volcanoes, hot springs, and geysers, are all examples of concentrated geothermal energy that has made its way to the surface. In general, however, it is not obvious where pockets of concentrated geothermal energy are located because most sources occur unevenly and deep underground. To find and access a geothermal reservoir, water or steam wells are generally drilled to test temperatures. Beyond concentrated geothermal pockets, there is some degree of geothermal potential almost everywhere because temperatures just several feet below the earth's surface tend to remain a relatively constant 50 to 60 °F.

Worldwide geothermal power capacity is around 12.8 gigawatts, and it is expected to rise to about 18 gigawatts by 2020

Geothermal Energy Generated Deep Inside the Earth

Geothermal energy is generated in the Earth's core. Temperatures hotter than the sun's surface are continuously produced inside the Earth by the slow decay of radioactive particles, a process that happens in all rocks. The Earth has a number of different layers:

- The core itself has two layers: a solid iron core and an outer core made of very hot melted rock, called magma.
- The mantle surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.
- The crust is the outermost layer of the Earth, the land that forms the continents and ocean floors. It can be 3 to 5 miles thick under the oceans and 15 to 35 miles thick on the continents.

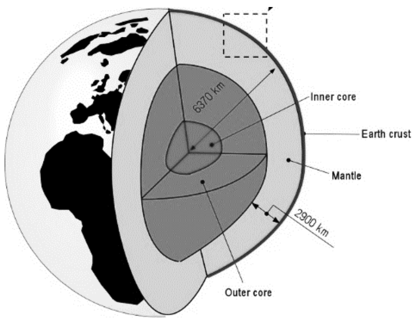


Fig. 12. Earth core

Use of Geothermal Energy

Some applications of geothermal energy use the Earth's temperatures near the surface, while others require drilling miles into the Earth. The three main uses of geothermal energy are:

- **Direct use** and district heating systems use hot water from springs or reservoirs near the surface.
- **Electricity generation power plants** require water or steam at very high temperature (300° to 700°F)
- **Geothermal heat pumps** use stable ground or water temperatures near the Earth's surface to control building temperatures above ground.

Geothermal energy is generated in the earth's core, almost 4,000 miles beneath the earth's surface.

Direct Use

Direct or non-electric use of geothermal energy refers to the immediate use of the energy for both heating and cooling applications. The primary forms of direct use include heating swimming pools and baths or therapeutic use (i.e., balneology), space heating and cooling (including district heating), agriculture (mainly greenhouse heating, crop drying, and some animal husbandry), aquaculture (heating mainly fish ponds and raceways), and providing heat for industrial processes and heat pumps (for both heating and cooling).

Heat exchangers

The principle heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods. The counter-current flow and high turbulence achieved in plate heat exchangers provide for efficient thermal exchange in a small volume. In addition, compared to shell-and-tube exchangers, they have the advantage of occupying less space, they can easily be expanded when additional load is added, and are typically 40% cheaper. The plates are usually made of stainless steel, but titanium can be used when the fluids are especially corrosive.

- Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (the difference between incoming and outgoing fluid temperature), and the larger size as compared to the plate type.
- Downhole heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads, such as the heating of individual homes, a small apartment, house, or business.

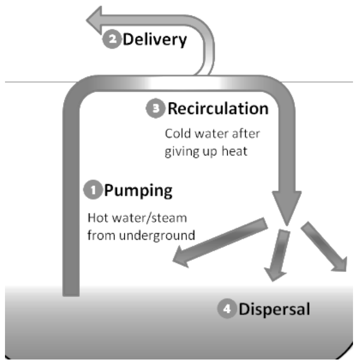


Fig.13. Deep hole geothermal

Refrigeration systems

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems.

- The lithium bromide system is the most common because it uses water as the refrigerant. However, it is limited to cooling above the freezing point of water. The major application of lithium bromide units is for the supply of chilled water for space and process cooling in either one- or two-stage units. The two-stage units require higher temperatures (about 320°F), but they also have high efficiency. The single-stage units can be driven with hot water at temperatures as low as 180°F. Lower geothermal water temperatures result in lower efficiency and require a higher flow rate.
- For geothermally driven refrigeration below the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above 250°F for a reasonable performance.

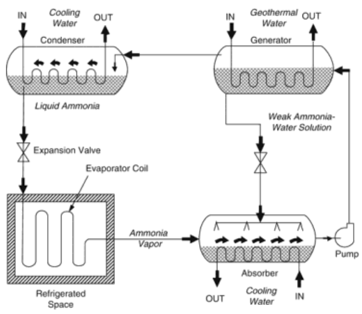


Fig.14. Refrigeration system

Distribution networks

Supply and distribution networks can consist of either a single-pipe or a two-pipe system. The single-pipe system is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system, the fluid is re-circulated so the fluid and residual heat are conserved.

A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems cost typically 20% to 30% more than single-pipe systems.

Heating mode

- **Circulation:** The above-ground heat pump moves water or another fluid through a series of buried pipes or ground loops.
- **Heat absorption:** As the fluid passes through the ground loop, it absorbs heat from the warmer soil, rock, or ground water around it.
- **Heat exchange and use:** The heated fluid returns to the building where it is used for useful purposes, such as space or water heating. The system uses a heat exchanger to transfer heat into the building's existing air handling, distribution, and ventilation system, or with the addition of a desuperheater it can also heat domestic water.
- **Recirculation:** Once the fluid transfers its heat to the building, it returns at a lower temperature to the ground loop to be heated again. This process is repeated, moving heat from one point to another for the user's benefit and comfort.

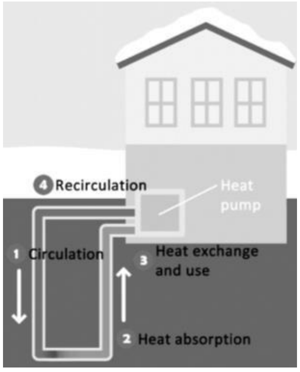


Fig. 15. Heating mode

Cooling mode

- **Heat exchange and absorption:** Water or another fluid absorbs heat from the air inside the building through a heat exchanger, which is the way a typical air conditioner works.
- **Circulation:** The above-ground heat pump moves the heated fluid through a series of buried pipes or ground loops.
- **Heat discharge:** As the heated fluid passes through the ground loop, it gives off heat to the relatively colder soil, rock, or ground water around it.
- **Recirculation:** Once the fluid transfers its heat to the ground, the fluid returns at a lower temperature to the building, where it absorbs heat again. This process is repeated, moving heat from one point to another for the user's benefit and comfort.

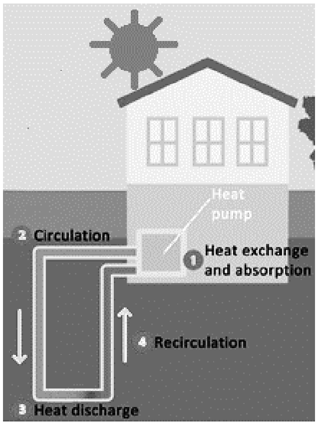


Fig. 16. Cooling mode

Geothermal Electricity

All geothermal energy plants literally uses super hot steam to run large turbines, coupled with generators to produce electricity. In the Geysers geothermal area, dry steam from the below ground is used directly in the steam turbine. Where as in some areas, super hot water is flashed in to steam within the power plant and that steam turns the turbine. There are another type of geothermal energy plants, which uses

The largest hot spring in the world is Frying Pan Lake in New Zealand. It's spans around nine acres and its average temperature is 131 degrees Fahrenheit.

different type of fluid instead of hydro thermal fluids to drive the turbine by using a heat exchanger to transfer heat from the water to special fluid.

Direct Dry Steam

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels) This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904. These plants emit excess steam and very minor amounts of gases.

They work by piping hot steam from underground reservoirs directly into turbines from geothermal reservoirs, which power the generators to provide electricity. After powering the turbines, the steam condenses into water and is piped back into the earth via the injection well.

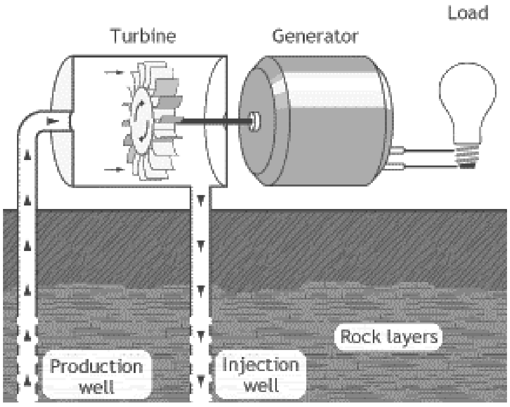


Fig. 17. Direct Dry Steam

Flash and Double Flash Cycle

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank (double flash) to extract even more energy. Flash steam plants differ from dry steam because they pump hot water, rather than steam, directly to the surface. These flash steam plants pump hot water at a high pressure from below the earth into a ―flash tank‖ on the surface.

The flash tank is at a much lower temperature, causing the fluid to quickly ―flash‖ into steam. The steam produced powers the turbines. The steam is cooled and condensed into water, where it is pumped back into the ground through the injection well.

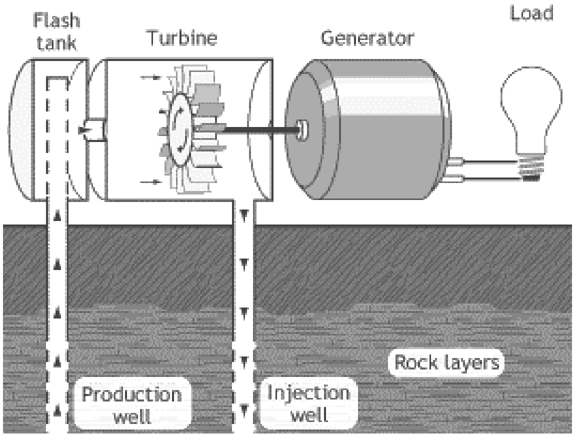


Fig. 18. Flash and Double Flash Cycle

> *Geothermal energy produces 0.03% of the emissions that coal produces and .05% of the emissions that natural gas produces.*

Binary Cycle

Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapour, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.

In these binary cycle plants, the main difference is that the water or steam from below the earth never comes in direct contact with the turbines. Instead, water from geothermal reservoirs is pumped through a heat exchanger where it heats a second liquid—like isobutene (which boils at a lower temperature than water.) This second liquid is heated into steam, which powers the turbines that drives a generator. The hot water from the earth is recycled into the earth through the injection well, and the second liquid is recycled through the turbine and back into the heat exchanger where it can be used again.

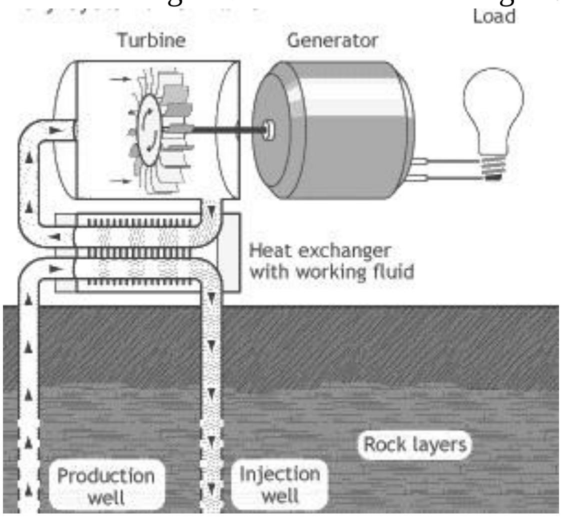


Fig. 19. Binary Cycle

Mini/micro hydro power: Classification of hydropower schemes

The hydroelectric power plants may be classified according to:-

A. Classification According to the Extent of Water Flow Regulation Available
   i. Run off river power plants without pondage
   ii. Run off river power plants with pondage
   iii. Reservoir power plants
B. Classification According to Availability of Water Head
   i. Low Head
   ii. Medium Head
   iii. High Head
C. Classification According to Type of Load Supplied
   i. Base Load
   ii. Peak Load
   iii. Pumped storage plants for the peak load
D. Classification of Hydroelectric Power Plants Based on Installed Capacity.
   i. Large hydro
   ii. Medium hydro
   iii. Small hydro
   iv. Mini hydro
   v. Micro hydro
   vi. Pico hydro

A. Classification According to the Extent of Water Flow Regulation Available

As of 31 March 2020, India's installed utility-scale hydroelectric capacity was 45,699 MW, or 12.35% of its total utility power generation capacity.

i. **Run off river power plants without pondage:** In this type of hydroelectric power plant, water is not available all the time. So this type of power station is not suitable for constant steady load. There is no pondage or storage facility available in such type of power plant. Plant is placed in such a area, where water is coming directly from the river or pond. This type of hydroelectric power plant is called run off power plant without pondage. Plant produces hydro electricity only when water is available. This type of plant cannot be used all the time. During high flow and low load period, water is wasted and the lean flow periods the plant capacity is very low. Power development capacity of this type of plant is very low and it produces power incidentally. The development cost of such a plant is relatively cheaper than full-time power development hydro electric power plant. Though it is not used for constant steady load supply, it's objective is to generate electricity by using excessive flow of water during flood or rainy season or whatever flow is available to save some sort of our natural resource of energy such as coal etc., diesel etc.

ii. **Run off river power plants with pondage:** This type of plant is used to increase the capacity of pond. The pond is used as a storage water of hydro electric power plant. Increased pond size means more water is available in the plant, so such type of hydro electric power plant is used during fluctuating load period depending on the size of pondage. On a certain limitation, this type of power plant can be a part of load curve and it is more reliable than a hydro plant without pondage. Such type of plant is suitable for both base load or peak load period. During high flow period, this plant is suitable for base load and during lean flow period it is used to supply peak loads only. During high flood period, the flood should not raise tail-race water level. Such types of power plant save conservation of coal.

iii. **Reservoir power plants:** Most hydroelectric power plant in the world is reservoir power plant. In this type of plant, water is stored behind the dam and water is available throughout the year even in dry season. This type of power plant is very efficient and it is used during both base and peak load period as per requirement. It can also take a part of load curve in grid system.

B. Classification According to Availability of Water Head

Though there is no rule regarding water head height but below 30 meters is considered as low head, above 30 meters to 300 meters is called medium head and above 300 meters is known as high head hydro electric power plant.

i. **Low head hydro electric power plant:** Francis, Kaplan or propeller turbines are used for this type of hydro electric power plant. To create a low head, dam construction is essential. Water resource level i.e. river or pond is placed just behind the dam to create a necessary water head level. Water is led to the turbine through the penstock. This type of hydro plant is located just below the dam and it creates useful water level as well. No surge tank is required for this plant, dam itself discharges the surplus water from the river. Science head is low, huge amount of water is required for desire output. That's why large diameter and low length pipe is used for this plant. Such types of power plant use low speed and large diameter type generators.

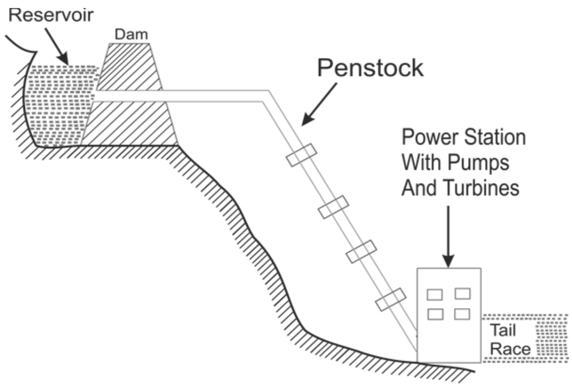


Fig. 20. Low head hydro electric power plant

ii. **Medium head hydro electric power plant:** In these power plants, the river water is usually tapped off to a forebay on one bank of the river as in case of a low head plant. From forebay the water is led to the turbines through penstocks. The forebay provided at the beginning of penstock serves as a water reservoir for such power plants. In these plants, water is usually carried in open channel from main reservoir to the forebay and then to the turbines through the penstock. The forebay itself serves as the surge tank in this case. In these plants horizontal shaft Francis, propeller or Kaplan turbines are used.

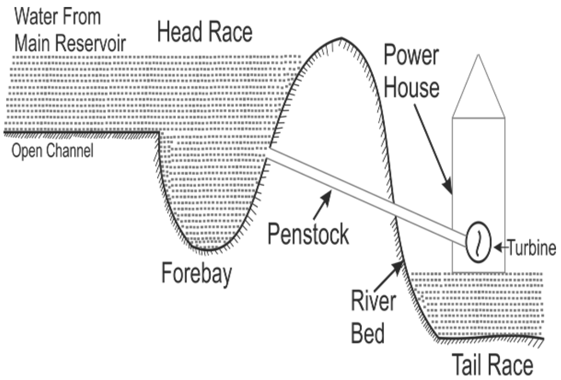


Fig. 21. Medium head hydro electric power plant

As of 31 January 2020, Tamilnadu's installed capacity of Hydro power is 2,178 MW

iii. **High head hydro electric power plant:** The head of this power plant is more than 300 meters. A dam is constructed in such a level that maximum reserve water level is formed. A pressure tunnel is constructed which is connected to the valve house. Water is coming from reservoir to valve house via this pressure tunnel and it is the starting of penstock. A surge tank is also constructed before valve house which reduces water hammering to the penstock in case of sudden closing of fixed gates of water turbine. Surge tank also store some extra water which is useful for picking load demand because it will serve extra water to the turbine. Valve house consists of a main valve sluice valves and automatic isolating valves, which operate on bursting of penstock and cut off further supply of water to penstock. The penstock is a connecting pipe which supplies water from valve house to turbine. For high head more than 500 meters, Pelton wheel turbine is used for lower head Francis turbine.

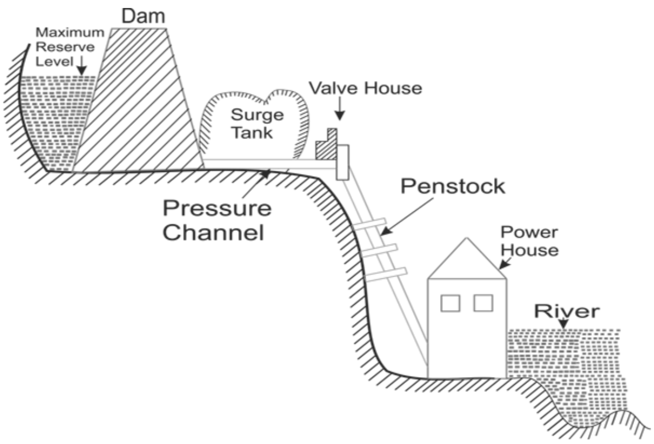


Fig. 22. High head hydro electric power plant

C. **According to the types of load supply**

i. **Base load hydro electric power plant:** This is a large capacity power plant. This plant work as a base portion of load curve of power system, that's why it is called base load plants. Base load plant is suitable for constant load. load factor of this plant is high and it is performed as a block load. Run off river plants without pondage and reservoir plants are used as base load plants.

ii. **Peak load hydro electric power plant:** This plant is suitable for peak load curve of power system. when demand is high, this type of plant do their job very well. Run off river plants with pondage can be employed as peak load plants. If water supply is available, it generates large portion of load at a peak load period. It needs huge storage area. Reservoir plants can be used as peak load plants. This type of plant can serve power throughout the year.

iii. **Pumped storage hydro electric power plant for the peak load:** This is unique design of peak load plants. Here two types of water pond is used, called upper head water pond and tail water pond. Two water ponds are connected each other by a penstock. Main generating pumping plant is lower end. During the off load period, surplus energy of this plant is utilized to pumping the lower head pond water to upper head pond water. This extra water is used to generate energy at pick load periods. By doing this arrangement, same water is used again and again. Extra water is required only to take care of evaporation and seepage.

D. Classification of Hydroelectric Power Plants Based on Installed Capacity.

i. Large hydro	Exceeding 100 MW and usually feeding into a large grid.
ii. Medium hydro	15 – 100 MW and usually feeding into a grid
iii. Small hydro	1-15 MW and usually feeding into the grid
iv. Mini hydro	100 kW – 1 MW either isolated or feeding into the grid
v. Micro hydro	100 kW – 1 MW usually provides power for a small community or rural industry in remote areas away from the grid
vi. Pico hydro	From few hundred watts upto 5 kW

Classification of water turbine

Water turbines or hydraulic turbines are rotary prime movers which convert the potential or kinetic energy of water into mechanical energy in the form of rotational energy. A water turbine when coupled with an electrical generator produces electrical energy. It is one of the most suitable means of electric power generation system. It is estimated that about 20% of the total electric power in the world comes from hydro power plants. The only limitation is that it can be operated through the turbine, if there is a continuous flow of water.

In the areas which are surrounded by hills and mountains known as catchment area, water turbine systems can be installed. The small rivers form a big river to flow. By constructing a machinery dam across flowing rivers, a water reservoir can be formed. The water is carried from the reservoir to water turbine by a long pipe known as penstock and the hydraulic energy possessed by water is converted into mechanical energy and then to electrical energy.

The main classification of water turbines depend upon the type of action of the water on the turbine. These are mainly categorized into two categories.

i. **Impulse turbine:** In this case, the total potential energy of water is converted to kinetic energy in the nozzles. The impulse due to the high velocity jet coming out of the nozzles is used to turn the turbine wheel. The pressure inside the turbine is atmospheric. It is found suitable when the available potential energy is high and flow available is comparatively low. E.g. Pelton wheel

ii. **Reaction Turbines:** In these turbines, water enters the runner under pressure having some velocity head. While the water passes over the runner, its pressure is gradually converted into velocity head until its pressure is reduced to atmospheric pressure along with the change in K.E based on its absolute velocity.

Water turbines are classified on various parameters:

A. Based on Direction of Flow of Water Through the Runner:

   i. Radial flow:
      - Inward radial flow: E.g. Old francis turbine, Girard radial flow turbine, etc.
      - Outward radial flow: E.g Fourneyron turbine

   ii. Axial Flow Turbines:
   These are also called as parallel flow turbines. E.g Kaplan and propeller turbines

   iii. Mixed Flow Turbines:
   E.g Modern francis turbine

B. Based on Available Head and Discharge

Reaction turbines are used for low and medium heads.

   i. Medium Head Turbines:
      - 60m-250m- Medium flow rate E.g. Modern Francis

   ii. Low Head Turbines:
      - Head<60m- Large flow rates E.g. Axial flow Kaplan and propeller turbines.

C. Based on Specific Speed, Ns:
   - Pelton turbine, Ns=9 to 35
   - Francis turbine, Ns=50 to 250
   - Kaplan turbine, Ns=250 to 850

D. Based on position of Shaft
- Horizontal shaft type
- Vertical shaft type

Tehri Dam Hudro Electric project is the highest Hydal project in India which generates 2400MW capacity of power and 575m in length

a) Impulse Turbine: In an impulse turbine, the total potential energy available with water is fully converted into kinetic energy by means of nozzle. The turbine is quite suitable for high head and low discharge available with it. In this type of turbine, there is a water nozzle which converts the total potential energy available with water into kinetic energy. Water is discharged from the nozzle in the form of water jet and high kinetic energy.

The high kinetic energy jet is made to strike on a series of curved buckets or blades mounted on the periphery of a wheel which is placed on the turbine shaft. This is the type of impulse turbine which requires high head and less water availability.

Pelton wheel is one of the most commonly used impulse turbines. A Pelton turbine or Pelton wheel is a type of hydro turbine (specifically an impulse turbine) used frequently in hydroelectric plants. These turbines are generally used for sites with heads greater than 300 meters.

The operation of a Pelton turbine is fairly simple. In this type of turbine, high speed jets of water emerge from the nozzles that surround the turbine. These nozzles are arranged so the water jet will hit the buckets at splitters, the center of the bucket where the water jet is divided into two streams. The two separate streams then flow along the inner curve of the bucket and leave in the opposite direction that it came in. This change in momentum of the water creates an impulse on the blades of the turbine, generating torque and rotation in the turbine.

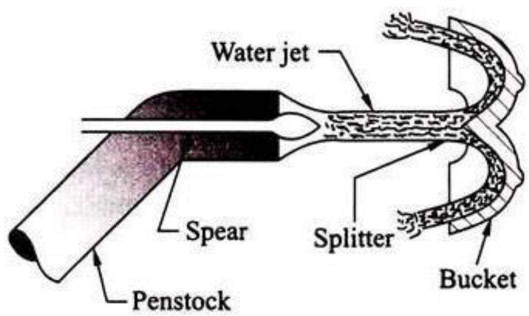


Fig.23. Discharge of water from nozzle

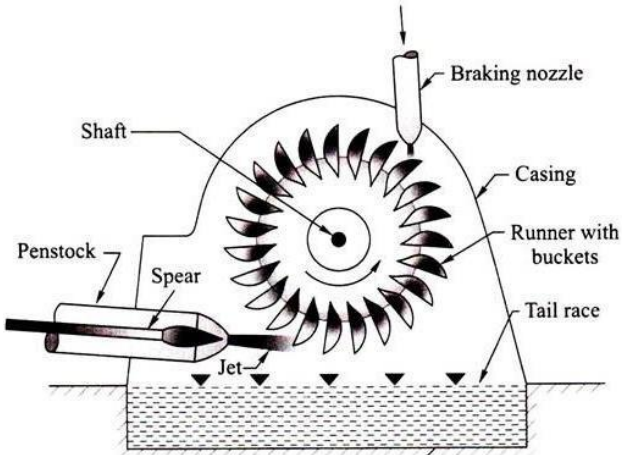


Fig. 24. Pelton turbine

b) Reaction Turbine:

Reaction turbine is quite suitable for low head and high discharge. The water supplied to the reaction turbine possesses both pressure as well as kinetic energy. The total pressure energy is not fully converted to kinetic energy initially, as it happens in impulse turbine. The water flows first of all to guide blades which supply water in a proper direction and then it is passed through moving blades which are mounted on the wheel. A part of the pressure energy of water, when flowing through the moving blades, is converted into kinetic energy which is absorbed by the turbine wheel. The water leaving the moving blades is at low pressure. Thus, there is a difference in pressure between the entrance and exit of the moving blades.

Due to this difference in pressure, there is an increase in kinetic energy and hence a reaction is developed in opposite direction which acts on the moving blades. The rotation of the wheel is set up in opposite direction. In case of reaction turbine, the water is discharged at the tail race through draft tube.

i. Francis Turbine:

Francis turbine is also called medium head turbine. In this turbine, water flows radially and finally discharges axially. Hence, this turbine is also called mixed flow turbine. It consists of a spiral casing, inside which there are large numbers of stationary guide blades/guide vanes. They are fixed all around the circumference of an inner ring of moving vanes called runner. The runner is fixed on the turbine shaft.

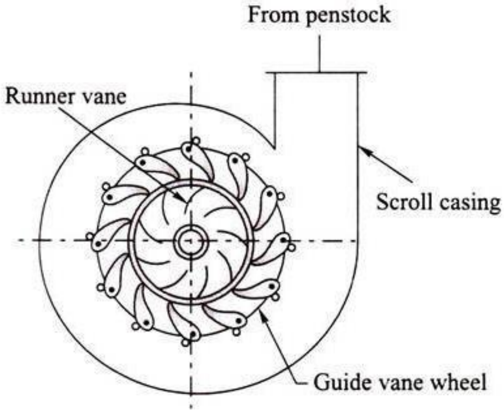


Fig. 25. Components of Franics Turbine

The runner consists of a series of curved blades numbering 16-24. The runner vanes are so well-designed in shape that water enters the runner radially and leaves the runner axially. Water with pressure energy enters through the passage into the casing radially through the guide vanes. It flows from the outer periphery of the runner in the radial direction over the moving vanes and finally it is discharged at the centre axially at low pressure. The kinetic energy is imparted to the runner when it flows over the moving vanes which produce rotation to the shaft. Water is then discharged at lower pressure through a diverging conical tube known as draft tube, which is fitted at the centre of the runner.

The draft tube converts kinetic energy into pressure energy and hence the pressure available at the exit of draft tube is the atmospheric pressure. The other end of the tube is immersed in water known as tail race.

ii. Kaplan Turbine:

Kaplan turbine is also called as low head reaction turbine which is suitable for comparatively low discharge and is known as axial flow reaction turbine. It is similar to Francis turbine. It consists of a spiral casing in which there are large numbers of stationery guide vanes. They are fixed all around the circumference of an inner ring of moving vanes called runner.

High-pressure water enters the turbine casing and enters into the guide vanes. The water strikes the runner and flows axially through guide vanes and imparts kinetic energy to the runner which produces rotation. The water is then discharged at the centre of the runner in axial direction into the draft tube. The outlet of the draft tube is immersed in water. The construction of Kaplan turbine is just similar to Francis turbine except the shape of runner. The runner of Kaplan turbine has only 3, 4, or 6 blades, either fixed or adjustable on hub The latter is known as propeller turbine.

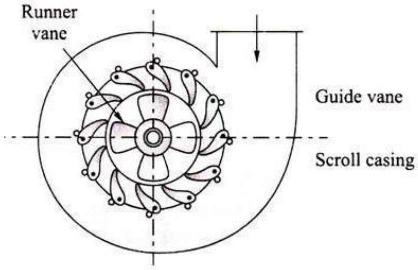


Fig. 26. Components of Kaplan turbine

Turbine theory

Like steam turbines, water turbines may depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the blades to turn the turbine shaft which in turn drives the generator. Several different families of turbines have been developed to optimise the performance for particular water supply conditions.

Turbine Power Output

The turbine converts the kinetic energy of the working fluid, in this case water, into rotational motion of the turbine shaft. Swiss mathematician Leonhard Euler showed in 1754 that the torque on the shaft is equal to the change in angular momentum of the water flow as it is deflected by the turbine blades and the power generated is equal to the torque on the shaft multiplied by the rotational speed of the shaft.

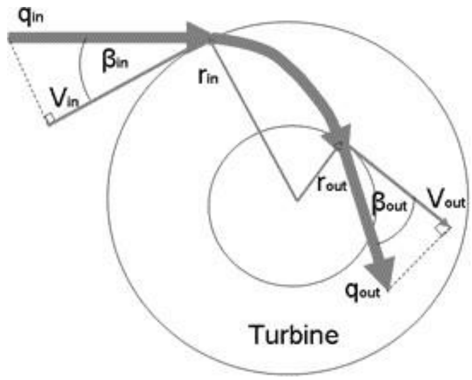


Fig.27. Turbine power

Torque $T = \rho Q(r_{in}V_{in} - r_{out}V_{out})$
Power $P = \omega T = \omega\rho Q(r_{in}q_{in}\cos\beta_{in} - r_{out}q_{out}\cos\beta_{out})$
Q = Fluid flow rate
P = Fluid density
q = Fluid velocity
β = incident angle
V = Tangential fluid velocity
V = qcosβ
r = turbine radius
ω = turbine rotation speed
T = torque
P = Power output

In most types of power generation the kinetic energy of a moving fluid is converted by a turbine into the rotational motion of a shaft. The turbine blades deflect the fluid and the rate of change of angular momentum of the fluid is equal to the net torque on the shaft.

A fluid of density ρ flowing through the turbine with a volume flow rate Q has a mass flow per second given by ρQ. Suppose that the fluid enters at a radius r_1 with a circumferential velocity v_{t1} and exists at a radius r_2 with a circumferential v_{t2}.

The torque exerted on the turbine is equal to the rate of change of angular momentum. Thus

$$T = \rho Q(r_1Vt_1 - r_2V_{t2}) \qquad (1)$$

The power delivered to a turbine rotating with angular velocity ω is given by

$$P = \omega T \qquad (2)$$

Substituting for T from eqn 1 in eqn 2 yields the power as

$$P = \omega\rho Q(r_1v_{t1} - r_2v_{t2}) \qquad (3)$$

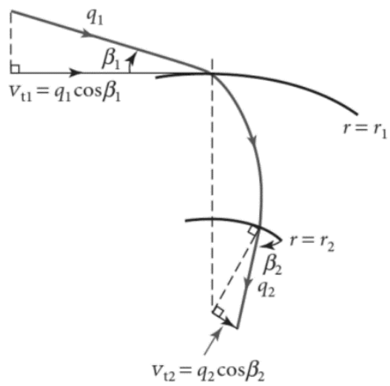


Fig. 28. Triangle diagram

Writing the tangential velocity in the form $v_t = q\cos\beta$, where q is the total quality of the fluid and β is the angle between the direction of motion of the fluid and the tangent to the wheel,

$$P = \omega\rho Q(r_1q_1\cos\beta_1 - r2q2\cos\beta_2) \qquad (4)$$

Eqn 4 is known as the Euler's turbine equation. The importance of Euler's turbine equation is that the details of the flow inside the turbine are irrelevant. All that matters is the total change in the angular momentum of the fluid between the inlet and the outlet. The maximum torque is achieved when the fluid flows out in the radial direction, i.e when $\cos \beta_2 = 0$ Eqn 4 reduces to

$$P = \omega\rho Q r_1 q_1 \cos\beta_1 \qquad (5)$$

Essential components of hydroelectric system

The main components of a Hydro electric power plant are given below.

1. Power House
2. Penstock
3. Water Reservoir
4. Water Turbine or Hydraulic Turbine (Prime mover)
5. Spillway
6. Dam
7. Surge Tank
8. Draft Tube
9. Tail Race Level
10. Gate
11. Pressure Tunnel

1. **Power House:** Power house contains generator, water turbine, with transformer and control room. When the water rushes through the turbine, it turns the turbine shaft, which is attached to electric generator. Generator has a rotary electromagnet called as rotor with a stationary element called as stator. Rotors generates magnetic fields that create an electric charge in stator. Charge is transmitted as electricity. Step up transformer increase the voltage coming from the stator. Electricity is than dispersed through power lines.
2. **Penstock:** Penstock pipe is use to convey water from the dam to hydraulic turbine. Penstock pipes are made of steel or reinforced material. Turbine is installed at a lesser level from the dam. Penstock is connected by a gate valve at inlet to totally close the water supply. It has a control valve to control water flow rate into turbine.
3. **Water Reservoir:** In reservoir, water is collected at the catchment area during raining period and is stored at the dam. Catchment area obtains its water from rains and streams. Permanent accessibility of water is a essential necessity for hydroelectric power plant. The stage of water surface in reservoir is call Head water level. Eater head presented for power generation depends on reservoir height.
4. **Water Turbine or Hydraulic Turbine (Prime mover):** Hydraulic turbines change energy of water into mechanical energy. Mechanical energy (revolution) accessible on turbine shaft is attached to shaft of an electric generator were electricity is created. Water after performing work on turbine blade is discharge through draft tube. Prime movers which are in regular use are Francis turbine, Pelton wheel, Kaplan turbine.
5. **Spillway:** Overload addition of water endanger the strength of dam construction. Also in order to avoid the overflow of water out of dam mainly during raining seasons spillways are provided. This prevents the increase of water level in dam. Spillways are passage which allows excess water to flow to a dissimilar storage area away from the dam.
6. **Dam:** The function of dam is to store water and control the outgoing flow of water. Dam helps to store all incoming water. It also helps to raise the head of water. In order to make a necessary quantity of power, it is needed that an enough head is available.
7. **Surge Tank:** Surge tank is a little tank or reservoir in which water level rise or fall due to unexpected changes in pressure. There might be rapid enhancement of pressure in penstock pipe due to rapid backflow of water, as load on turbine is condensed. This rapid rise of pressure in penstock pipe is identified as water hammer.

   Surge tank is initiated from the dam with the turbine and serves the follow reason:
   - To decrease the distance among the free water surface in dam and turbine, thus dropping the water hammer cause. Otherwise, penstock will damage the water effect.

- To provide as a supply tank to turbine while the water in pipe accelerates during amplified load situation and as a storage tank while the water is decelerating during reduced load situation.

8. **Draft Tube:** Draft tube is joined to outlet of turbine. It changes the kinetic energy available in water in pressure energy in diverge section. Therefore, it retains a pressure of just above the atmospheric level at the end of draft tube to travel the water into a tail race. Water from the tail race is free for irrigation.
9. **Tail Race Level:** Tail race is a water path to guide the water discharged from the turbine to river or canal. Water held in the tail race is call Tail race water level.
10. **Gate:** Gate is use to adjust or control the flow of water from the dam.
11. **Pressure Tunnel:** It carries the water from the reservoir to surge tank.

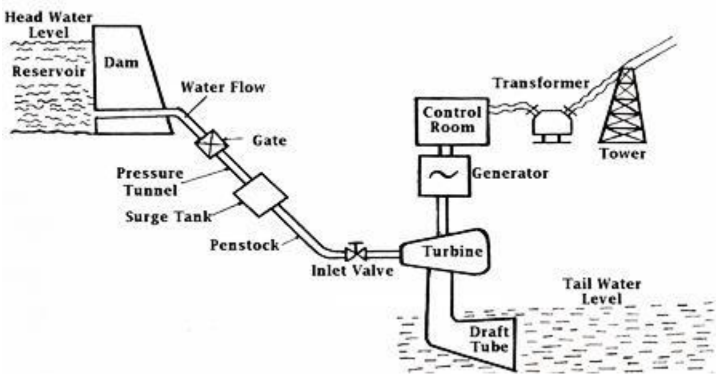


Fig. 29. Components of Hydro power plant

UNIT V - OTHER ENERGY SOURCES

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

Introduction

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

Tidal Energy: Energy from the tides

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

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

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

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

Barrage and Non Barrage Tidal power systems

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

Tidal Barrages

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

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

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

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

Tidal Barrage Flood Generation

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

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

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

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

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

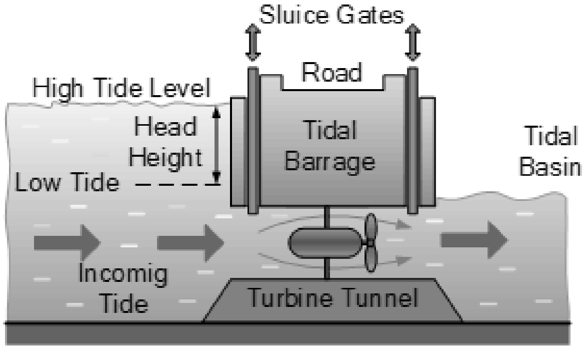


Fig. 1. Tidal Barrage Flood Generation

Tidal Barrage Ebb Generation

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

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

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

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

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

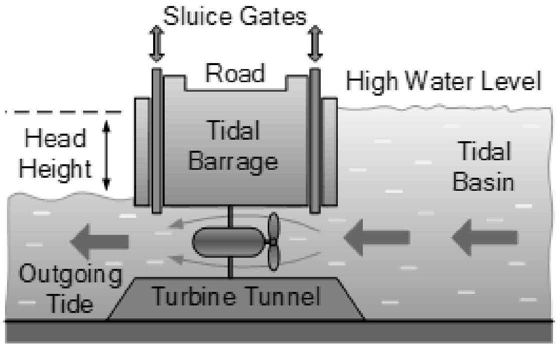


Fig. 2. Tidal Barrage Ebb Generation

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

Two-way Tidal Barrage Generation Scheme

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

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

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

Non Barrage Tidal power systems

Tidal turbines

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

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

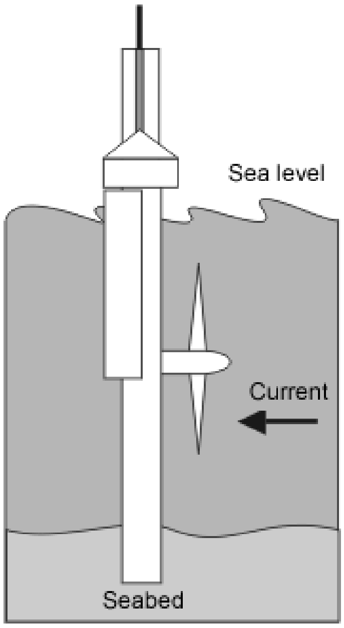


Fig. 3. Tidal turbine

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

Tidal lagoon

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

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

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

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

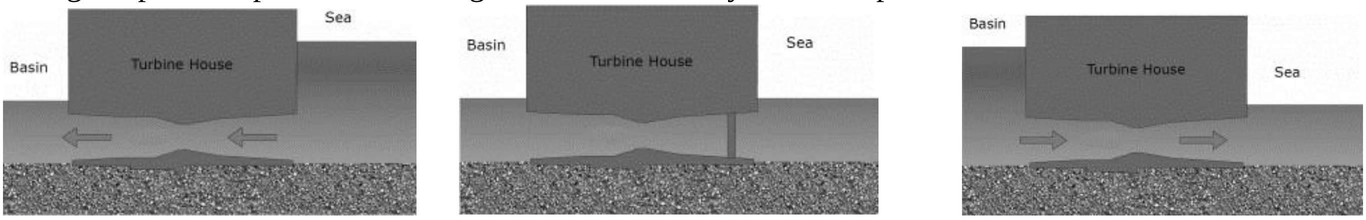


Fig. 4. a. Generating on the flood tide b. Holding period at high or low water c. Generating on the ebb tide

Advantages of Tidal Energy

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

Disadvantages of Tidal Energy

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

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

Wave Energy: Energy from waves

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

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

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

Wave power devices

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

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

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

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

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

Wave Profile Devices

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

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

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

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

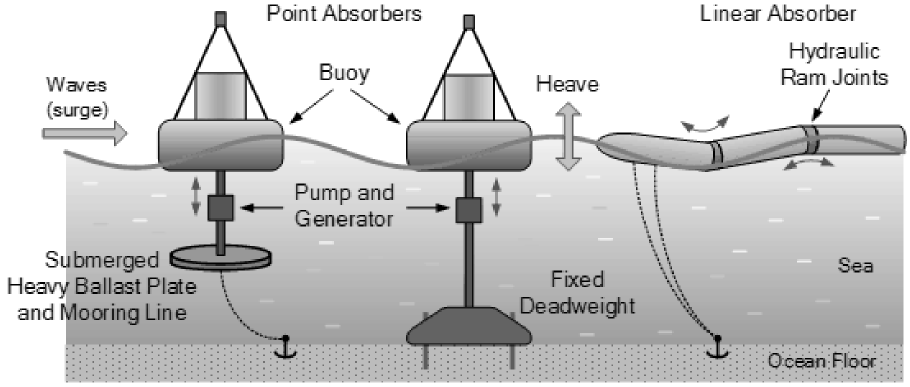


Fig. 5. Wave Profile Devices

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

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

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

Oscillating Water Column

The Oscillating Water Column, (OWC) is a popular shoreline wave energy device normally positioned onto or near to rocks or cliffs which are next to a deep sea bottom. They consist of a partly submerged hollow chamber fixed directly at the shoreline which converts wave energy into air pressure.

The structure used to capture the waves energy could be a natural cave with a blow hole or a man made chamber or duct with a wind turbine generator located at the top well above the waters surface. Either way, the structure is built perpendicular to the waves with part of the ocean surface trapped inside the chamber which itself is open to the sea below the water line. The constant ebbing and flowing motion of the waves forces the trapped water inside the chamber to oscillate in the vertical up-down direction.

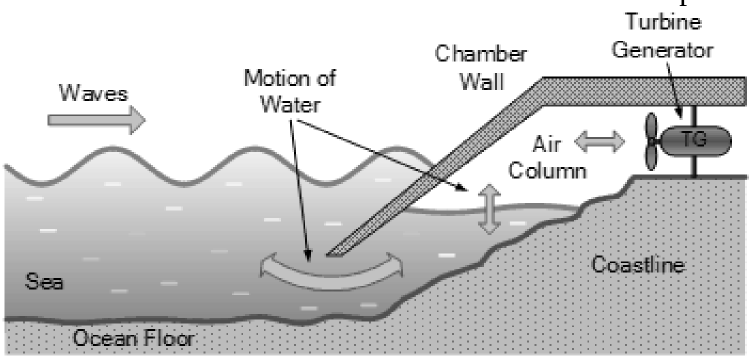


Fig. 6. Oscillating Water Column

As the incident waves outside enter and exit the chamber, changes in wave movement on the opening cause the water level within the enclosure to oscillate up and down acting like a giant piston on the air above the surface of the water, pushing it back and forth. This air is compressed and decompressed by this movement every cycle. The air is channelled through a wind turbine generator to produce electricity as shown.

The type of wind turbine generator used in an oscillating water column design is the key element to its conversion efficiency. The air inside the chamber is constantly reversing direction with every up-and-down movement of the sea water producing a sucking and blowing effect through the turbine. If a conventional turbine was used to drive the attached generator, this too would be constantly changing direction in unison with the air flow. To overcome this problem the type of wind turbine used in oscillating water column schemes is called a Wells Turbine. The Wells turbine has the remarkable property of rotating in the same direction regardless of the direction of air flow in the column. The kinetic energy is extracted from the reversing air flow by the Wells turbine and is used to drive an electrical induction generator. The speed of the air flow through the wells turbine can be enhanced by making the cross-sectional area of the wave turbines duct much less than that of the sea column.

As with other wave energy converters, oscillating wave column technology produces no greenhouse gas emissions making it a non-polluting and renewable source of energy, created by natural transfer of wind energy through a wells turbine. The advantage of this shoreline scheme is that the main moving part, the turbine can be easily removed for repair or maintenance because it is on land. The disadvantage though is that, as with the previous wave energy devices, the oscillating wave columns output is dependent on the level of wave energy, which varies day by day according to the season.

Wave Capture Device

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

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

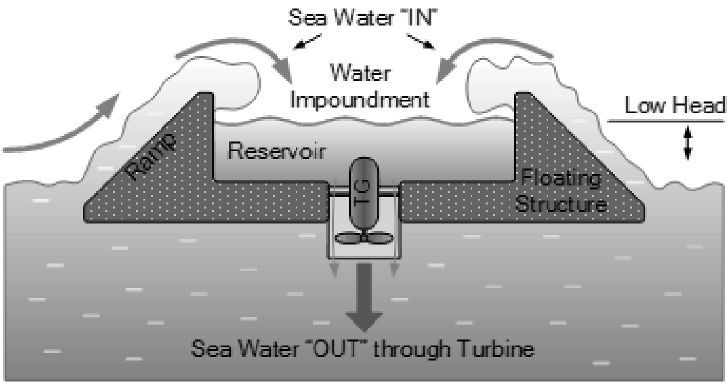


Fig. 7. Wave Capture Device

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

Ocean Thermal Energy Conversion (OTEC)

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

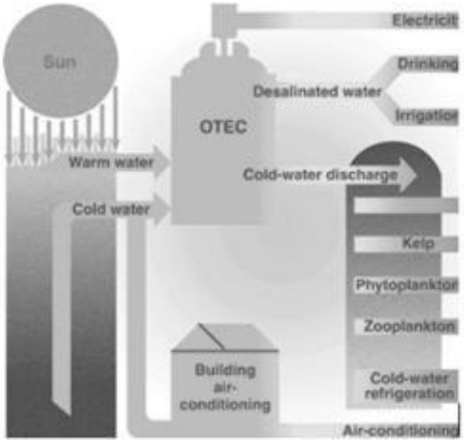


Fig. 8. Ocean Thermal Energy Conversion

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

Types of Ocean Thermal Energy Conversion Systems

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

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

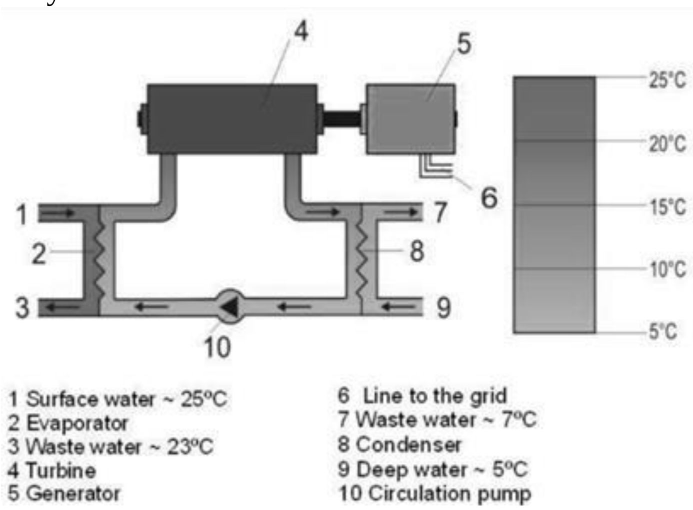


Fig. 9. Closed cycle Ocean Thermal Energy Conversion Systems

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

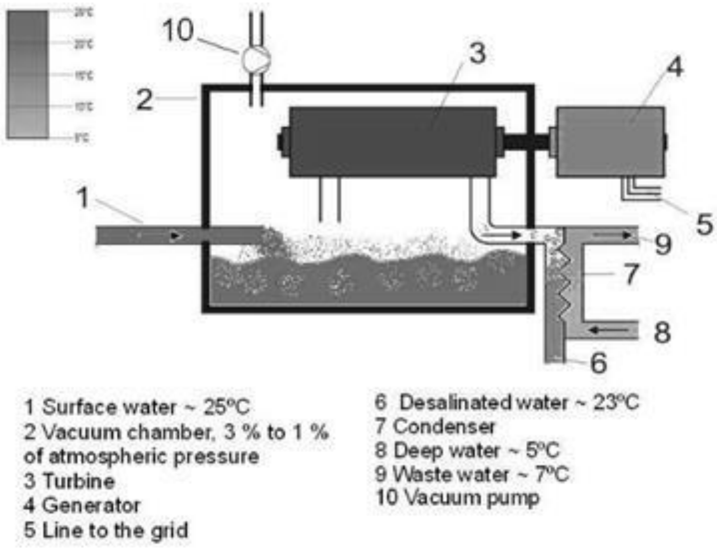


Fig. 10. Open cycle Ocean Thermal Energy Conversion Systems

Land- and sea-based OTEC

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

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

Advantages:

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

Disadvantages:

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

Hydrogen Production and Storage - Fuel cell

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

Production

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

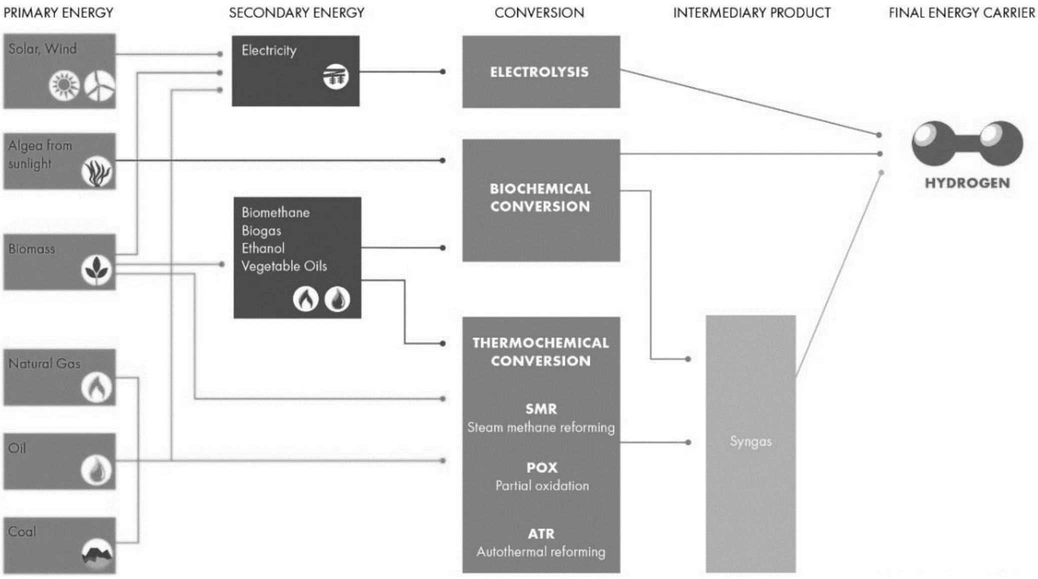


Fig. 11. Methods of producing hydrogen

Electrolysis
Method: Electrolysis
In short: Process where water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) gas with energy input and heat in the case of high temperature Electrolysis.
In Practice: An electric current splits water into its constituent parts. If renewable energy is used, the gas has a zero-carbon footprint, and is known as green hydrogen.

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

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

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

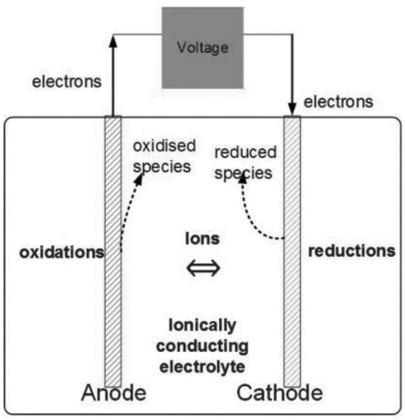


Fig. 12. Electrolysis

Steam Methane Reforming
Method: Reforming - most notably Reforming of natural gas but also biogas
In short: The primary ways in which natural gas, mostly methane, is converted to hydrogen involve reaction with either steam (steam reforming or steam methane reforming SMR when methane is used), oxygen (partial oxidation), or both in sequence (autothermal reforming)

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

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

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

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

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

Partial Oxidation

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

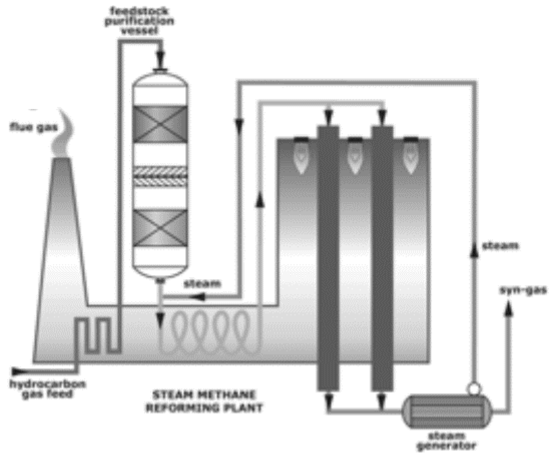


Fig. 13. Steam-methane reforming

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

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

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

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

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

Fermentation

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

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

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

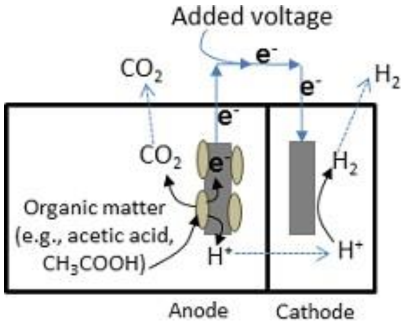


Fig. 14. Fermentation

Hydrogen storage

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

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

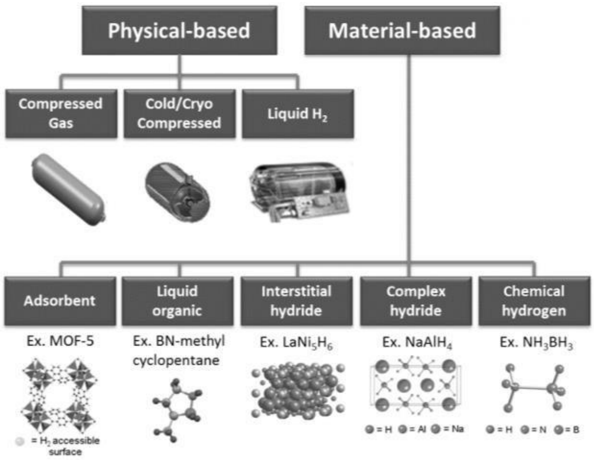


Fig. 15. Methods of hydrogen storage

Liquefied Hydrogen

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

Cold- and cryo-compressed Hydrogen

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

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

Materials-Based H_2 Storage

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

Hydride storage systems

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

Liquid organic hydrogen carriers

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

Surface storage systems (sorbents)

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

Underground Storage

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

Gas Grid

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

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

Fuel cell

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

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

Construction

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

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

Principle of working

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

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

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

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

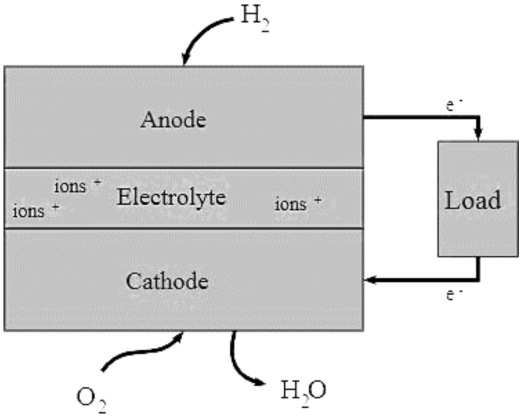


Fig. 16. Operation of fuel cell

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

Types of fuel cells

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

The Polymer Electrolyte Membrane (PEM) Fuel Cell

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

Phosphoric Acid Fuel Cell

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

Solid Acid Fuel Cell

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

Alkaline Fuel Cell

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

Solid Oxide Fuel Cell

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

Molten Carbonate Fuel Cell

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

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

Applications of fuel cell

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

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

Energy Storage System

Energy storage systems are an essential part of the renewable power generation system. The renewable power sources like solar, wind, and hydro are fluctuating resources. To supply a smooth output power to the power grid, energy storage systems are installed to the power generation system. Again the renewable sources (wind and solar) are unreliable, and in the case of the wind energy, the wind velocity sometimes drops below the power generation level, and sunlight may only be available 6–8 h per day to generate electricity. When the power generation becomes zero or the energy demand is high, the energy storage systems can deliver power to the consumers. Therefore, an energy storage system can be an important component to improve the reliability of the power network. There are various types of energy storages, such as electric double layer capacitor (EDLC), BESS, superconducting magnetic energy storage (SMES), flywheel (FW), plug in electric vehicle (PEV), etc.

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

Electric double layer capacitor

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

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

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

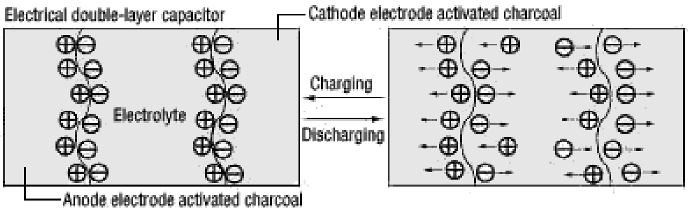


Fig. 17. Electric double-layer capacitors

Battery energy storage system

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

SMF Battery

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

Fig. 18. SMF Battery

Lithium (Li) Battery:

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

Fig. 19. Lithium (Li) Battery

Nickel Cadmium (Nicd) Battery

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

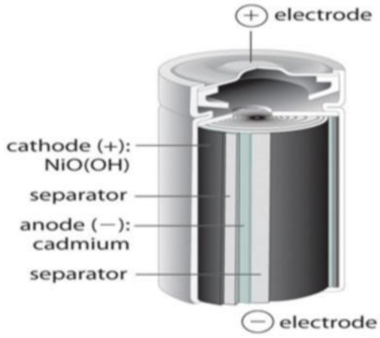


Fig. 20. Nickel Cadmium (Nicd) Battery

Lead Acid Battery

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

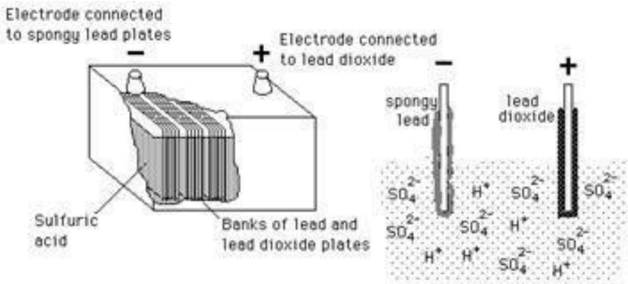


Fig. 21. Lead Acid Battery

Lithium – Ion Battery

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

Fig. 22. Lithium – Ion Battery

Lithium Ion Polymer (Li-ion polymer)

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

Fig.23. Lithium Ion Polymer

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

Superconducting magnetic energy storage

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

Flywheel

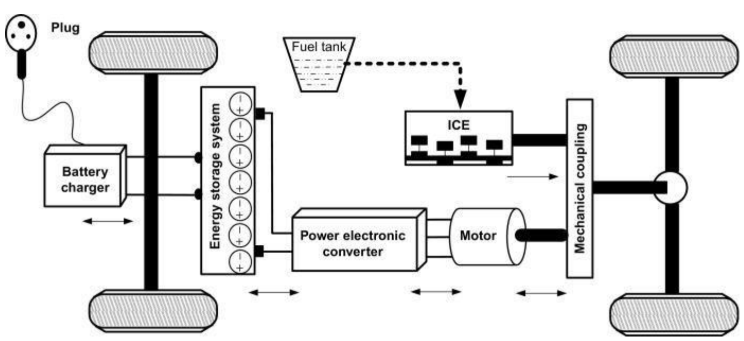
In an FW the storage capacity is based on the kinetic energy of a rotating disc which depends on the square of the rotational speed. A mass rotates on two magnetic bearings in order to decrease friction at high speed, coupled with an electric machine. Energy is transferred to the FW when the machine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

Plug in electric vehicle

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

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

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



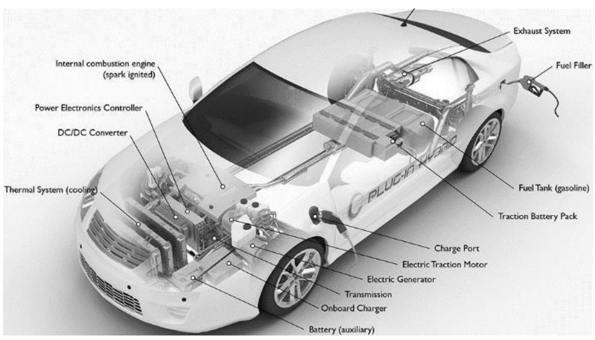


Fig. 24. Plug in electric vehicle

Hybrid Energy Systems

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

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

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

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

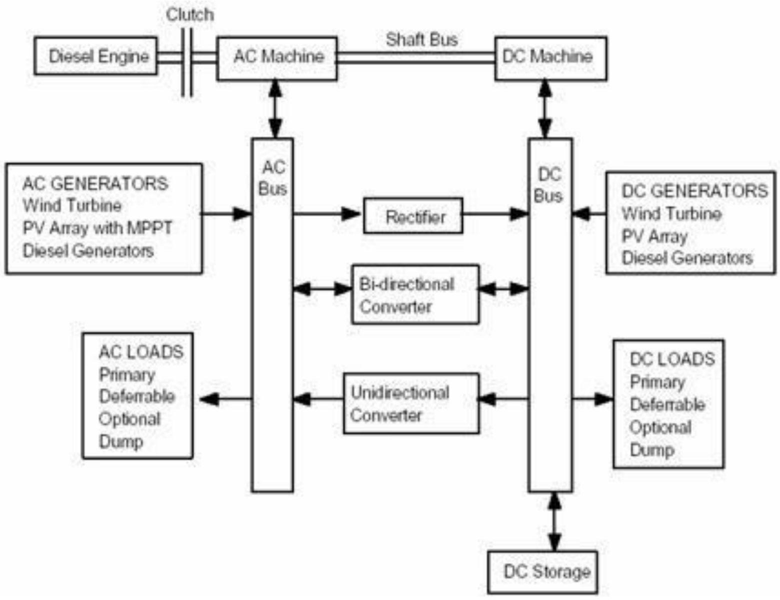


Fig. 25. Hybrid energy storage system

Examples of hybrid systems

Wind-solar hybrid system

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

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

Working

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

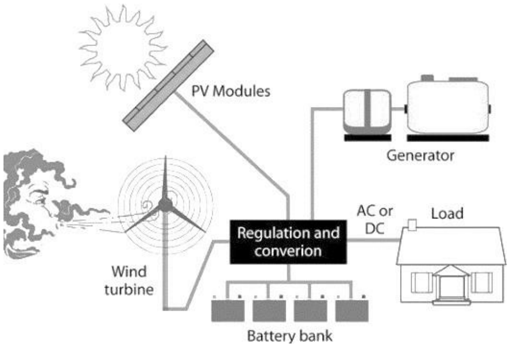


Fig. 26. Wind-solar hybrid system

Wind–hydro hybrid system

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

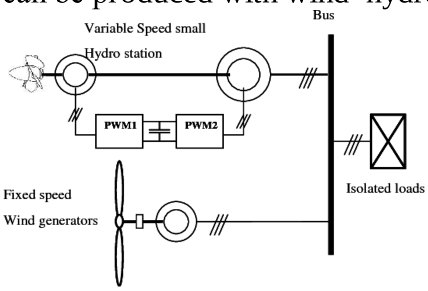


Fig. 27. Wind–hydro hybrid system

Wind–hydrogen system

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

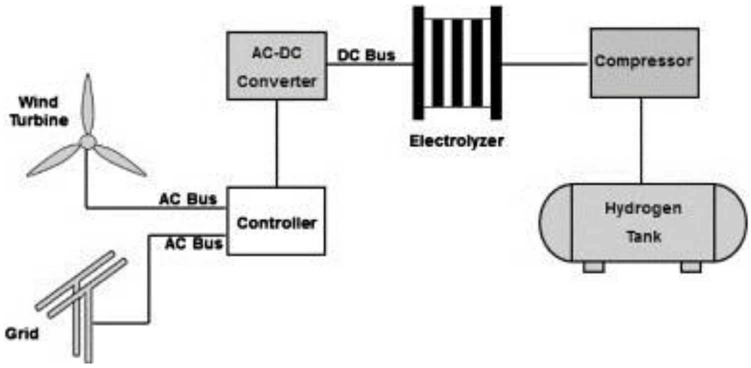


Fig. 28. Wind–hydrogen system

Wind–diesel power generation system

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

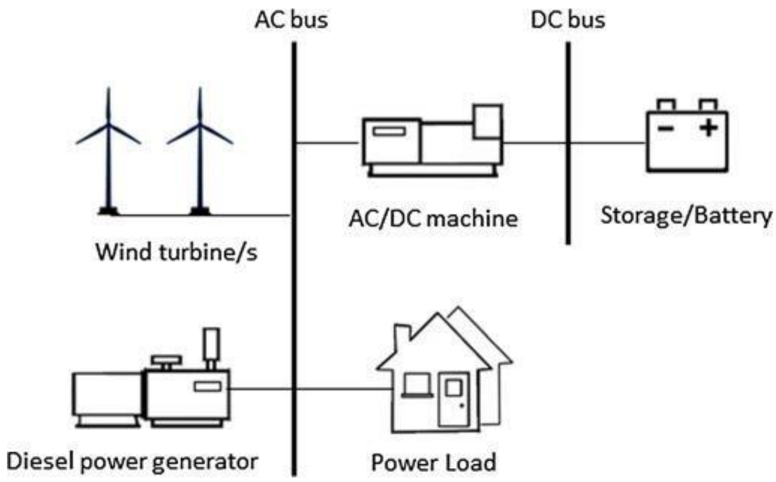


Fig. 29. Wind–diesel power generation system