AALIM MUHAMMED SALEGH COLLEGE OF ENGINEERING

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

(AFFILIATED TO ANNA UNIVERSITY, CHENNAI)

MUTHAPUDUPET, AVADI I.A.F, CHENNAI – 600055.

OEE351- RENEWABLE ENERGY SYSTEMS
QUESTION AND ANSWERS

OEE351 **RENEWABLE ENERGY SYSTEM** **L T P C**
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COURSE OBJECTIVES:

To Provide knowledge about various renewable energy technologies

To enable students to understand and design a PV system.

To provide knowledge about wind energy system.

To Provide knowledge about various possible hybrid energy systems

To gain knowledge about application of various renewable energy technologies

UNIT I INTRODUCTION **9**

Primary energy sources, renewable vs. non-renewable primary energy sources, renewable energy resources in India, Current usage of renewable energy sources in India, future potential of renewable energy in power production and development of renewable energy technologies.

UNIT II SOLAR ENERGY **9**

Solar Radiation and its measurements, Solar Thermal Energy Conversion from plate Solar Collectors, Concentrating Collectors and its Types, Efficiency and performance of collectors,. Direct Solar Electricity Conversion from Photovoltaic, types of solar cells and its application of battery charger, domestic lighting, street lighting, and water pumping, power generation schemes. Recent Advances in PV Applications: Building Integrated PV, Grid Connected PV Systems,

UNIT III WIND ENERGY **9**

Wind energy principles, wind site and its resource assessment, wind assessment, Factors influencing wind, wind turbine components, wind energy conversion systems (WECS), Classification of WECS devices, wind electric generating and control systems, characteristics and applications.

UNIT IV BIO-ENERGY **9**

Energy from biomass, Principle of biomass conversion technologies/process and their classification, Bio gas generation, types of biogas plants, selection of site for biogas plant, classification of biogas plants, Advantage and disadvantages of biogas generation, thermal gasification of biomass, biomass gasifies, Application of biomass and biogas plants and their economics.

UNIT V OTHER TYPES OF ENERGY **9**

Energy conversion from Hydrogen and Fuel cells, Geo thermal energy Resources, types of wells, methods of harnessing the energy, potential in India. OTEC, Principles utilization, setting of OTEC plants, thermodynamic cycles. Tidal and wave energy: Potential and conversion techniques, mini-hydel power plants and their economics.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

At the end of the course students will be able to:

CO1: Attained knowledge about various renewable energy technologies

CO2: Ability to understand and design a PV system.

CO3: Understand the concept of various wind energy system.

CO4: Gained knowledge about various possible hybrid energy systems

CO5: Attained knowledge about various application of renewable energy technologies

REFERENCES

1. Twidell & Wier,'Renewable Energy Resources' CRC Press(Taylor & Francis).
2. Tiwari and Ghosal/ Narosa,'Renewable energy resources'.
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4. D.S.Chauhan, S.K. Srivastava, 'Non – Conventional Energy Resources', New Age Publishers, 2006.
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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.

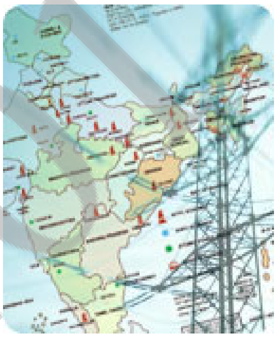
Power Sector at a Glance "ALL INDIA"

Source: OM SECTION

1.Total Installed Capacity (As on 31.12.2023)- Source : Central Electricity Authority (CEA)

➢ **Installed Generation Capacity (Sector wise) as on 31.12.2023 :**

Sector	Installed Generation Capacity (MW)	% Share in Total
Central Sector	1,02,275	23.9%
State Sector	1,06,333	24.8%
Private Sector	2,19,691	51.3%
Total Installed Capacity	**4,28,299**	**100.0%**



➢ **Installed Generation Capacity (Fuel wise) as on 31.12.2023 :**

	Category		Installed Generation Capacity (MW)	% Share in Total	
Fossil Fuel	Coal		2,07,776	48.5%	
	Lignite		6,620	1.5%	
	Gas		25,038	5.8%	
	Diesel		589	0.1%	
	Total Fossil Fuel :		**2,40,023**	**56.0%**	
Non-Fossil Fuel	RES (Incl. Hydro)		1,80,796	42.2%	
	Hydro	46,910			11.0%
	Wind, Solar & Other RE	1,33,886			31.3%
	Wind	*44,736*			*10.4%*
	Solar	*73,318*			*17.1%*
	BM Power/Cogen.	*10,262*			*2.4%*
	Waste to Energy	*583*			*0.1%*
	Small Hydro Power	*4,987*			*1.2%*
	Nuclear		7,480	1.7%	
	Total Non-Fossil Fuel :		**1,88,276**	**44.0%**	
	Total Installed Capacity (Fossil Fuel & Non-Fossil Fuel)		**4,28,299**	**100%**	

Policy Initiatives / Decision Taken

Electricity Act 2003 has been enacted and came into force from 15.06.2003. The objective is to introduce competition, protect consumer's interests and provide power for all. The Act provides for National Electricity Policy, Rural Electrification, Open access in transmission, phased open access in distribution, mandatory SERCs, license free generation and distribution, power trading, mandatory metering and stringent penalties for theft of electricity.

It is a comprehensive legislation replacing Electricity Act 1910, Electricity Supply Act 1948 and Electricity Regulatory Commission Act 1998.The Electricity Act, 2003 has been amended on two occasions by the Electricity (Amendment) Act, 2003 and the Electricity (Amendment) Act, 2007. The aim is to push the sector onto a trajectory of sound commercial growth and to enable the States and the Centre to move in harmony and coordination.

Performance of Generation from all Sources

1.0 Performance of Electricity Generation (Including RE)

1.1 The electricity generation target (Including RE) for the year 2023-24 has been fixed as 1750 Billion Unit (BU). i.e. growth of around 7.2% over actual generation of 1624.158 BU for the previous year (2022-23). The generation during 2022-23 was 1624.158 BU as compared to 1491.859 BU generated during 2021-22, representing a growth of about 8.87%.

1.2 **Total Generation and growth over previous year in the country during 2009-10 to 2023-24 :-**

Year	Total Generation (Including Renewable Sources) (BU)	% Growth
2009-10	808.498	7.56
2010-11	850.387	5.59
2011-12	928.113	9.14
2012-13	969.506	4.46
2013-14	1,020.200	5.23
2014-15	1,110.392	8.84
2015-16	1,173.603	5.69
2016-17	1,241.689	5.80
2017-18	1,308.146	5.35
2018-19	1,376.095	5.19
2019-20	1,389.102	0.95
2020-21	1,381.855	-0.52
2021-22	1,491.859	7.96
2022-23	1,624.465	8.89
2023-24 *	1,308.098	6.90

** Upto December, 2023 (Provisional), Source: CEA*

1.3 The electricity generation target for the year 2023-24 was fixed at 1750 BU comprising of 1324.110 BU Thermal; 156.700 BU Hydro; 46.190 Nuclear; 8 BU Import from Bhutan and 215 BU RES (Excl. Large Hydro).

2.0 Plant Load Factor (PLF):

2.1 The PLF in the country (Coal & Lignite based) from 2009-10 to 2023-24 is as under:

Year	All India PLF (%)	Sector-wise PLF (%)		
		Central	State	Private
2009-10	77.5	85.5	70.9	83.9
2010-11	75.1	85.1	66.7	80.7
2011-12	73.3	82.1	68.0	69.5
2012-13	69.9	79.2	65.6	64.1
2013-14	65.60	76.10	59.10	62.10
2014-15	64.46	73.96	59.83	60.58
2015-16	62.29	72.52	55.41	60.49
2016-17	59.88	71.98	54.35	55.73
2017-18	60.72	72.38	56.90	55.34
2018-19	61.07	72.64	57.81	55.24
2019-20	55.99	64.21	50.24	54.64
2020-21	54.51	63.40	46.23	54.66
2021-22	58.87	69.71	54.50	53.62
2022-23	64.15	74.67	61.86	56.64
2023-24 *	68.06	74.30	63.41	66.63

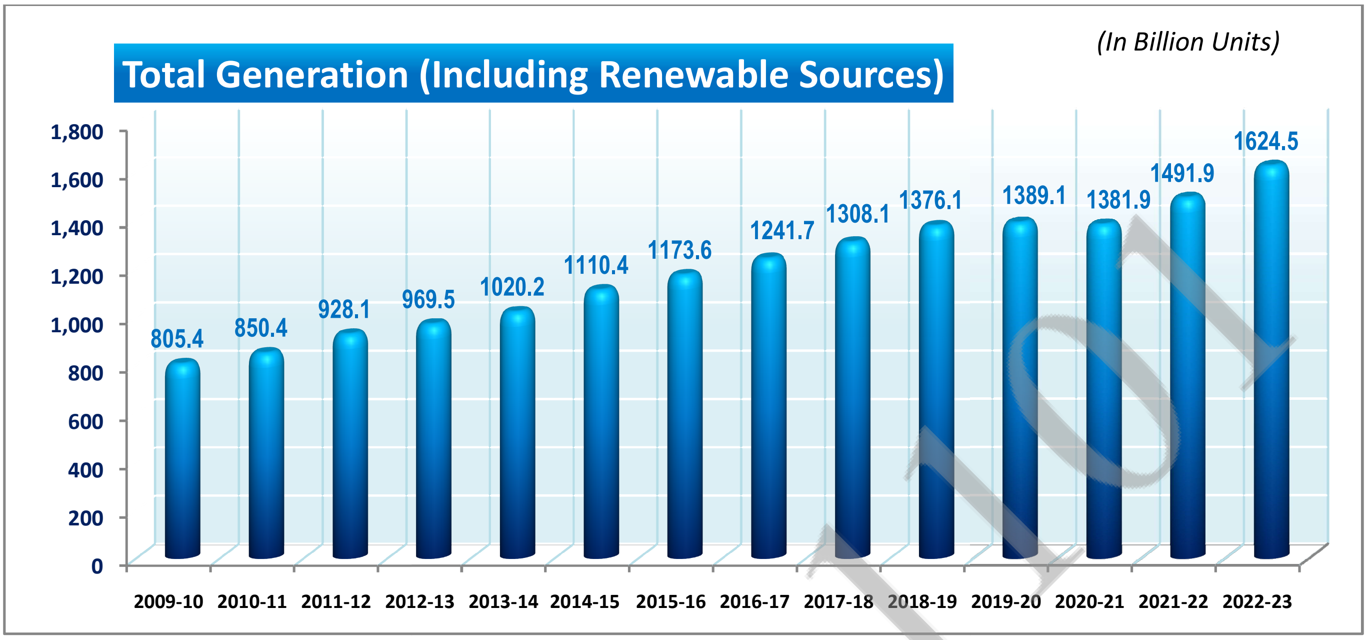
** Upto December, 2023 (Provisional), Source : CEA*

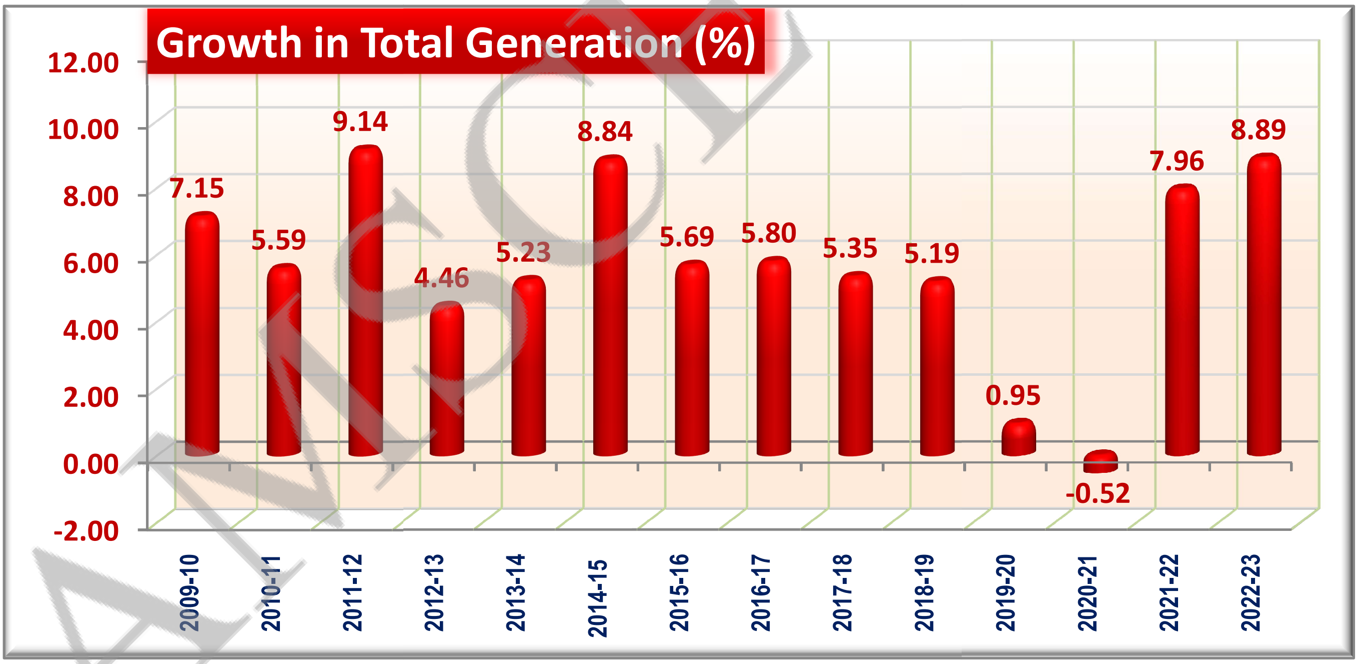
3.0 Power Supply Position

The power supply position in the country during 2009-10 to 2023-24 :

Year	Energy				Peak			
	Requirement	Availability	Surplus (+) / Deficits (-)		Peak Demand	Maximum Demand Met	Surplus (+) / Deficits (-)	
	(MU)	(MU)	(MU)	(%)	(MW)	(MW)	(MW)	(%)
2009-10	8,30,594	7,46,644	-83,950	-10.1	1,19,166	1,04,009	-15,157	-12.7
2010-11	8,61,591	7,88,355	-73,236	-8.5	1,22,287	1,10,256	-12,031	-9.8
2011-12	9,37,199	8,57,886	-79,313	-8.5	1,30,006	1,16,191	-13,815	-10.6
2012-13	9,95,557	9,08,652	-86,905	-8.7	1,35,453	1,23,294	-12,159	-9.0
2013-14	10,02,257	9,59,829	-42,428	-4.2	1,35,918	1,29,815	-6,103	-4.5
2014-15	10,68,923	10,30,785	-38,138	-3.6	1,48,166	1,41,160	-7,006	-4.7
2015-16	11,14,408	10,90,850	-23,558	-2.1	1,53,366	1,48,463	-4,903	-3.2
2016-17	11,42,929	11,35,334	-7,595	-0.7	1,59,542	1,56,934	-2,608	-1.6
2017-18	12,13,326	12,04,697	-8,629	-0.7	1,64,066	1,60,752	-3,314	-2.0
2018-19	12,74,595	12,67,526	-7,070	-0.6	1,77,022	1,75,528	-1,494	-0.8
2019-20	12,91,010	12,84,444	-6,566	-0.5	1,83,804	1,82,533	-1,271	-0.7
2020-21	12,75,534	12,70,663	-4,871	-0.4	1,90,198	1,89,395	-802	-0.4
2021-22	13,79,812	13,74,024	-5,787	-0.4	2,03,014	2,00,539	-2,475	-1.2
2022-23	15,11,847	15,04,264	-7,583	-0.5	2,15,888	2,07,231	-8,657	-4.0
2023-24 *	12,24,291	12,21,152	-3,139	-0.3	2,43,271	2,39,931	-3,340	-1.4

** Upto December, 2023 (Provisional), Source : CEA*


(In Billion Units)
Total Generation (Including Renewable Sources)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
805.4
850.4
928.1
969.5
1020.2
1110.4
1173.6
1241.7
1308.1
1376.1
1389.1
1381.9
1491.9
1624.5
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23

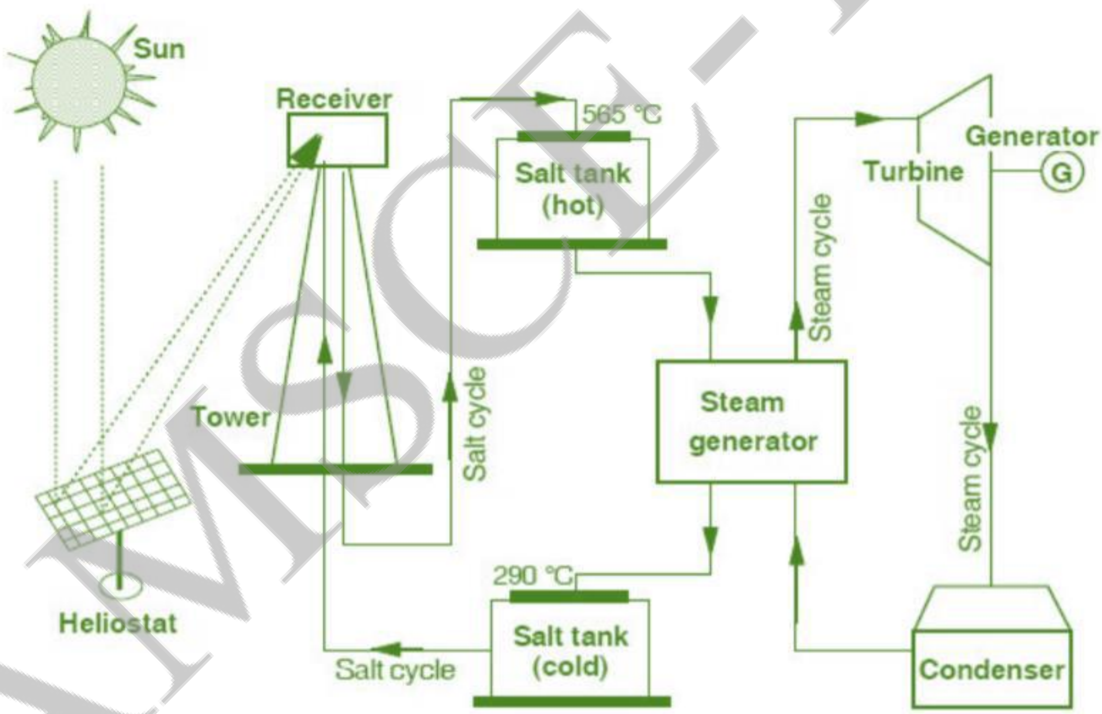

Growth in Total Generation (%)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
7.15
5.59
9.14
4.46
5.23
8.84
5.69
5.80
5.35
5.19
0.95
-0.52
7.96
8.89
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23

Aalim Muhammed Salegh College of Engineering
Department of Electrical & Electronics Engineering
Sub: OEE351 Renewable Energy Systems Class: III/VI sem CSE
IMPORTANT QUESTIONS
UNIT II- SOLAR ENERGY

1. Explain about the Central Receiver solar thermal system OR Explain the solar tower power stations.

Main principles and components:

- Central receiver systems in the tower
- Mirrors tracking the course of the sun in two axes (Heliostats)
- Heliostats reflect the direct solar radiation onto a receiver, centrally positioned on a tower.
- In the receiver, radiation energy is converted into heat and transferred to a heat transfer medium (e.g. air, liquid salt, water/steam). This heat drives a conventional thermal engine.
- To ensure constant parameters and a constant flow of the working medium also at times of varying solar radiation, either a heat storage can be incorporated into the system or additional firing using e.g. fossil fuels (like natural gas) or renewable energy (like biofuels) can be used.



Heliostats

Heliostats are reflecting surfaces provided with a two-axis tracking system which ensures that the incident sunlight is reflected towards a certain target point throughout the day.

Heliostats commonly concentrate sunlight by means of a curved surface or an appropriate orientation of partial areas, so that radiation flux density is increased.

Heliostats consist of the reflector surface (e.g. mirrors, mirror facets, other sunlight-reflecting surfaces) a sun-tracking system provided with drive motors foundations and control electronics.

The individual heliostat‟s orientation is commonly calculated on the basis of: the current position of the sun, the spatial position of the heliostats, the target point.

The target value is communicated electronically to the respective drive motors via a communication line. This information is updated every few seconds.

The concentrator surface size of currently available heliostats varies between 20 and 150 m2 ; to date, the largest heliostat surface amounts to 200 m².

Controller:

Heliostats are usually centrally controlled and centrally supplied with electrical energy.

As an alternative, autonomous heliostats have been developed which are controlled locally. There, the energy required for the control processor and the drives is provided by photovoltaic cells mounted parallel to the reflector surface.

Heliostat fields

The layout of a heliostat field is determined by technical and economic optimization: Heliostats located closest to the tower present the lowest shading,

Heliostats placed north on the northern hemisphere (or south on the southern hemisphere) show the lowest cosine losses.

Heliostats placed far off the tower, by contrast, require highly precise tracking and, depending on the geographic location, have to be placed farer from the neighboring heliostats.

The cost of the land, the tracking and the orientation precision thus determine the economic size of the field.

Cosine losses: representing the difference between the amount of energy falling on a surface pointing at the sun, and a surface parallel to the surface of the earth.

Tower

The height of the tower, on which the receiver is mounted, is also determined by technical and economic optimization.

Higher towers are generally more favorable, since bigger and denser heliostat fields presenting lower shading losses may be applied.

However, this advantage is counteracted by the high requirements in terms of tracking precision placed on the individual heliostats, tower and piping costs as well as pumping and heat losses.

Common towers have a height of 80 to 100 m. Lattice as well as concrete towers are applied.

RECEIVER

Receivers of solar tower power stations serve to transform the radiation energy, diverted and concentrated by the heliostat field, into technical useful energy.

Nowadays, common radiation flux densities vary between 600 and 1,000 kW/m2.

Receivers classification according to:

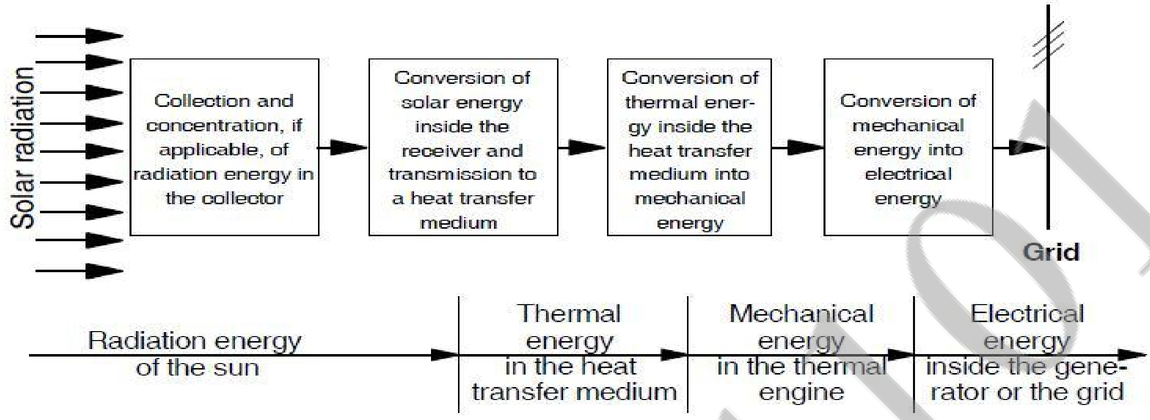
- the applied heat transfer medium (e.g. air, molten salt, water/steam, liquid metal)
- the receiver geometry (e.g. even, cavity, cylindrical or cone-shaped receivers)

According to heat transfer medium:

- Water/steam receiver
- Salt receiver
- Open volumetric air receiver
- Closed (pressurized) air receivers

WORKING :

In these power plants, solar radiations are reflected from arrays of mirrors (called heliostats) installed in circular arcs around the central tower. Reflected radiations concentrate on to the receiver. The array is provided with a tracking control system that focuses beam radiation towards the receiver as shown in Figure 5.11. Water is converted into steam in the receiver itself that operates a turbine coupled with a generator. Alternatively, the receiver may be utilised to heat a molten salt and this fluid is allowed to flow through a heat exchanger where steam is generated to operate the power cycle



2.With a schematic diagram explain the structure of medium temperature solar power plant.

Solar thermal power plants operating on medium temperatures up to 400°C, use the line focusing parabolic collector for heating a synthetic oil flowing in the absorber tube. A schematic diagram of a typical plant is shown in Figure 5.10. A suitable sun-tracking arrangement is made to ensure that maximum quantity of solar radiation is focused on the absorber pipeline.

Preheater and superheater are used to increase the inlet steam temperature for the High Pressure (HP) turbine. Reheaters are used to raise the steam temperature for Low Pressure (LP) turbine. The system generates superheated high pressure steam to operate a Rankine cycle with maximum efficiency

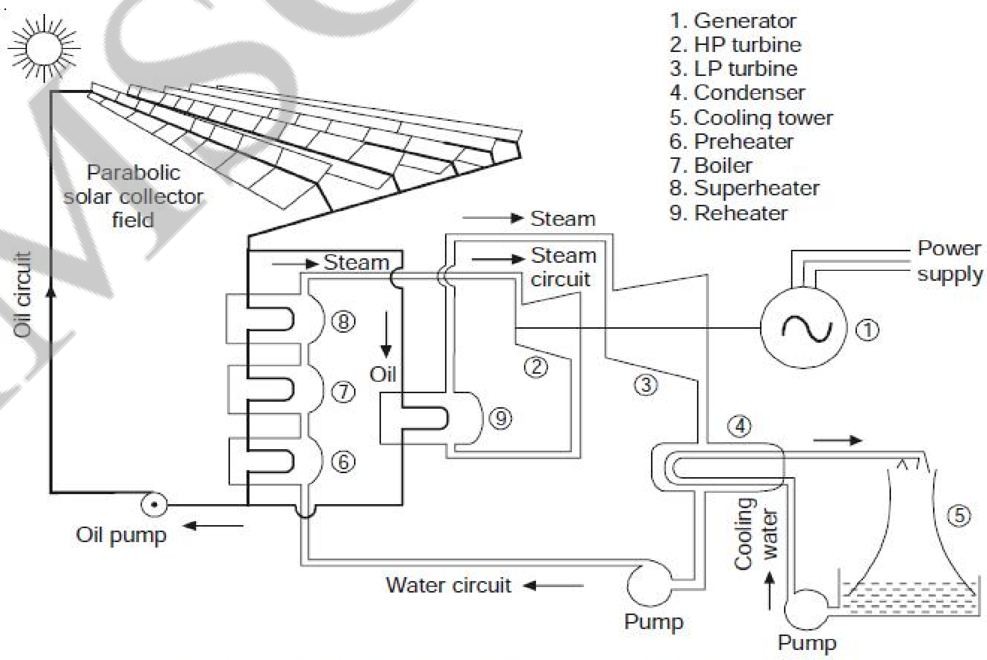
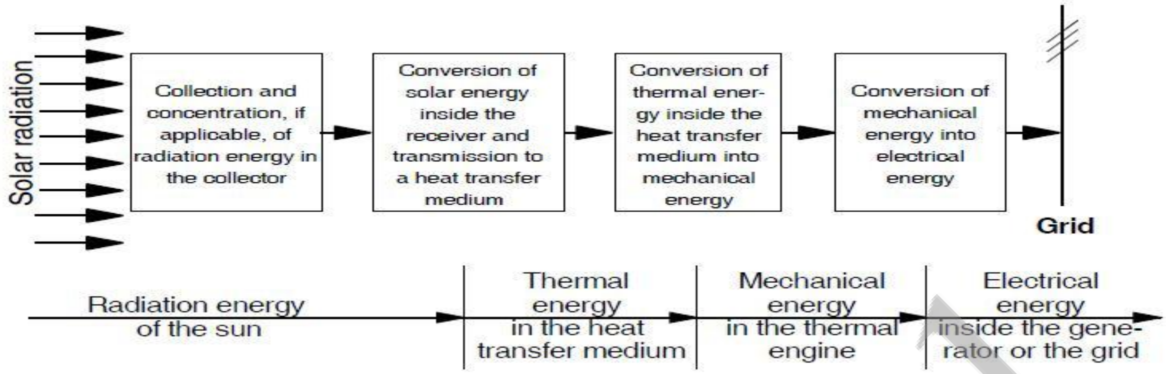


Figure 5.10 Medium temperature solar power plant.



Process of solar thermal power generation:

− concentrating solar radiation by means of a collector system;

− increasing radiation flux density (i.e. concentrating of the solar radiation onto a receiver), if applicable;

− absorption of the solar radiation (i.e. conversion of the radiation energy into thermal energy (i.e. heat) inside the receiver);

− transfer of thermal energy to an energy conversion unit;

− conversion of thermal energy into mechanical energy using a thermal engine (e.g. steam turbine);

− conversion of mechanical energy into electrical energy using a generator.

3.A).With the help of block diagrams, explain the operations of stand-alone and grid interactive solar PV systems.

B).What is MPPT? And explain it with any two techniques.

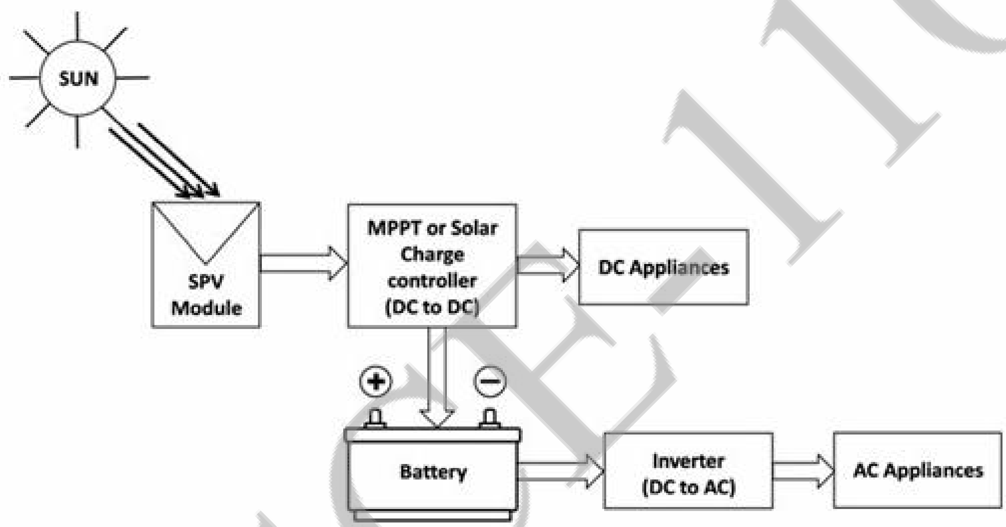
PV systems produce some electric current any time the sun is shining, but more power is produced when the sunlight is more intense and strikes the PV modules directly (as when rays of sunlight are perpendicular to the PV modules). While solar thermal systems use heat from the sun to heat water or air, PV does not use the sun's heat to make electricity. Instead, electrons freed by the interaction of sunlight with semiconductor materials in PV cells create an electric current. PV modules are much less tolerant of shading than are solar water-heating panels. When siting a PV system, it is most important to minimize any shading of the PV modules.

Generally there are two types of Solar Photovoltaic System they are

1. Autonomous Solar Photovoltaic system or Stand alone Solar Photovoltaic system.
2. Grid Connected PV system.
    a) Without Battery.
    b) With Battery.

1. Stand alone SPV System:

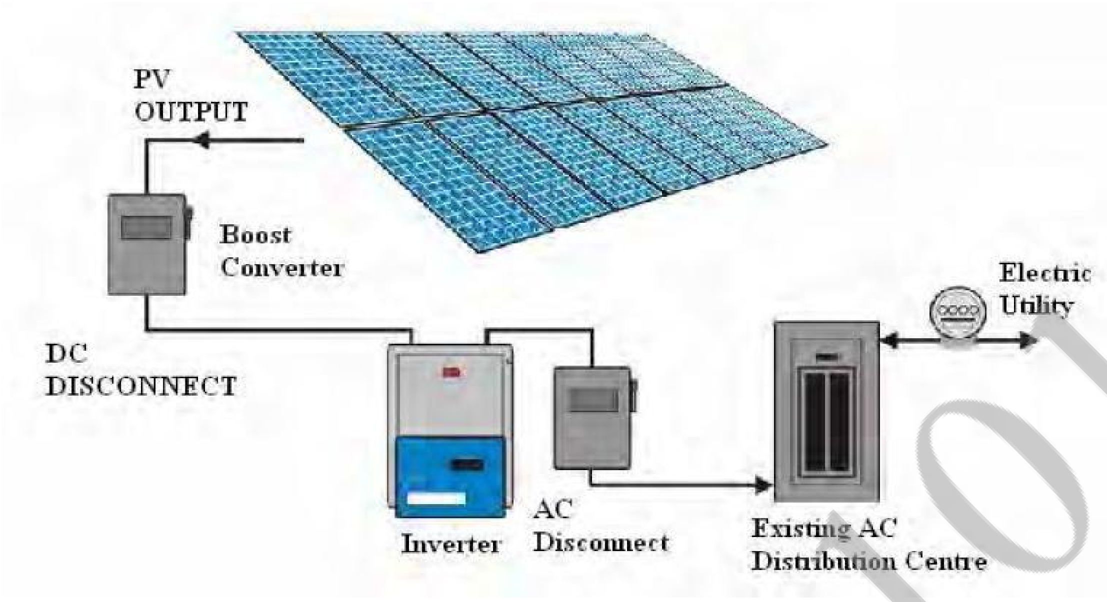
A Solar PV panel produces DC electrical power, which is different from AC power that we receive from our electrical grid supply. There are appliances that use either DC power or AC power for their operation. Most of the equipment used in our homes use AC power. Therefore it is often required to convert DC power into AC power. The conversion of DC power to AC power can be achieved using a device called inverter (or DC to AC converter). It is also possible to convert AC power into DC power using a rectifier.



2. Grid connected PV System:

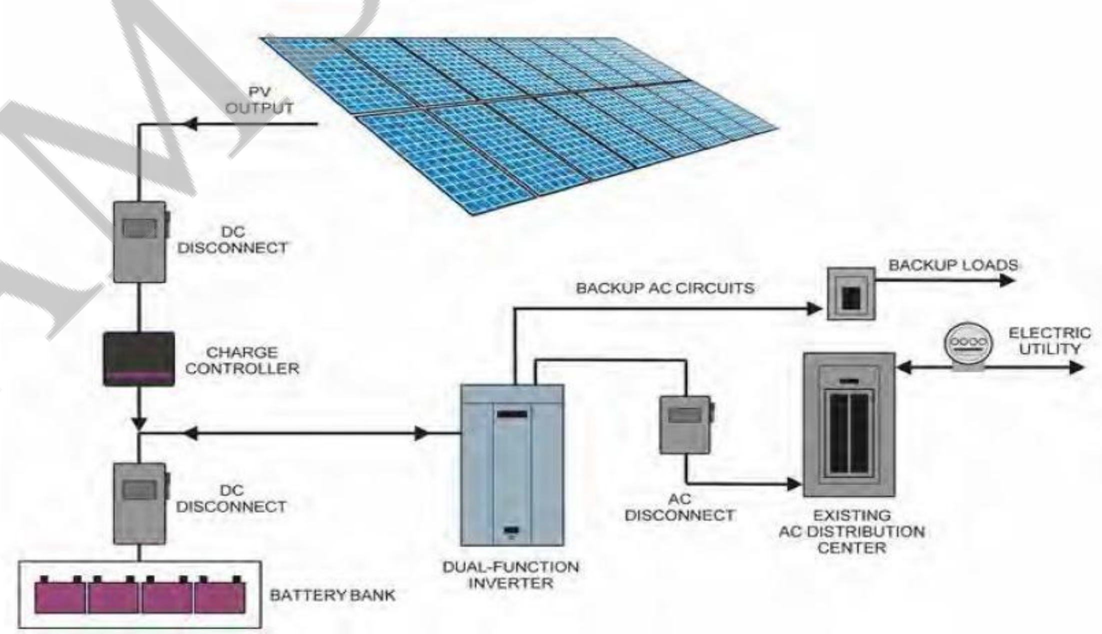
a) Without Battery Bank:

There are no batteries to store excess power generated-the electric utility essentially stores it for you through a system called "net-metering." DC (direct current) generated by the PV panels is converted into AC (alternating current) power by the inverter (exactly the same high quality AC current delivered to your site by the utility-provided power grid). Output from the inverter is connected to your existing distribution panel (breaker panel) which feeds the rest of your site. While the system is generating electricity, power needs are provided by the PV system (up to its capacity), reducing or eliminating the power you would have drawn from the utility grid at that time. During periods when your grid-tie system is generating even more energy than your site requires, any excess is fed back into the grid for others to use and the electric utility company "buys" it from you at the retail rate. They provide credits to your account for all the power that is pushed back into the grid through the meter. And your meter will literally run backwards! When your site needs to draw more energy than it is producing (say, during cloudy conditions or at night), electricity is provided by the power grid in the normal manner and is first paid for by your accumulated credits.



b) . With Battery Bank:

The "Grid-Tie With Battery Backup" PV system incorporates one or more special AC circuits which are not directly connected to the electric grid like the rest of the building, but are always powered through the inverter and/or charge controller. These circuits may power a refrigerator, selected lights, computers or servers... any devices the owner deems essential. The "dual function" inverter can supply the utility grid with any excess power produced by the system like the "grid-tie" inverter, plus the inverter works with the PV modules and battery bank (through the charge controller) to provide AC power to the backup circuits when the grid is down. The charge controller manages the battery voltage, keeping them fully charged when the grid is live, and preventing them from being depleted when the system is drawing power from them.



B). **MAXIMUM POWER POINT TRACKING**

MPPT or Maximum Power Point Tracking is algorithm that 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.

A MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries.

Several algorithms were proposed to accomplish MPPT controller. Published MPPT methods include:

(1) Perturb and Observe (PAO) ,

(2) Incremental Conductance Technique (ICT), and

(3) Constant Reference Voltage/Current.

Perturb and Observe (PAO)

Perturb-and-observe (P&O) method, also known as perturbation method is a type of MPPT algorithm. The concept behind the "perturb and observe" method is to modify the operating voltage or current of the photovoltaic panel until you obtain maximum power from it. It is often referred to as hill climbing method, because they depend on the fact that on the left side of the MPP, the curve is rising (dP/dV > 0) while on the right side of the MPP the curve is falling (dP/dV < 0). Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

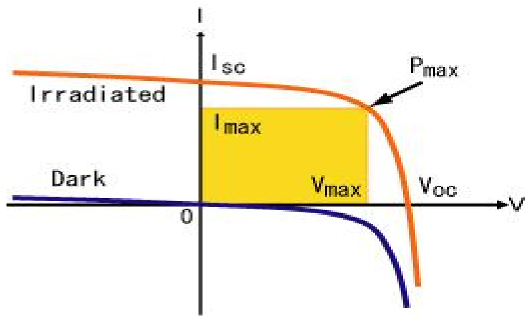
Algorithm:

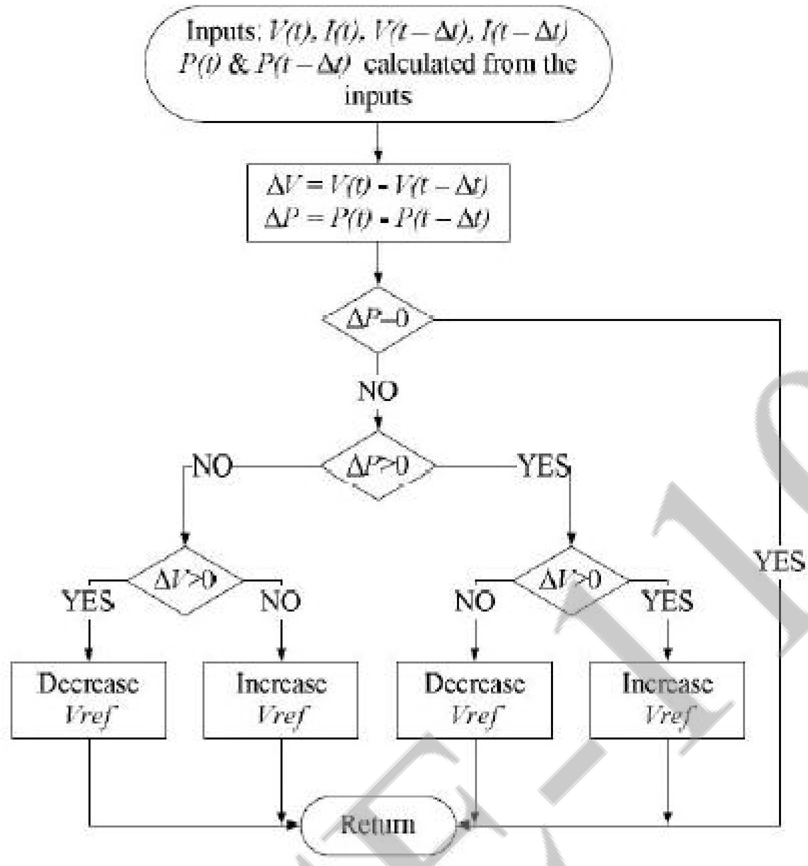
The voltage to a cell is increased initially. If the output power increases, the voltage is continually increased till the output power starts decreasing. Once the output power starts decreasing, the voltage to the cell is decreased till maximum power is reached. This process is continued till the MPP is attained. This results in an oscillation of the output power around the MPP.

Drawback:

One of the major drawbacks of the perturb and observe method is that under steady state operation, the output power oscillates around the maximum power point.

This algorithm can track wrongly under rapidly varying irradiation conditions.

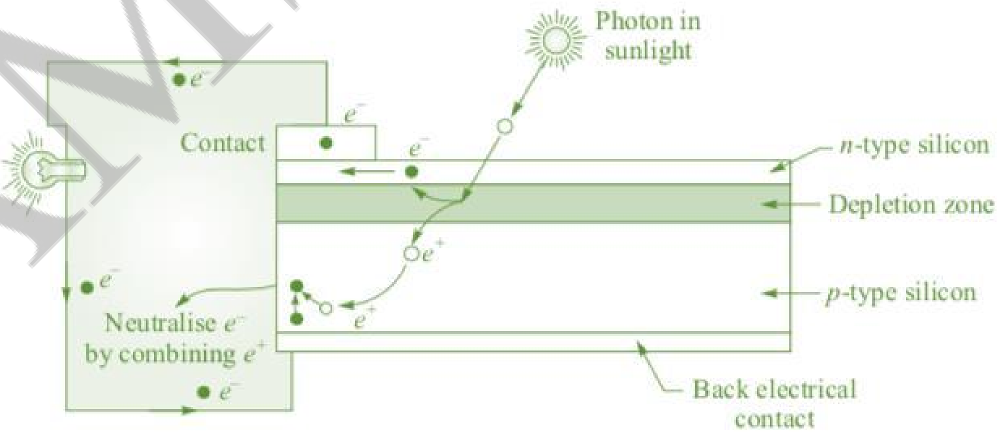




4. Explain about the Solar cells with types and its Characteristics. Also define the fill factor.

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

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



SOLAR CELL, MODULE, PANEL AND ARRAY

Solar Cell

The solar cell consists of

(i) p-type silicon material layer,

(ii) n-type silicon material layer,

(iii) front metallic grid and

(iv) opaque back metal contact as shown in Figure 3.24

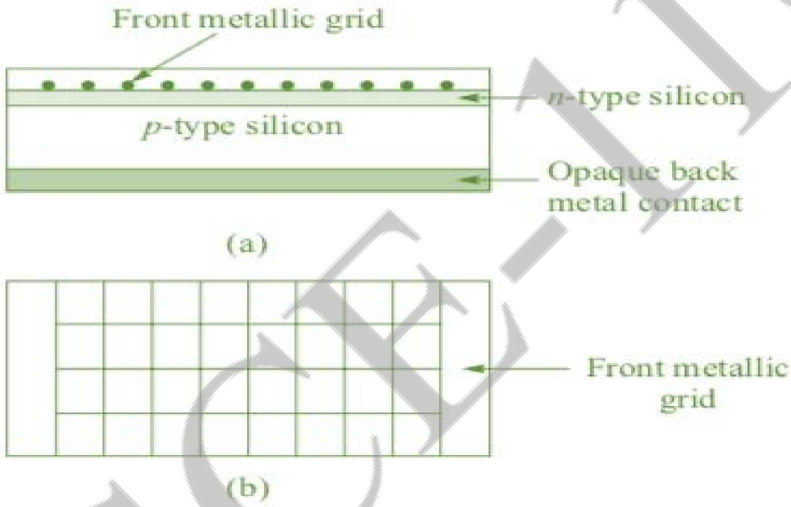
The bulk material consists of p-type silicon having thickness about 100 350 mm. A thin layer of n-type silicon having thickness of about 2 mm is diffused on this bulk material, providing p-n junction. A metallic grid at top with n-type material and an opaque back metal contact at the bottom of p-type material are provided which also act as negative and positive terminals.

Solar PV Module

A Single solar cell cannot be used as such as it has

(1)A very small output

(2)No protection against dust moisture , mechanical impacts and atmospheric harsh condition

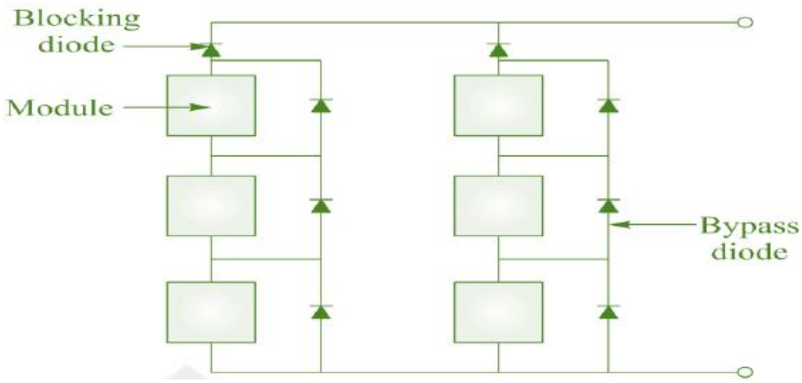


Solar PV panel.

Solar PV panel consists of a number of solar PV modules connected in series and parallel to obtain the power of desired voltage and current. When modules are connected in series, it is desirable that each module should produce maximum power at the same current. When solar PV modules are connected in parallel, it is desirable that each module should produce maximum power at the same voltage. A frame is used to mount several modules to form a solar PV panel.

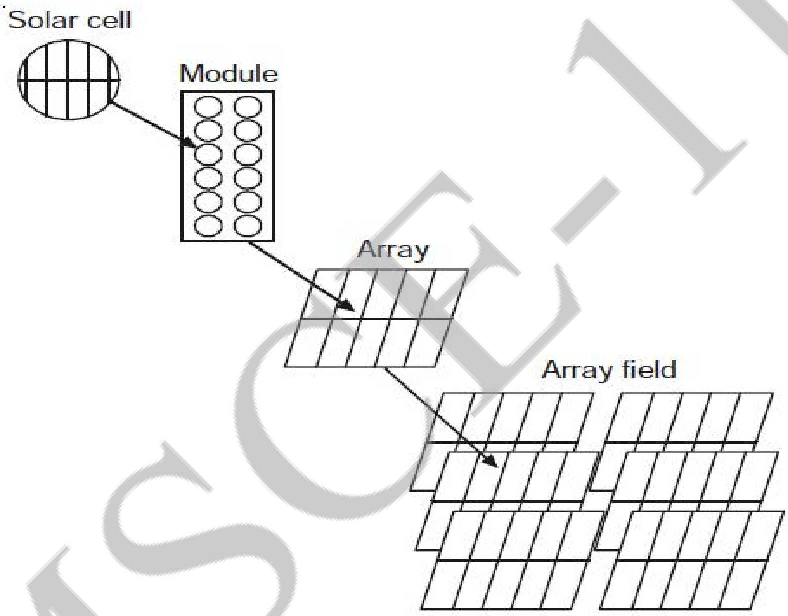
In the panel, bypass diodes are installed across each module so that any defective module can be bypassed by the output of remaining modules.

The blocking diodes are connected in series with each series string of modules which enable the output of the remaining series strings should not be absorbed by the failed string. A typical panel with the series and the parallel connections is shown in Figure



Solar PV Array

A PV array consists of a number of solar panels which are installed in an array field. The solar panels may be installed as stationary facing the sun or installed with some tracking mechanism. The installation should ensure that no panel should cast shadow on any of the neighboring panels and those panels can be easily maintained.



Solar cells are fixed on a board and connected in series and parallel combinations to provide the required voltage and power to form a PV module

TYPES OF SOLAR CELL

The solar cells depending on the type of material used can be classified as

(1) single crystal silicon solar cell,
(2) polycrystalline and amorphous silicon cell,
(3) cadmium sulphide-cadmium telluride cell,
(4) copper indium diselenide cell
(5) gallium arsenide cell.

Single Crystal Silicon

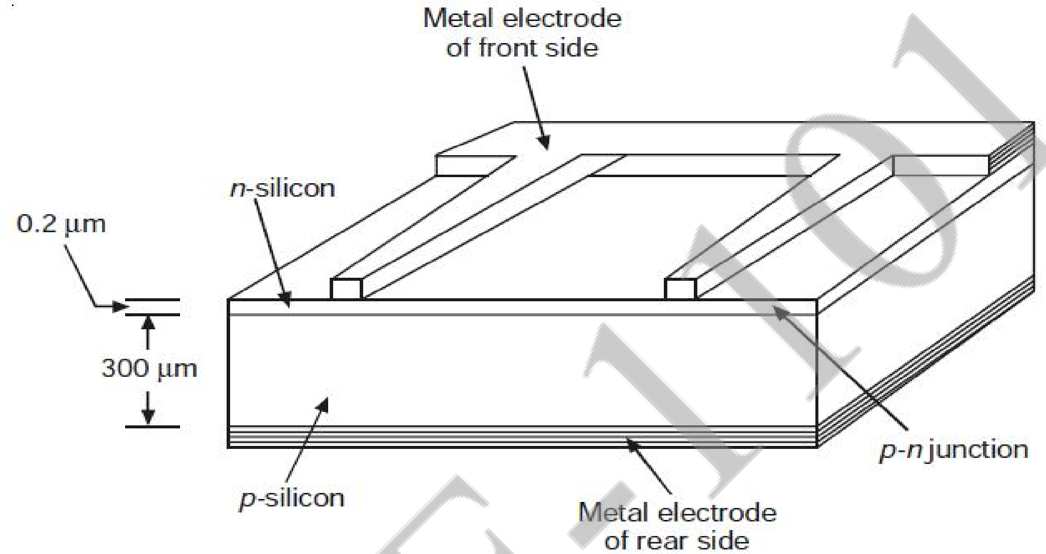
Silicon solar cells are commonly used for both terrestrial and space applications. The basic raw material is sand ($SiO2$) from which silica (Si) is extracted and purified repeatedly to obtain the metallurgical grade silicon. It contains about 1% impurities and further processed to convert it to a purer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

A single crystal ingot is a long cylindrical block of about 6 cm to 15 cm in diameter.

Crystalline cells basically require 300 mm to 400 mm of absorber material; the ingot is sliced in wafers of 300 mm thickness. These wafers are the starting material for a series of process steps such as surface preparation, dopants diffusion, anti-reflection coating, contact grid on the surface and base contact on the upper surface and on the lower one.

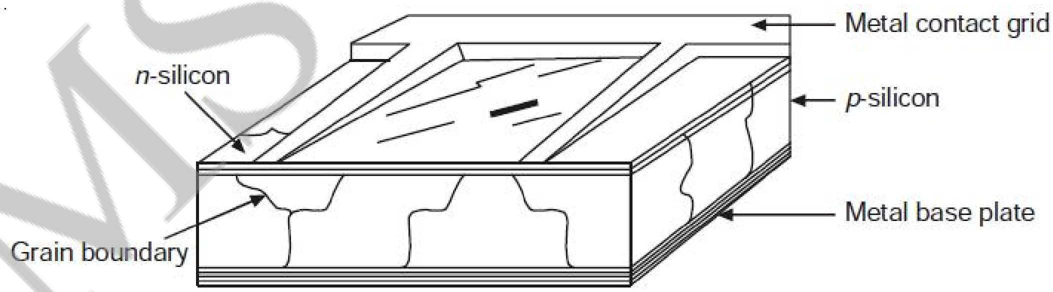
The efficiency of single crystal silicon is about 22%. It is most efficient and robust.

It has two main drawbacks: (i) it needs high energy to produce and hence is costly and (ii) it requires high intensity of radiation to produce solar electricity.



Polycrystalline Silicon Cells

The production cost of a single crystal silicon cell is quite high compared to the polycrystalline silicon cell. Polysilicon can be obtained in thin ribbons drawn from molten silicon bath and cooled very slowly to obtain large size crystallites. Cells are made with care so that the grain boundaries cause no major interference with the flow of electrons and grains are larger in size than the thickness of the cell.



The polycrystalline silicon solar cell can be fabricated in three designs, namely p-n junction cells, Metal Insulator Semiconductor (MIS) cells, and conducting oxide-insulator semiconductor cells.

For a p-n junction solar cell, a polycrystalline silicon film is deposited by chemical vapour deposition on substrates like glass, graphite, metallurgical grade silicon and metal. An MIS cell can be developed by inserting a thin insulting layer of SiO2 between the metal and the semiconductor.

A nicely developed cell with chromium metal base with SiO2 insulation over it, the p-type crystalline silicon can give efficiency up to 12% at AM-1 condition with cell dimension of 0.2 cm2.

Amorphous Silicon Cells

Amorphous silicon is pure silicon with no crystal properties. It is highly light absorbent and requires only 1 mm to 2 mm of material to absorb photons of the incident light. Thin amorphous layers can be deposited on cheap substrates like steel, glass and plastic. Hydrogenated amorphous silicon (a-Si : H) is a suitable material for thin film solar cells, mainly due to its high photo-conductivity, high optical absorption of visible light with optical band gap of 1.55 eV. Thin films of nearly 0.7 mm can produce solar cells comparatively at low cost.

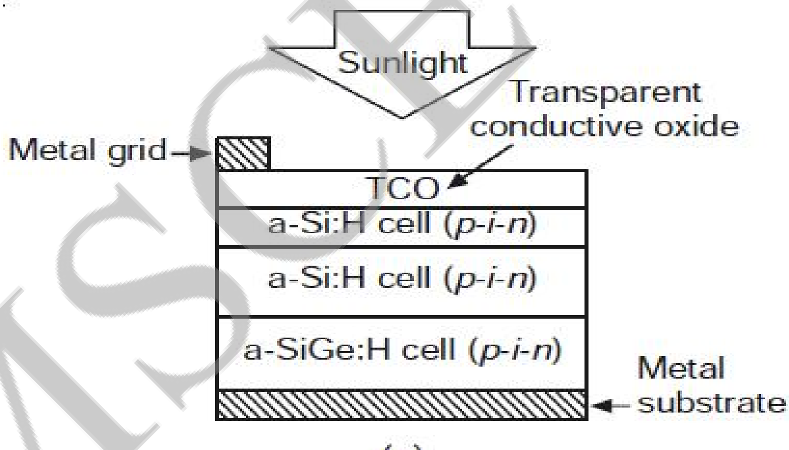
Amorphous silicon cells can be fabricated in four structures: (i) metal, insulator–semiconductor (MIS), (ii) p-i-n devices, (iii) hetrojunction, and (iv) Schottky barriers.

The p-i-n junction, a-Si solar cells are beneficial for commercial production due to their good performance.

A common type of p-i-n junction, a-Si solar cell, consists of a deposited layer of boron doped a-Si : H(200 Å) and above it, is a deposited layer of n-doped a-Si : H (80 Å). Then, a 70 Å thick layer of Indium Tin Oxide (ITO) is deposited over the n-type layer which serves in two ways, i.e., conducting electrode and anti reflective coating.

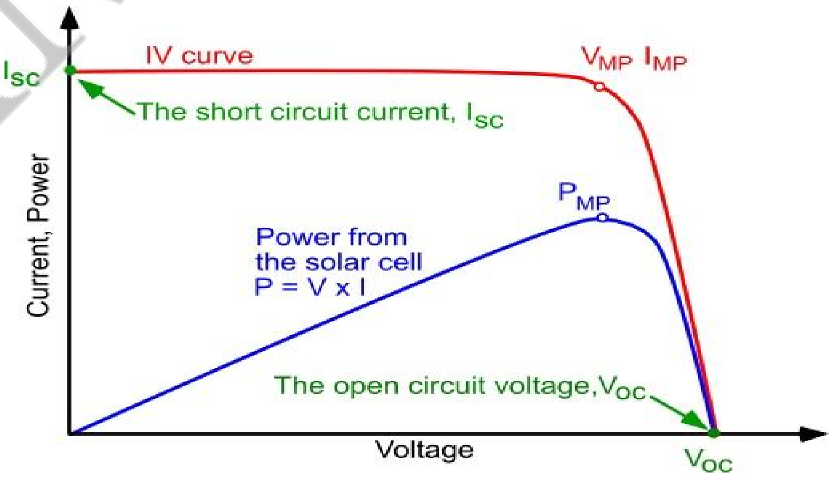
In a single junction (a-Si : H) solar cell, a part of solar radiation with less energy than band gap remains unutilized and wasted as heat, causing low cell efficiency.

This drawback is solved by adopting a 'tandem structure' that involves stacked junctions where semiconductors having different energy gaps are erected on top of each other with decreasing band gap in the direction of light path.

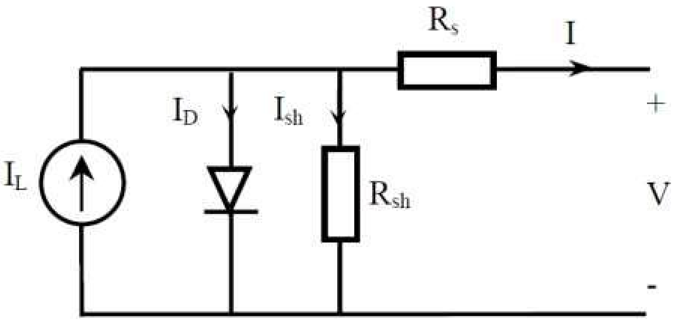


(a)

V-I and P-V characteristics of a solar cell:



Mathematical Model of Solar Cell



$$I = I_L - I_o \left(e^{\frac{q(V + IR_s)}{kT}} - 1\right) - \frac{V + IR_s}{R_{sh}}$$

Where:

I is the cell current (A).
I_L is the light generated current (A).
I_o is the diode saturation current.
q is the charge of electron = 1.6×10^{-19} (coul).
K is the Boltzman constant (j/K).
T is the cell temperature (K).
R_s , R_{sh} are cell series and shunt resistance (ohms).
V is the cell output voltage (V).

EFFICIENCY OF SOLAR CELLS

Electrical characteristics of a solar cell are expressed by the current–voltage curves plotted under a given illumination and temperature conditions. The significant points of the curve are short-circuit current Isc and open circuit voltage Voc.

Maximum useful power of the cell is represented by the rectangle with the largest area. When the cell yields maximum power, the current and voltage are represented by the symbols Im and Vm respectively. Leakage across the cell increases with temperature which reduces voltage and maximum power. Cell quality is maximum when the value of 'fill factor' approaches unity where the Fill Factor (FF) is expressed as

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}}$$

Energy conversion efficiency (h) is defined as the ratio of power output of cell (in watts) at its maximum power point (PMAX) and the product of input light power (E, in W/m2) and the surface area of the solar cell (S in m2) under standard conditions

η= maximum output power/(irradiance × area) = PMAX/(E × S)

The performance of a photovoltaic device defines the prediction of the power that the cell will produce. Current–voltage (I–V) relationships, which measure the electrical characteristics of solar cell devices, are represented by I–V curves. These I–V curves are obtained by exposing the cell to a constant level of light while maintaining a constant cell temperature, varying the resistance of the load, and measuring the current that is produced.

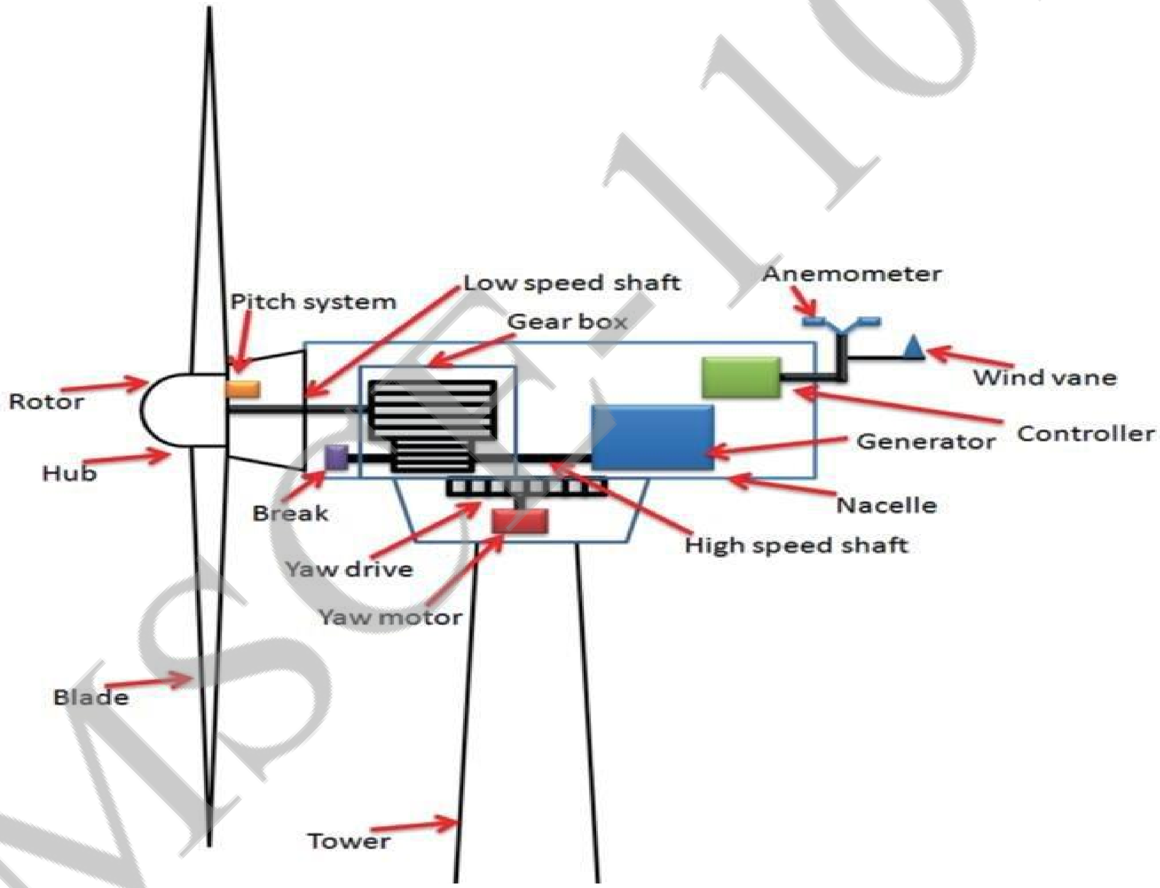
By varying the load resistance from zero (a short circuit) to infinity (an open circuit), researchers can determine the highest efficiency as the point at which the cell delivers maximum power. The power is the product of voltage and current. Therefore, on the I–V curve, the maximum power point (PMAX) occurs where the product of current and voltage is a maximum. No power is produced at the short-circuit current with no voltage or at open-circuit voltage with no current.

Therefore, the maximum power generated is expected to be somewhere between these two points. Maximum power is generated at only one place on the power curve, at about the „knee" of the curve. This point represents the maximum efficiency of the solar device at converting sunlight into electricity.

UNIT - WIND ENERGY

1. Clearly explain the principle of WECS with neat block diagram. (OR) Describe the working of a wind power system and its components with a neat schematic diagram.

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



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

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

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

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

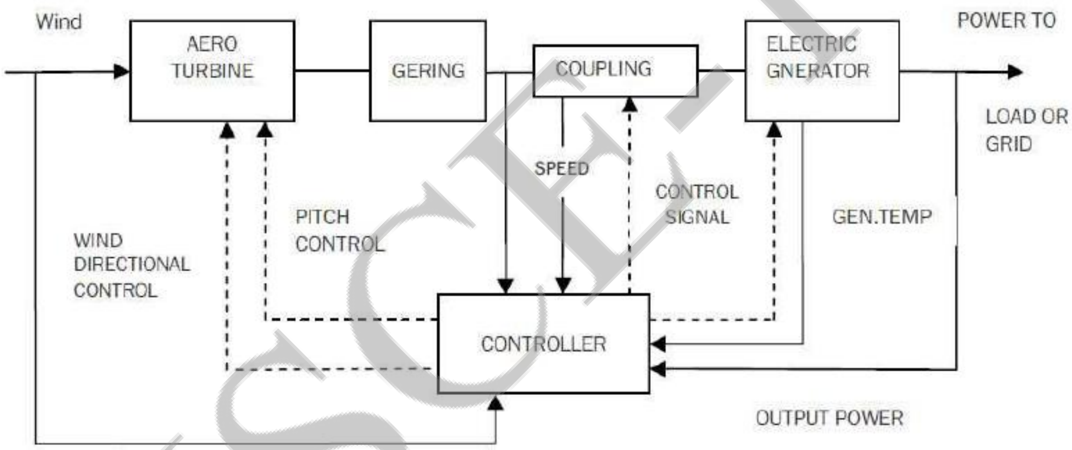
Yaw control: Yawing is done by two yawing motors, which mesh with a big-toothed wheel mounted on top of the tower. Yaw control continuously tracks and keeps the rotor axis in the wind direction. During high speed wind, i.e., more than the cut-out speed, the machine is stopped by turning the rotor axis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

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

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

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

WORKING:



There is an air turbine of large blades attached on the top of a supporting tower of sufficient height. When wind strikes on the turbine blades, the turbine rotates due to the design and alignment of rotor blades.

The shaft of the turbine is coupled with an electrical generator. The output of the generator is collected through electric power cables

When the wind strikes the rotor blades, blades start rotating. The turbine rotor is connected to a high-speed gearbox. Gearbox transforms the rotor rotation from low speed to high speed.

The high-speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed. An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity. The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator.

The speed is governed by wind power which is out of control. Hence to maintain uniformity of the output power from the alternator, excitation must be controlled according to the availability of natural wind power. The exciter current is controlled by a turbine controller which senses the wind speed.

Then output voltage of electrical generator(alternator) is given to a rectifier where the alternator output gets rectified to DC. Then this rectified DC output is given to line converter unit to convert it into stabilized AC output which is ultimately fed to either electrical transmission network or transmission grid with the help of step up transformer.

An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc.), this is called Internal Supply Unit. There are other two control mechanisms attached to a modern big wind turbine.

- Controlling the orientation of the turbine blade.
- Controlling the orientation of the turbine face.

The orientation of turbine blades is governed from the base hub of the blades. The blades are attached to the central hub with the help of a rotating arrangement through gears and small electric motor or hydraulic rotary system.

The system can be electrically or mechanically controlled depending on its design. The blades are swiveled depending upon the speed of the wind. The technique is called pitch control. It provides the best possible orientation of the turbine blades along the direction of the wind to obtain optimized wind power.

The orientation of the nacelle or the entire body of the turbine can follow the direction of changing wind direction to maximize mechanical energy harvesting from the wind.

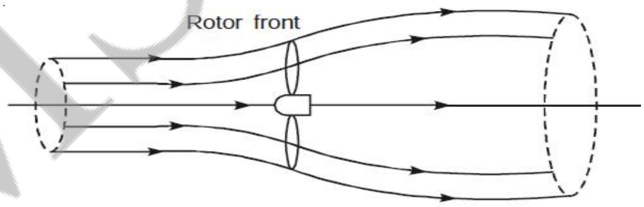
The direction of the wind along with its speed is sensed by an anemometer (automatic speed measuring devices) with wind vanes attached to the back top of the nacelle.

The signal is fed back to an electronic microprocessor-based controlling system which governs the yaw motor which rotates the entire nacelle with gearing arrangement to face the air turbine along the direction of the wind.

2. A).How energy from wind can be extracted? Explain the process by using suitable diagram.

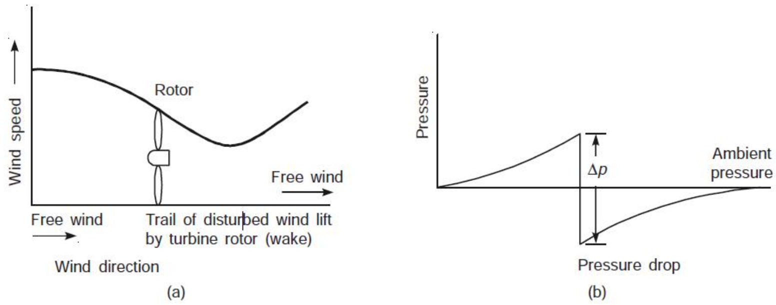
Wind turbines extract energy from wind stream by converting the kinetic energy of the wind to rotational motion required to operate an electric generator. By virtue of the kinetic energy, the velocity of the flowing wind decreases. It is assumed that the mass of air which passes through rotor is only affected and remains separate from the air which does not pass through the rotor.

Accordingly, a circular boundary surface is drawn showing the affected air mass and this boundary is extended upstream as well as downstream as detailed in Figure



As the free wind (stream) interacts with the turbine rotor, the wind transfers part of its energy into the rotor and the speed of the wind decreases to a minimum leaving a trail of disturbed wind called wake. The variation in velocity is considered to be smooth from far upstream to far downstream. However, the fall in static wind pressure is sharp.

The wind leaving the rotor is below the atmospheric pressure (in wake region) but at far downstream it regains its value to reach the atmospheric level. The rise in static pressure is at the cost of kinetic energy, consequently further decreasing the wind speed.



Wind flow is considered incompressible and hence the air stream flow diverges as it passes through the turbine. Also the mass flow rate of wind is assumed constant at far upstream, at the rotor and at far downstream. To compute the mathematical relationships, suppose:

P = atmospheric wind pressure

P_u = pressure on upstream of wind turbine

P_d = pressure on downstream of wind turbine

V = atmospheric wind velocity

V_u = velocity of wind upstream of wind turbine

V_b = velocity of wind at blades

V_d = velocity of wind downstream of wind turbine before the wind front reforms and regains the atmospheric level

A = area of blades

M = mass flow rate of wind

r = air density.

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

$$\text{KE} = \frac{1}{2}\bar{M}V_b^2$$

and $$\bar{M} = \rho A V_b$$

Hence, $$\text{KE} = \frac{1}{2}\rho A V_b^3 \quad (7.1)$$

The force on the disc of the rotor can be expressed as

$$F = (P_u - P_d)A \quad (7.2)$$

Force on the rotor can be expressed as change of momentum per unit time from upstream to downstream winds, i.e.,

$$F = \bar{M}(V_u - V_d) \quad (7.3)$$

Applying the Bernaulli's equation to upstream and downstream sides,

$$P + \frac{1}{2}\rho V_u^2 = P_u + \frac{1}{2}\rho V_b^2 \quad (7.4)$$

$$P_d + \frac{1}{2}\rho V_b^2 = P + \frac{1}{2}\rho V_d^2 \quad (7.5)$$

Solving Eqs. (7.4) and (7.5), we get

$$P_u - P_d = \frac{1}{2}\rho(V_u^2 - V_d^2) \quad (7.6)$$

Equating Eqs. (7.2) and (7.3), we get

$$(P_u - P_d)A = \bar{M}(V_u - V_d) = \rho A V_b(V_u - V_d) \quad (7.7)$$

Solving Eqs. (7.6) and (7.7), we get

$$\frac{1}{2}\rho(V_u^2 - V_d^2) = \rho V_b(V_u - V_d)$$

or

$$V_b = \frac{V_u + V_d}{2} \tag{7.8}$$

In a wind turbine system "Steady Flow Work", W, is equal to the difference in kinetic energy between upstream and downstream of the turbine for unit massflow, $\dot{\bar{M}} = 1$. Therefore,

$$W = (\text{KE})_u - (\text{KE})_d$$

$$= \frac{1}{2}(V_u^2 - V_d^2) \tag{7.9}$$

The power output P of wind turbine is the rate of work done, using the mass flow rate equation.

$$P = \dot{\bar{M}}\left(\frac{V_u^2 - V_d^2}{2}\right)$$

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

$$= \frac{1}{4}\rho A(V_u + V_d)(V_u^2 - V_d^2) \tag{7.10}$$

The above quadratic equation has two solutions, i.e., $V_d = \frac{1}{3}V_u$ and $V_d = V_u$

For power generation $V_d < V_u$, so we can have only $V_d = \frac{1}{3}V_u$ (7.10a)

Therefore,

$$P_{\max} = \frac{8}{27}\rho A V_u^3 \tag{7.11}$$

$$= \frac{16}{27}\left(\frac{1}{2}\rho A V_u^3\right)$$

$$= 0.593\left(\frac{1}{2}\rho A V_u^3\right)$$

Total power in wind stream is

$$P_{total} = \frac{1}{2}\rho A V_u^3 \quad (7.11a)$$

Therefore, $P_{max} = 0.593 P_{total}$

Maximum theoretical efficiency η_{max} (also called the power coefficient C_p) is the ratio of maximum output power to total power available in the wind, i.e.,

$$\text{Power coefficient, } C_p = \frac{P_{max}}{P_{total}} = 0.593 \quad (7.12)$$

The factor 0.593 is known as the **Bitz limit** (After the name of the engineer who first derived this relationship).

Available efficiency

Theoretically, the maximum power extracted by a turbine rotor is 59.3% of the total wind energy in the area swept by the rotor. Considering the rotor efficiency to be 70%, bearing, vibrations, friction losses and generator efficiency 90%, the available efficiency η is 60% of C_p, i.e.,

$$\eta_a = 0.6 \times 0.593$$
$$= 35.5\%$$

Air density ρ varies directly with air pressure. Its value is inversely proportional to air temperature expressed in kelvin scale as

$$\rho = \frac{P}{RT}$$

where P is the air pressure in Pa, T is the air temperature in kelvin and R is the gas constant, 287 J/kg·K. The standard value of air pressure = 1.01325×10^5 Pa (at 1 atmosphere) and at 15°C. Therefore,

$$\rho = \frac{1.01325 \times 10^5}{287 \times 288} = 1.226 \text{ J/kg}\cdot\text{K/m}^3$$

Air density is maximum at sea level and reduces gradually as one moves up to higher altitudes.

A Wind Energy Generator (WEG) is designed for a mean air density of 1.23 J/kg·K/m^3. The operational data and the power curves are given at this air density. If the mean air density differs from this value, the data and power curves will change accordingly.

B) .

Wind at one standard atmospheric pressure and 15°C has a speed of 10 m/s. A 10-m diameter wind turbine is operating at 5 rpm with maximum efficiency of 40%. Calculate (i) the total power density in wind stream, (ii) the maximum power density, (iii) the actual power density, (iv) the power output of the turbine, and (v) the axial thrust on the turbine structure.

Solution

$$\text{Total power density} = \frac{1}{2}\rho V_u^3 = \frac{1}{2} \times 1.226 \times 10^3$$
$$= 613 \text{ W/m}^2$$

$$\text{Maximum power density [Eq. (7.11)]} = \frac{P_{max}}{A} = \frac{8}{27}\rho V_u^3$$
$$= \frac{8}{27} \times 1.226 \times 10^3 = 363 \text{ W/m}^3$$

Actual power density = Efficiency × Total power density

$$= 0.40 \times 613 = 245.2 \text{ W/m}^2$$

Power output, $P = 0.245 \times \frac{\pi D^2}{4} = \frac{0.245 \times \pi \times 10^2}{4} = 19.33$ kW

Axial thrust [Eq. (7.20)], $F_{x(\max)} = \frac{\pi}{9} \rho D^2 V_u^2 = \frac{\pi}{9} \times 1.226 \times 10^2 \times 10^2$

$= 4277.40$ N

3.Explain about the a).<u>control strategies</u> of Wind Energy Conversion System with b).<u>its characteristics</u>.

Control Strategy

For every wind turbine, there are five different ranges of wind speed, which require different speed control strategies (Fig. 1.23).

(a) Below a cut-in speed, the machine does not produce power. If the rotor has a sufficient starting torque, it may start rotating below this wind speed. However, no power is extracted and the rotor rotates freely. In many modern designs the aerodynamic torque produced at the standstill condition is quite low and the rotor has to be started (by working the generator in the motor mode) at the cut-in wind speed.

(b) At normal wind speeds, maximum power is extracted from wind. We have seen earlier that the maximum power point is achieved at a specific (constant) value of the TSR. Therefore, to track the maximum power point, the rotational speed has to be changed continuously in proportion to the wind speed.

(c) At high winds, the rotor speed is limited to a maximum value depending on the design limit of the mechanical components. In this region, the C_p is lower than the maximum, and the power output is not proportional to the cube of the wind speed.

(d) At even higher wind speeds, the power output is kept constant at the maximum value allowed by the electrical components.

(e) At a certain cut-out or furling wind speed, the power generation is shut down and the rotation stopped in order to protect the system components.

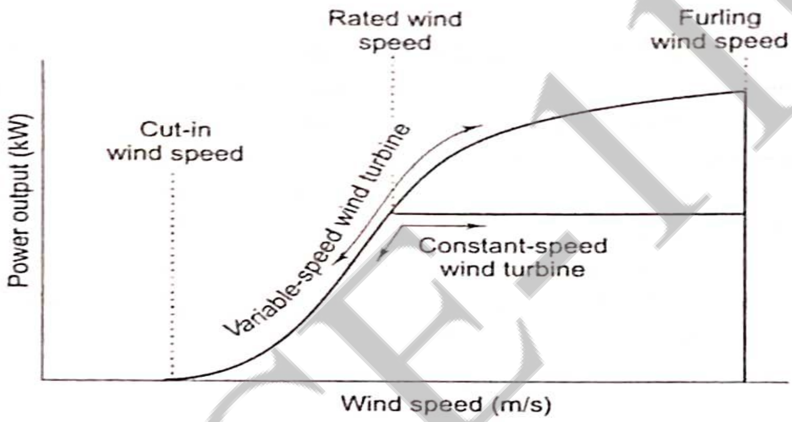


Fig. 1.23 Typical power versus wind speed characteristics of variable-speed wind machines

The last three control regimes can be realized with yaw control, pitch angle control (if these are installed), and eddy-current or mechanical brakes.

In the intermediate-speed range, the control strategy depends on the type of electrical power generating system used, and can be divided into two basic categories:

(a) the constant-speed generation scheme, and
(b) the variable-speed generation scheme.

Fixed Speed System

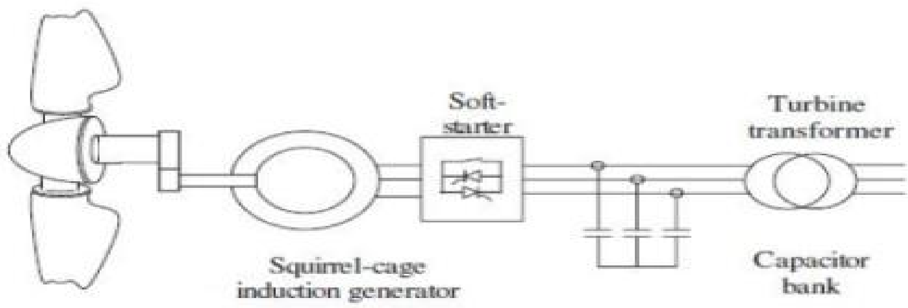


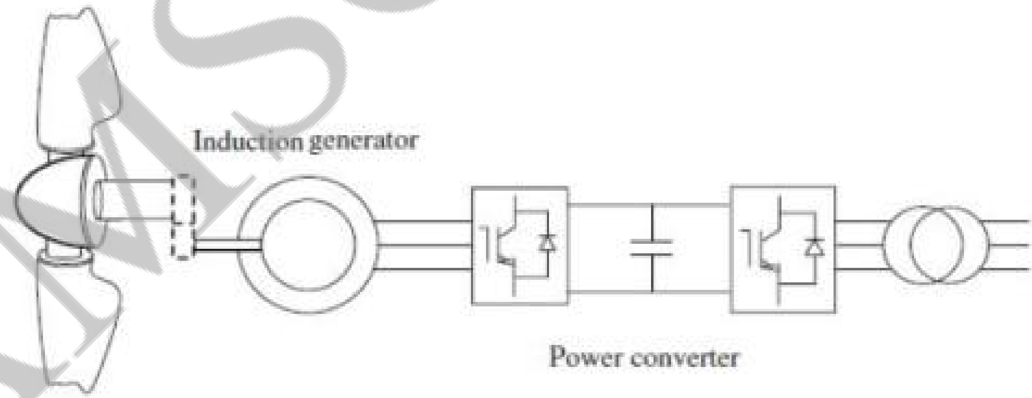
Fig 4.14 : SCIG Connected to Grid

Fixed-speed wind turbines are electrically fairly simple devices consisting of an aerodynamic rotor driving a low-speed shaft, a gearbox, a high-speed shaft and an induction (sometimes known as asynchronous) generator. From the electrical system viewpoint they are perhaps best considered as large fan drives with torque applied to the low-speed shaft from the wind flow.

It consists of a squirrel-cage induction generator coupled to the power system through a turbine transformer. The generator operating slip changes slightly as the operating power level changes and the rotational speed is therefore not entirely constant. However, because the operating slip variation is generally less than 1%, this type of wind generation is normally referred to as fixed speed. Squirrel-cage induction machines consume reactive power and so it is conventional to provide power factor correction capacitors at each wind turbine.

Variable Speed System

The typical configuration of a Variable Speed Grid Connected SCIG based fully rated converter wind turbine is shown in Figure 4.15. This type of turbine may or may not include a gearbox and a wide range of electrical generator types can be employed, for example, induction, wound-rotor synchronous or permanent magnet synchronous. As all of the power from the turbine goes through the power converters, the dynamic operation of the electrical generator is effectively isolated from the power grid. The electrical frequency of the generator may vary as the wind speed changes, while the grid frequency remains unchanged, thus allowing variable-speed operation of the wind turbine.



3. Explain the applications of Wind Energy Conversion Systems. OR Explain the modes of wind energy generation.

By nature, wind is not a steady source of energy, therefore, it cannot on its own meet the needs of consumers at all times. Necessarily, it has to be integrated with some other sources to provide a constant backup. Wind Electric Generators (WEGs) operate in one of the following three modes.

(i) Standalone mode

(ii) Backup mode like wind–diesel

(iii) Grid-connected mode.

Standalone Mode

This type of aero-generator represents decentralized application of wind energy and is characterized by the situation where an individual energy consumer or a group of consumers install their own wind turbine. The generating capacity of the WTG is matched with the energy requirement. The two most promising applications of the wind energy conversion system are:

(a) Power supply for domestic use and battery charging.

(b) Windmill water pump for irrigation and drinking purposes.

A WEG with a capacity of 2.5 kW to 5 kW is useful for domestic power supply. It operates independently with a battery and its charging equipment is as detailed in Figure 7.24. Such installations are useful for remote mountainous regions where the extension of grid or supply of oil is a remote possibility. Special benefit accrues where the wind speeds are suitable for power generation. It is preferred to have electric power at controlled frequency. As the wind changes speed, the pitch of the blades is adjusted to control the frequency of turbine rotation.

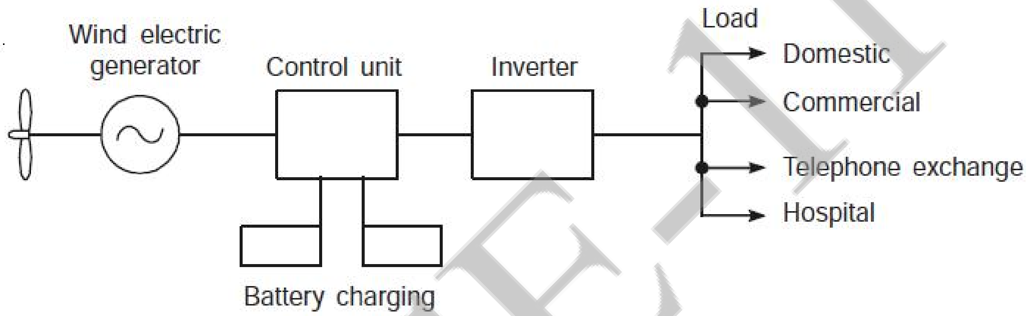


Figure 7.24 A standalone 5 kW wind electric generator.

Backup Mode Like Wind–Diesel

Wind energy, being intermittent, requires a backup of diesel generator to maintain a 24-hour power supply. In areas inaccessible to grid power, the emergency loads of hospitals, defence installations and communication services are met with a wind–diesel hybrid system, while the general loads of domestic and commercial establishments are fed by WTG, as detailed in Figure 7.27. As the wind speed drops, low tariff loads are automatically switched off to reduce the demand. During the period of no wind, priority loads are fed by the diesel generator. Load management allows the full capital value of WTG to be used at all times, besides maximum utilisation of free wind energy.

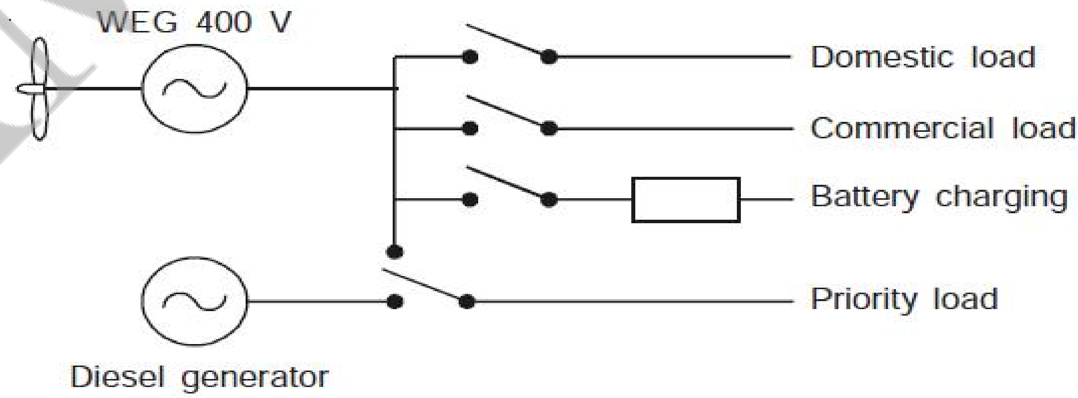


Figure 7.27 Wind–diesel power supply.

GRID CONNECTED WIND TURBINE GENERATORS

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

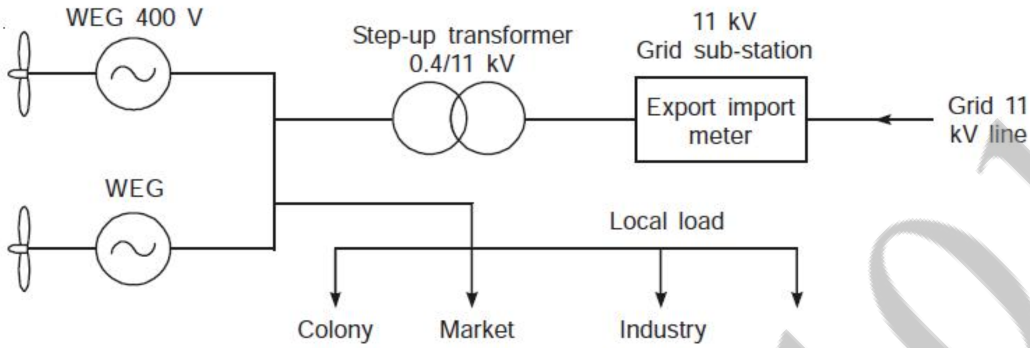


Figure 7.28 Grid-connected wind turbine generators.

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

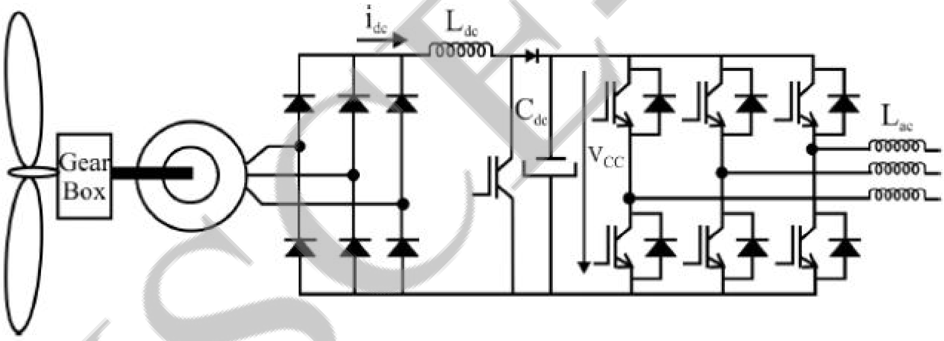


Fig 4.10. PM Synchronous generator with the rectifier, boost chopper, and the PWM line-side Converter

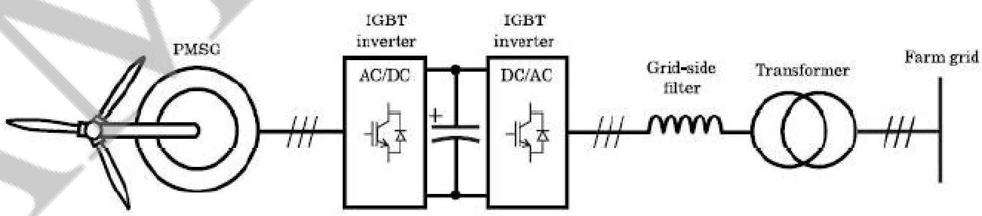


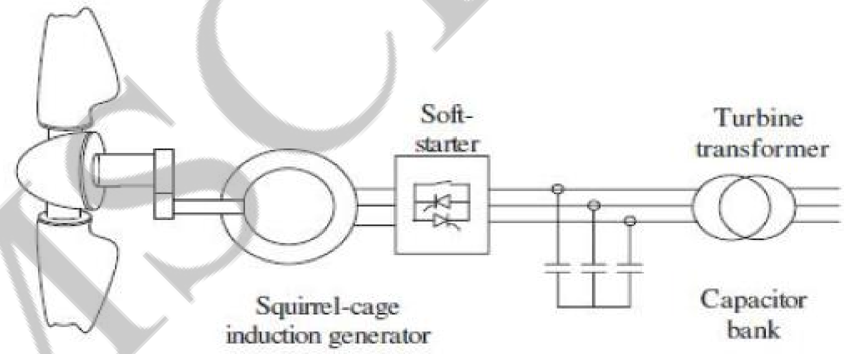
Fig 4.11. PM Synchronous generator with two back-to-back PWM converters.

A typical power electronics topology that is used for a permanent magnet synchronous generator is shown in Figure 4.10. The three-phase variable voltage, variable frequency output from the wind turbine is rectified using a diode bridge. With the change in the speed of the synchronous generator, the voltage on the DC side of the diode rectifier changes. To maintain a constant DC-link voltage of the inverter, a step-up chopper is used to adapt the rectifier voltage. As viewed from the DC inputs to the inverter, the generator/rectifier system is then modeled as an ideal current source. This rectified output signal from the diode bride is filtered into a smooth DC waveform using a large capacitor. The DC signal is then inverted through the use of semiconductor switches into a three-phase, 50 Hz waveform. This waveform can then be scaled using a transformer to voltage levels required by the utility's AC system. The generator is

decoupled from the grid by a voltage-sourced DC-link; therefore, this PE interface provides excellent controllable characteristics for the wind energy system. The power converter to the grid enables a fast control of active and reactive power. However, the negative side is a more complex system where more sensitive power electronic parts are required.

4.9 Grid Connected Squirrel Cage Induction Generator (SCIG) Based Wind Energy Conversion Systems.

4.9.1 Fixed Speed System



Fixed-speed wind turbines are electrically fairly simple devices consisting of an aerodynamic rotor driving a low-speed shaft, a gearbox, a high-speed shaft and an induction (sometimes known as asynchronous) generator. From the electrical system viewpoint they are perhaps best considered as large fan drives with torque applied to the low-speed shaft from the wind flow.

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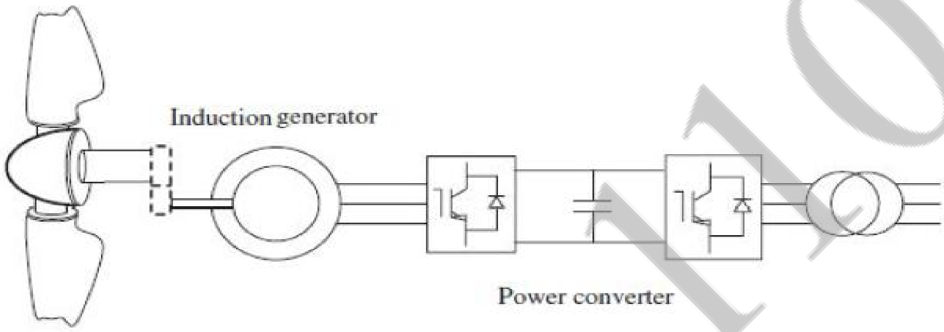
4.9.2 Variable Speed System

The typical configuration of a Variable Speed Grid Connected SCIG based fully rated converter wind turbine is shown in Figure 4.15. This type of turbine may or may not include a gearbox and a wide range of electrical generator types can be employed, for example, induction, wound-rotor synchronous or permanent magnet synchronous. As all of the power from the turbine goes through the power converters, the dynamic operation of the electrical generator is effectively isolated from the power grid. The electrical frequency of the generator may vary as the wind speed changes, while the grid frequency remains unchanged, thus allowing variable-speed operation of the wind turbine.



UNIT BIOMASS ENERGY

1. Explain briefly the components of a Biogas plant. With the help of neat sketch,explain the working of floating drum type Biogas plant

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

Floating Drum Type Biogas Plant

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

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

Fixed Dome Type Biogas Plant

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

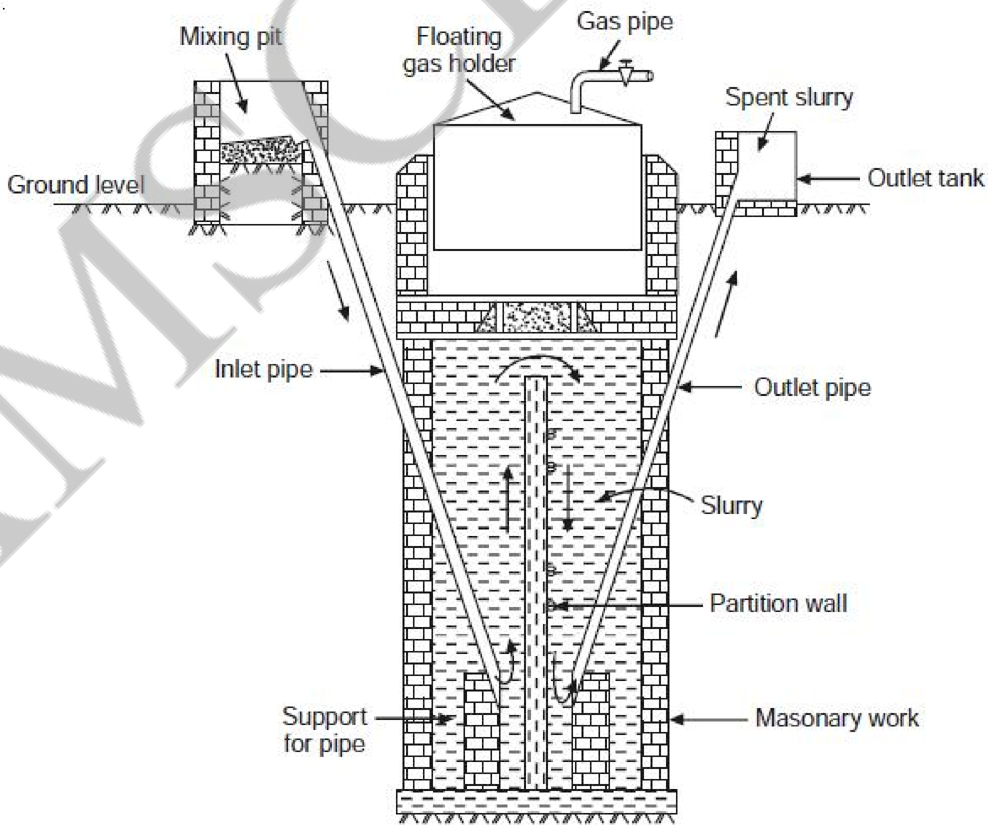


Figure 12.4 Floating drum biogas plant (KVIC model).

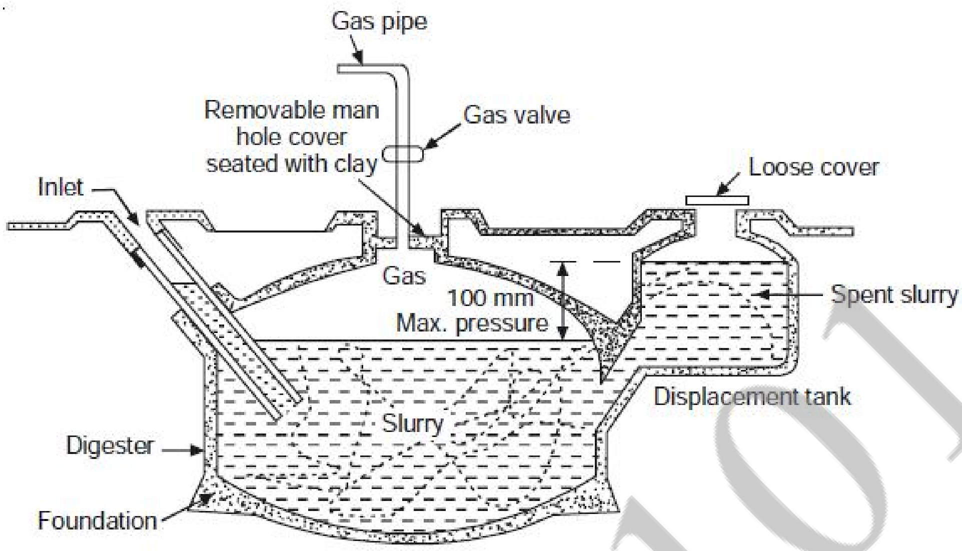
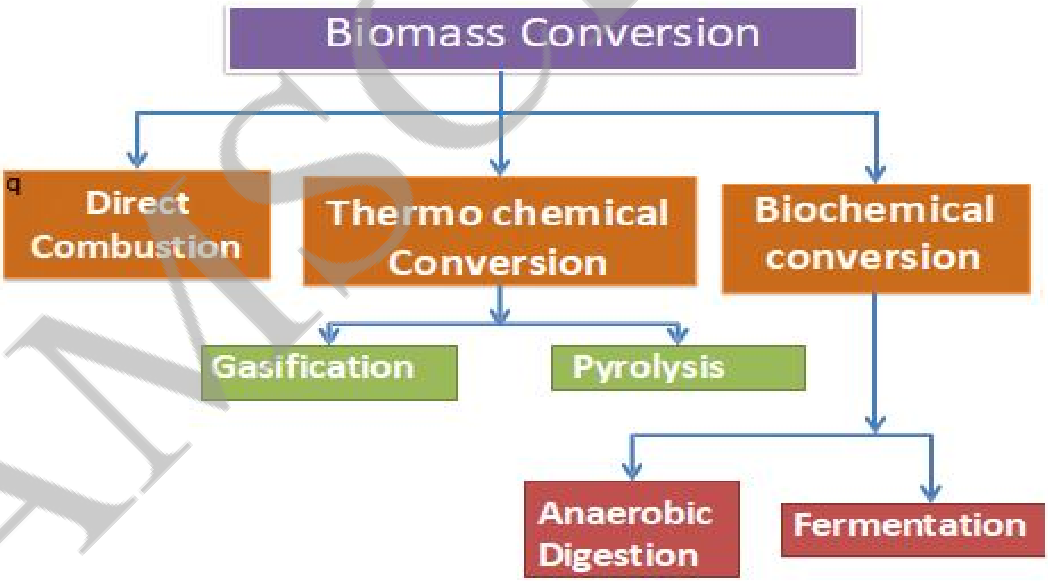


Figure 12.5 Fixed dome biogas plant (Janata model).

2. Explain the Biomass Energy Conversion process.

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

1. Densification of biomass
2. Combustion and incineration
3. Thermo-chemical conversion
4. Bio-chemical conversion



Densification

Bulky biomass is reduced to a better volume-to-weight ratio by compressing in a die at a high temperature and pressure. It is shaped into briquettes or pellets to make a more compact source of energy, which is easier to transport and store than the natural biomass. Pellets and briquettes can be used as clean fuel in domestic chulhas, bakeries and hotels.

Combustion

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

Incineration

Incineration is the process of burning completely the solid biomass to ashes by high temperature oxidation. The terms incineration and combustion are synonymous, but the process of combustion is applicable to all fuels, i.e., solid, liquid and gaseous. Incineration is a special process where the dry Municipal Solid Waste (MSW) is incinerated to reduce the volume of solid refuse (90%) and to produce heat, steam and electricity.

Waste incineration plants are installed in large cities to dispose off urban refuse and generate energy. It constitutes a furnace with adequate supply of air to ensure complete combustion up to a capacity of 1000 tonnes/day

Thermo-chemical conversion

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

Pyrolysis

Biomass is heated in absence of oxygen, or partially combusted in a limited oxygen supply, to produce a hydrocarbon, rich in gas mixture (H2, CO2, CO CH4 and lower hydrocarbons), an oil like liquid and a carbon rich solid residue (charcoal).

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

Gasification

Gasification is conversion of a solid biomass, at a high temperature with controlled air, into a gaseous fuel. The output gas is known as producer gas, a mixture of H2 (15–20%), CO (10–20%), CH4 (1–5%), CO2 (9–12%) and N2 (45–55%). The gas is more versatile than the

solid biomass, it can be burnt to produce process heat and steam, or used in internal combustion engines or gas turbines to generate electricity. The gasification process renders the use of biomass which is relatively clean and acceptable in environmental terms.

Liquefaction

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

Another liquefaction method is through methanol synthesis. Gasification of biomass produces synthetic gas containing a mixture of H2 and CO. The gas is purified by adjusting the hydrogen and carbon monoxide composition. Finally, the purified gas is subjected to liquefaction process, converted to methanol over a zinc chromium calatyst. Methanol can be used as liquid fuel.

BIOCHEMICAL CONVERSION

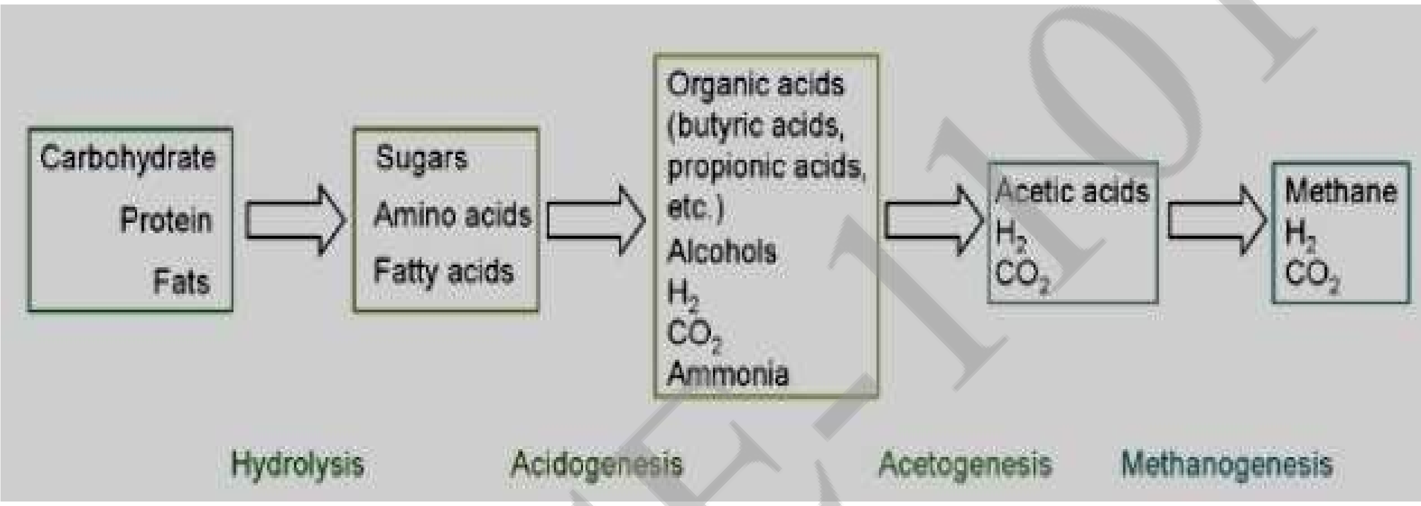
There are two forms of biochemical conversions:

1. Anaerobic digestion
2. Ethanol fermentation

Anaerobic Digestion (Anaerobic Fermentation)

This process converts the cattle dung, human wastes and other organic waste with high moisture content into biogas (gobar gas) through anaerobic fermentation in absence of air. Fermentation occures in two stages by two different metabolic groups of bacteria. Initially the organic material is hydrolyzed into fatty acids, alcohol, sugars, H2 and CO2. Methane forming bacteria then converts the products of the first stage to CH4 and CO2, in the temperature range 30–55°C.

Biogas produced can be used for heating, or for operating engine driven generators to produce electricity. Fermentation occurs in a sealed tank called 'digester' where the sludge left behind is used as enriched fertilizer.



Ethanol Fermentation

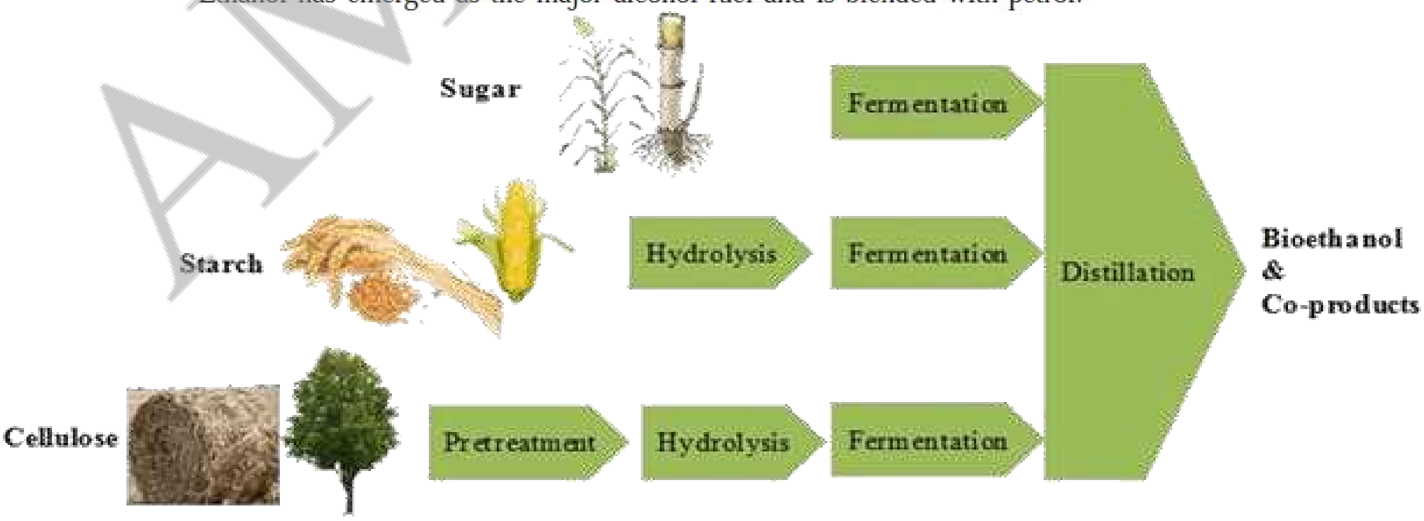
Ethanol can be produced by decomposition of biomass containing sugar like sugarcane, cassava sweet sorghum, beet, potato, corn, grape, etc. into sugar molecules such as glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$).

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

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2C_2H_5OH + 2CO_2$$

Ethanol has emerged as the major alcohol fuel and is blended with petrol.



UNIT OTHER ENERGY SOURCES

1. **Explain the Working of tidal power plant with neat layout and specify the site requirements.**

Tidal power, also called TIDAL ENERGY, is a form of HYDROPOWER which converts the energy of tides into the useful form of power, mainly in electricity.

Tides are the waves caused due to gravitational pull of the moon and sun. Ocean tides are the periodic rise and fall of ocean water level occurs twice in each lunar day. During one lunar day the ocean water level rises twice and fall twice.

Time interval between a consecutive low tide and high tide is 6.207 hrs.

Tidal range is the difference between the consecutive high tide and low tide. During high tide, the water flow into the dam and during low tide water flow out which result in moving the turbine.

Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power.

IMPORTANT COMPONENTS OF A TIDAL POWER PLANT

There are three important components of a tidal plant:

(i) A barrage to form a basin

(ii) Sluice gates in the barrage for flow of water from the sea to the basin and vice-versa

(iii) A powerhouse equipped with turbines, each coupled to a generator along with auxiliary equipment.

Barrage (Dam or Dyke)

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

Sluices

- Tidal power plants operate on the continuously varying difference in level at which the basin must be filled from the sea or emptied to the sea, as required by the operating regime of the power plant.
- This requires suitable sluice ways equipped with gates which can be operated quickly.
- These are required to be operated two or more times a day.
- There are two types of sluice ways, one type with crest gates and the other of the submerged gates associated with venturi type.
- Sluice ways with crest gates are more prone to damage by wave action and masses carried by the flow. Vertical lift gates are the natural choice and can be fabricated from stainless steel.

Turbines

- The energy potential in tidal power development is exploited from low to very low heads, for which large size turbines are required. If the water head is more than 8 metres, a propeller type turbine is quite suitable because the angle of blades can be changed to obtain maximum efficiency while the water is falling.
- The main aim of the designer for a tidal power plant is to achieve as long a period of operation as possible.
- The turbines beginning and finishing work at the minimum head provide maximum efficiency, and this is the advantage of having turbines with variable pitch blade

Types of Tidal Power Plants

Tidal power plants can be broadly classified into the following four categories:

(i) Single-basin single-effect plant

(ii) Single-basin double-effect plant

(iii) Double-basin with linked-basin operation

(iv) Double-basin with paired-basin operation

Single-basin Single-effect Plant

It is the oldest form of tidal power development and the basis of many tide mills.

The basin is filled through the sluice by the rising tide. The water level in the basin reaches the highest level of the tide. It provides the water head of tidal range to the turbine. The sluice gate is closed. The turbine is started only when the water in the sea is at falling tide level. As the tide continues to fall a hydraulic head is formed at the barrage and at an appropriate time water is released from the basin through the generating unit installed in the powerhouse.

Electric power generation continues until the head is reduced to the minimum turbine operating level. It normally occurs after the tide has reached its lowest point and has begun to rise again. At this stage the turbine water passage is closed and all discharge from the basin is stopped.

When the rising tide reaches the basin level, the filling sluice is opened, refilling of the basin starts and the cycle is repeated. The cycle of operation showing the water level, the generating and the refilling periods.

(i) The turbine capacity

(ii) Minimum head under which the turbine will operate efficiently

(iii) Time at which generation starts and stops.

These three variables need to be adjusted to produce the best possible results. In general the aim should be to get as long a period of operation as possible, and with this objective, the turbines would commence and stop operating at the minimum head consistent with high efficiency.

In a single-basin single-effect tidal plant with ebb tide operation, the generation period is only for 3.5 hours during every tide cycle. There are two tide cycles per day, so the energy available is intermittent and fluctuates from a maximum at spring tides to a minimum at neaps.

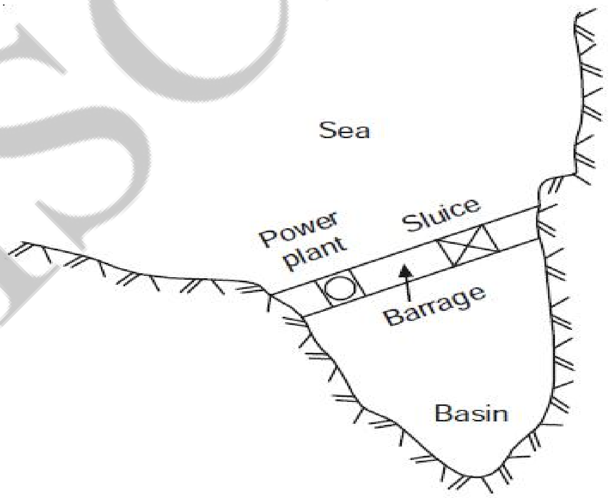


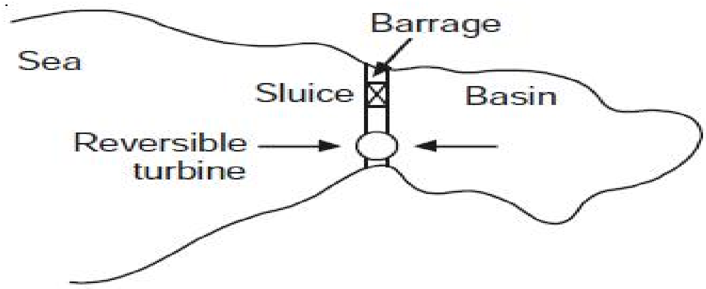
Figure 11.9 Single-basin single-effect tidal plant.

Single basin rising tide operation

In rising tide, there is rapid filling of the basin, so the turbine operates for a reduced period. In ebb tide operation, the turbine and the generator operate for a longer time giving higher output.

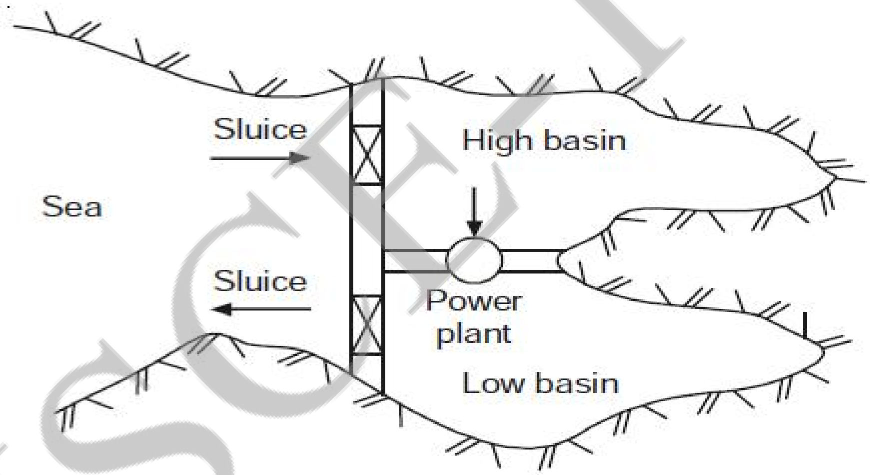
Single-basin Double-effect Plant

This arrangement makes use of the combination of the ebb tide and the flood tide working, and power is generated both during emptying and filling of the basin. With a single barrage, the water head which produces the energy operates from the sea towards the basin during the flood tide and from the basin towards the sea during the ebb tide. The most practical method of achieving the double tide operation is by the use of the reversible turbine which can operate in both directions of flow.



Double-basin with Linked-basin Operation

In this arrangement a large basin is converted into two basins of suitable dimensions; one which is at higher level is called high basin and the other low basin. The scheme consists of three barrages, one separating the high basin from the sea and containing the filling gates, another separating the low basin from the sea and containing the emptying gates. The third barrage separates the high basin from the low basin and contains the powerhouse.

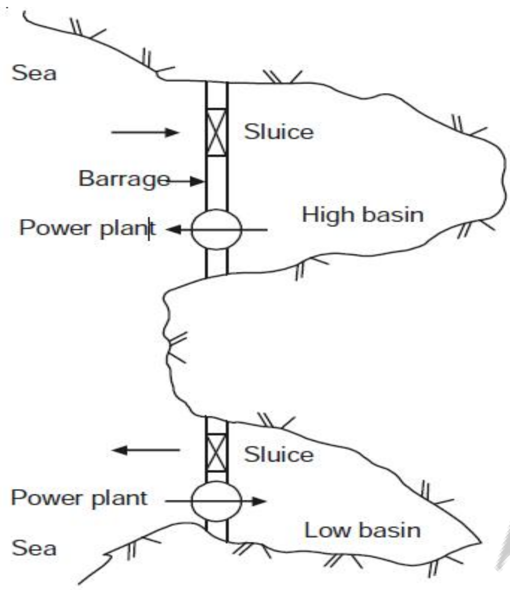


The upper basin filling gates are opened only during the time when the sea level is higher than the upper basin. The emptying gates of the lower basin are opened only when the sea level is lower than the lower basin. The head on the turbine is the difference in elevation between the upper and lower basins.

The two-basin scheme may be economically viable where power demand is less than the guaranteed output as determined by the tide cycle. Alternatively, the two-basin system can be operated by retaining water in high basin and releasing it to meet peak demands only.

Double-basin with Paired-basin Operation

The paired basin scheme consists of two single-basin single-effect separate schemes located at a distance from each other. The locations are so selected that there is a difference in tidal phase between them. Both the schemes never exchange water, but are interconnected electrically. Both the basins operate in single-basin single-effect mode. One basin generates electrical energy during the 'filling' process while the other during the 'emptying' process.



This arrangement affords a little more flexibility in operation of the plants to meet power demands. More benefit can be derived if there is a difference in tidal phase of the sea near the two basins.

In case where there is no difference in tidal phase, variations in power output can be evened out by resorting to ebb tide operation in one plant and flood tide operation in the other.

The paired-basin operation leads to a continuous output, still its power supply remains irregular and there is no solution for equalizing the great difference in output between the spring and the neap tide operation.

Further, it is difficult to find two tidal sites within reasonable distance of each other having the requisite difference in time of high water.

2.Explain the working principle of a geothermal power plant With the help of a neat sketch.

GEOTHERMAL POWER GENERATION

Electric power from geothermal resources can be developed in the following manner.

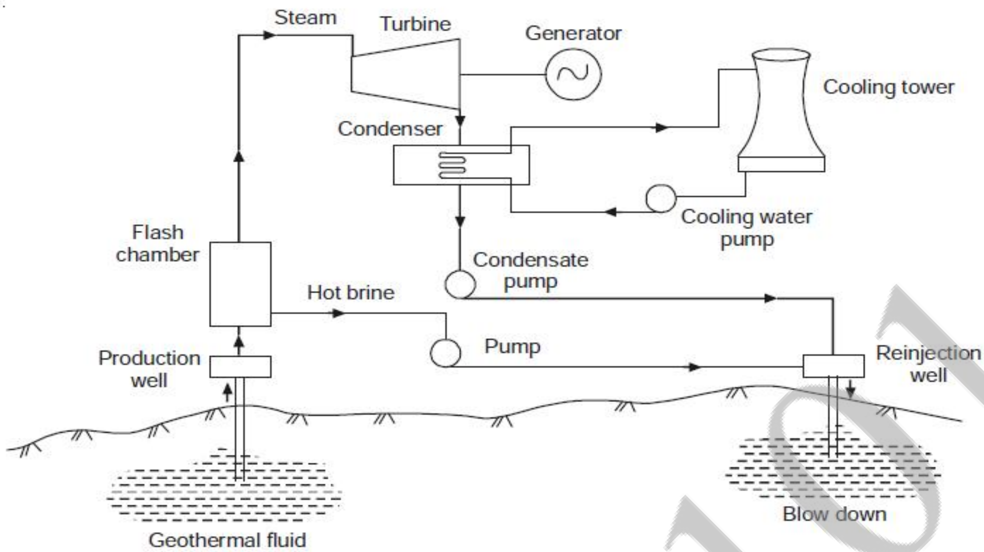
1. Liquid-dominated resource
(a) Flashed steam system
(b) Binary cycle system
2. Vapour-dominated resource

1.Liquid-dominated Resource

Geothermal fluid is either available from natural outflow or from a bored well. The drilling cost increases greatly with depth and the technically viable depth is 10 km. Thus, only the geothermal wells of maximum output at shallow depths offer the best prospects for power generation.

Flashed steam system

The choice of geothermal power plant is influenced by brine characteristics and its temperature. For brine temperatures more than 180°C, the geothermal fluid is used. This flashed steam system is suitable for power generation as detailed



Geothermal fluid is a mixture of steam and brine, it passes through a flash chamber where a large part of the fluid is converted to steam. Dry saturated steam passes through the turbine coupled with the generator to produce electric power. Hot brine from the flash chamber and the turbine discharge from the condenser are reinjected into the ground. Reinjuction of the spent brine ensures a continuous supply of geothermal fluid from the well.

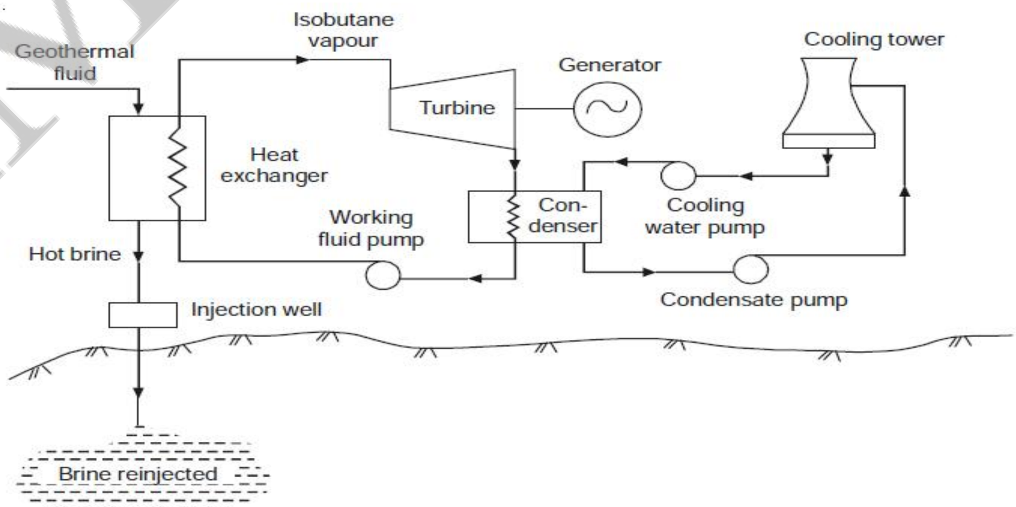
Commercially available turbogenerator units in the range of 5–20 MWe are in use. To improve the total efficiency of the system, hot water is utilised for poultry farming in cold regions.

Binary cycle system

A binary cycle is used where geothermal fluid is hot water with temperature less than 100°C.

This plant operates with a low boiling point working fluid (isobutane, freon) in a thermodynamic closed Rankine cycle. The working fluid is vaporized by geothermal heat in a heat exchanger

Vapour expands as it passes through the turbine coupled with the generator. Exhaust vapour is condensed in a water-cooled condenser and recycled through a heat exchanger. Power plants of 11 MW in California and 10 MW at Raft River Idaho USA operate on binary cycle.

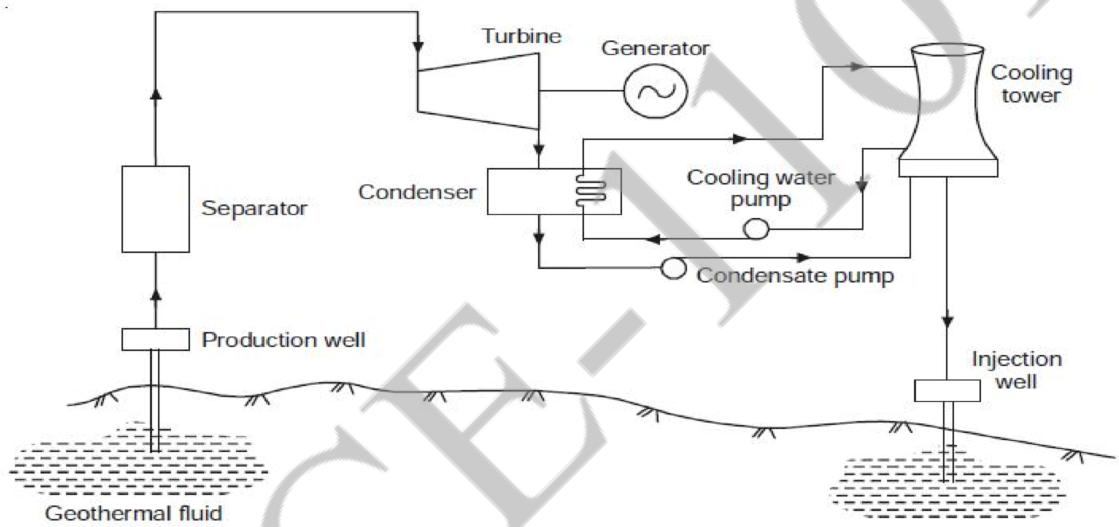


Vapour-dominated Geothermal Electric Power Plant

In a vapour-dominated plant, steam is extracted from geothermal wells, passed through a separator to remove particulate contents and flows directly to a steam turbine.

Steam that operates the turbine coupled with the generator is at a temperature of about 245°C and pressure 7 kg/cm2 (7 bar) which are less than those in conventional steam cycle plants (540°C and 130 kg/cm2). Thus, the efficiency of geothermal plants is low, i.e., about 20%.

Exhaust steam from the turbine passes through a condenser and the water so formed circulates through the cooling tower. It improves the efficiency of the turbine and controls environmental pollution associated with the direct release of steam into the atmosphere. Waste water from the cooling tower sump is reinjected into the geothermal well to ensure continuous supply.



3.Discuss the theory and working principle of ocean thermal energy conversion systems.

The OTEC converts the thermal energy, available due to temperature difference between the warm surface water and the cold deep water, into electricity. Power from the OTEC is renewable and eco-friendly.

An OTEC plant can operate in remote islands and sea-shore continuously. It is very low grade solar thermal energy, so the efficiency of energy recovery is quite low.

However, since the ocean thermal energy is dispersed over a large ocean surface area, it has a big potential.

According to MNRE, the overall potential of ocean energy in the country may be in excess of 50,000 MW. There is an enormous opportunity to tap this renewable source of energy.

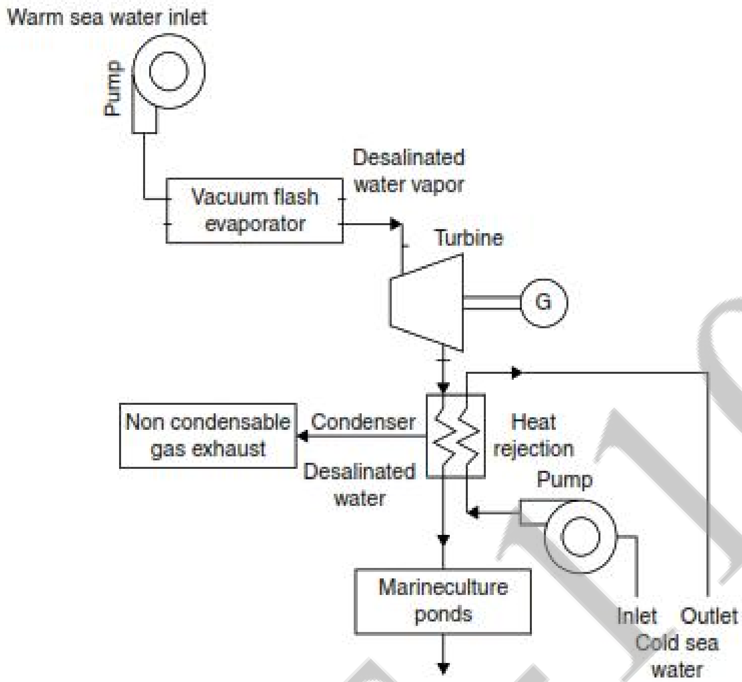
WORKING PRINCIPLE—OTEC

There exists a temperature difference of about 20°C between the warm surface water of the sea (receiving and absorbing solar radiation) and the cold deep water (which flows from the Arctic regions in deep layers) in equatorial areas between latitude 30° S and 30° N. Solar heat energy is absorbed by ocean water.

It can be explained by 'Lambert's law of absorption'. The law states that "each water layer of identical thickness absorbs an equal fraction of light that passes through it".

Thus, the intensity of heat decreases with the increase in water depth. Due to large heat transfer at the ocean surface water, the highest temperature is attained just below the top surface.

OPEN-CYCLE OTEC :



An open-cycle OTEC uses the warm ocean surface water as working fluid. It is a non-toxic and environment friendly fluid.

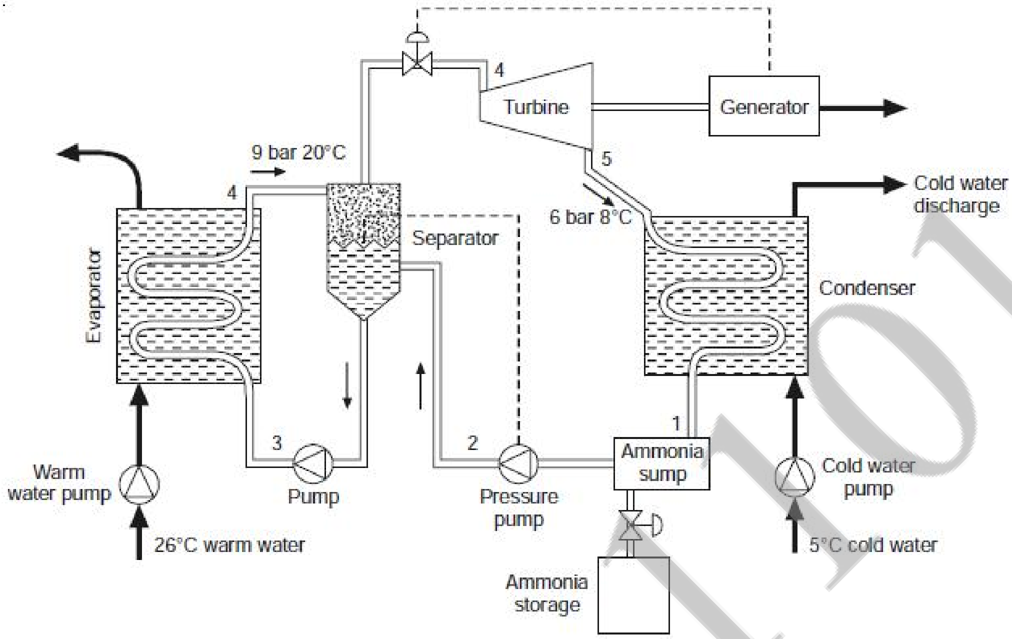
It consists of evaporator, low-pressure turbine coupled with electrical generator, condenser, marine culture ponds, non-condensable gas exhaust, and pumps.

Evaporator used in an open-cycle system is a flash evaporator in which warm sea water instantly boils or flash in the chamber that has reduced pressure than atmosphere or vacuum.

The working principles of open-cycle OTEC plants

1. The warm ocean surface water is pumped into flash evaporator where it is partially flashed into steam at a very low pressure. The remaining warm sea water is discharged into the sea.
2. The low-pressure vapour (steam) expands in turbine to drive a coupled electrical generator to produce electricity. A portion of electricity generated is consumed in plants to run pumps and for other work, and the remaining large amount of electricity is stored as net electrical power.
3. The steam with many gases (such as oxygen, nitrogen, and carbon dioxide) released from the turbine separated from sea water in an evaporator is pumped into condenser. The steam is cooled in a condenser by cold deep sea water.
4. The condensed non-saline water is discharged either directly in deep sea cold water or through the marine culture pond.
5. The non-condensable gases are compressed to pressure and exhausted simultaneously.
6. The warm ocean surface water is continuously pumped into evaporator and cycle repeats.

CLOSED RANKINE CYCLE OR ANDERSON CLOSED CYCLE OTEC SYSTEM



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

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

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

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

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

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

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

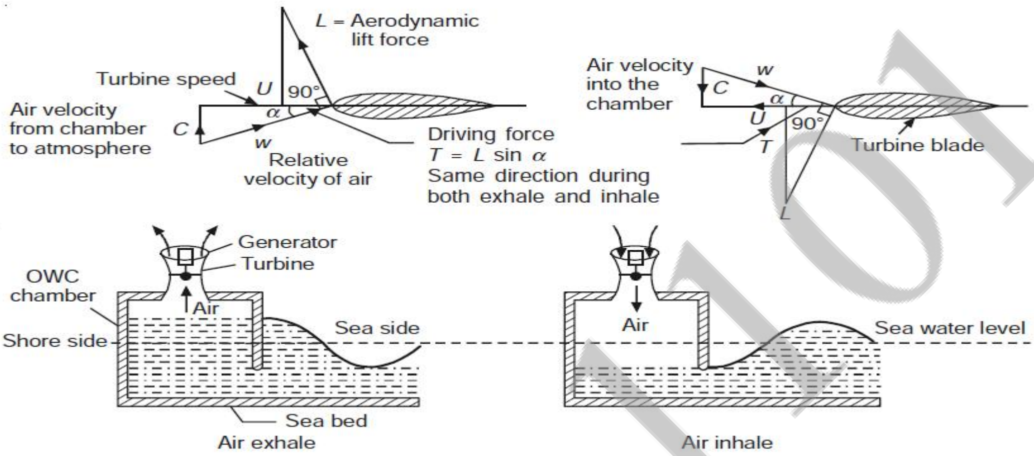
4.Explain the energy extracted from sea waves with expression and Discuss about the devices used for Wave Energy Conversion.

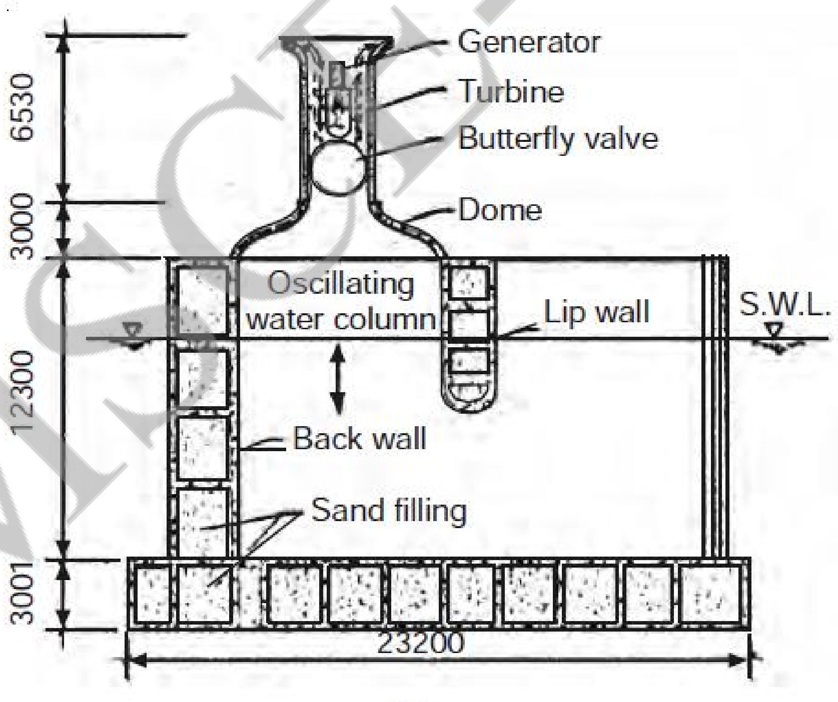
The movement of ocean water is termed as waves, which become huge in height as one goes farther from the coast. This movement of large quantities of water up and down can in principle be harnessed to convert into usable forms of energy such as electricity or mechanical power. Waves are formed on the surface of water by the frictional action of the winds resulting in the radial depression of energy from the blowing winds in all directions.

````````PRINCIPLE OF WAVE ENERGY CONVERSION AND DEVICES

The wave energy plant utilizes an ‘oscillating water column’ chamber and a self-rectifying air turbine to produce power. The device works similar to the operation of a bellow. Ocean waves enter the chamber inside the caisson and cause the water mass to move up and down producing a bidirectional air flow through an opening at the top of the caisson,

The special design of the turbine makes it rotate unidirectionally even though the actuating air flow is bidirectional. The turbine drives an induction generator connected to the grid.





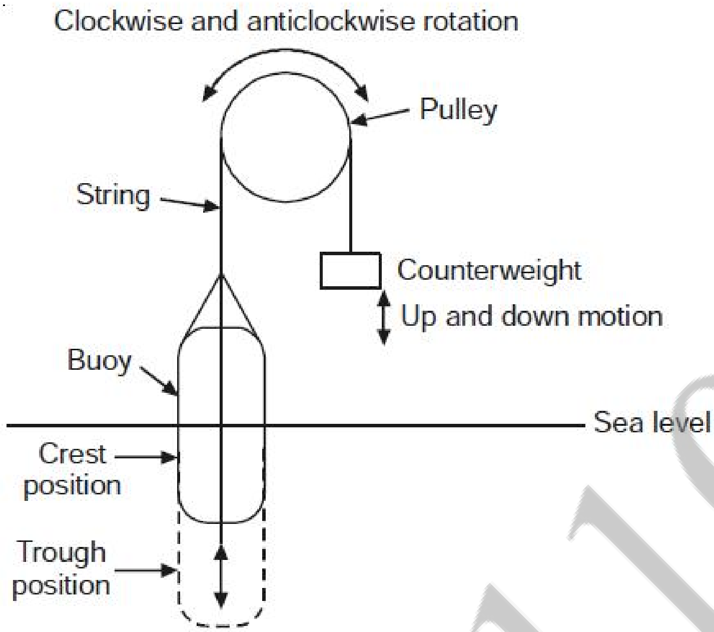
Cross section of the caisson module

Buoy Type Machine

The buoy is a floating part of a system which rises and falls with rise and fall of sea waves. However, the device is moored and anchored as per design methodology to avoid drifting.

The buoy oscillates up and down with the wave, the energy can be exhibited on a pulley with a string and counterweight arrangement.

The up and down motion of the counterweight can be converted into to and fro motion of a piston which can operate a machine or a generator.



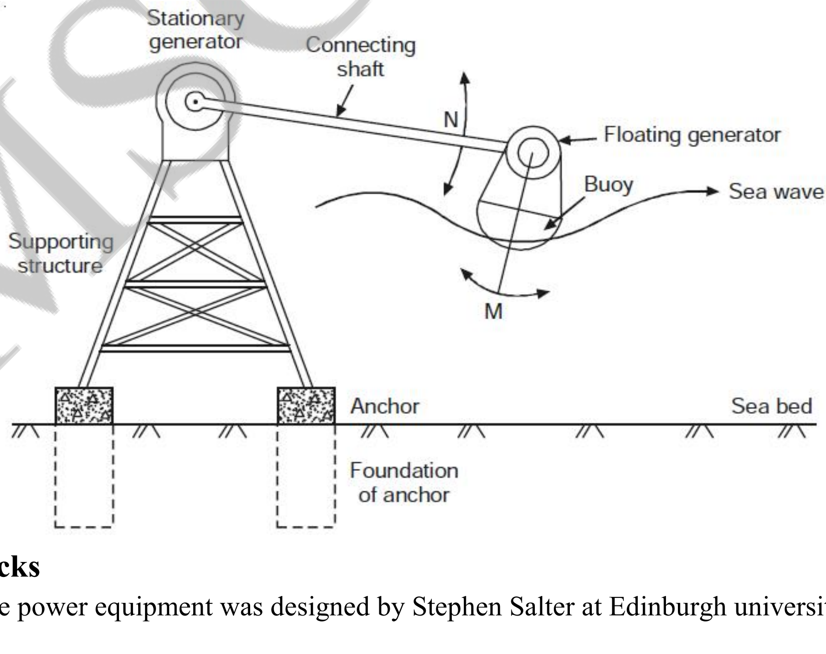
Oscillating buoy with a string, pulley and counterweight

Dolphin Type Wave Energy Generator

A supporting structure is built in the sea bed to provide a firm position for the equipment. The structure is erected on pile foundations. One generator is installed on the top of the structure which collects wave energy from the connecting shaft with rolling motion.

The gear arrangement with the stationary generator rotates the rotor to generate electric power. The buoy is at the other end of the connecting rod floats and has two motions, namely rolling motion and oscillatory motions represented by N and M respectively.

The floating generator collects wave energy from the buoy through a gear arrangement and continuously generates power.



Oscillating Ducks

This wave power equipment was designed by Stephen Salter at Edinburgh university in Scotland.

It is a float type wave energy conversion plant in which several duck-shaped devices (each 25 m long) are installed in a linear width-wise array along a line which is perpendicular to the direction of the wave.

The system consists of a long cylindrical spine of 15 m diameter on which cam shaped ducks are installed in an array to form an assembly

It responds to the incoming wave with a nodding action.