3RD SEMESTER ELECTRICAL ENGINEERING

RENEWABLE ENERGY POWER PLANTS TH-5

UNIT I: Solar PV and Concentrated Solar Power Plants

2 Marks Questions

1. **Q:What is solar radiation?**
   A: Solar radiation is the electromagnetic energy emitted by the sun, received on the Earth's surface in the form of sunlight and heat.
2. **Q:Define solar insolation**.
   A: Solar insolation is the amount of solar radiation received per unit area per unit time, usually measured in W/m² or kWh/m²/day.
3. **Q:What is the average solar radiation available in India?**
   A: India receives an average solar radiation of **4–7 kWh/m²/day** for about **300 sunny days** per year.
4. **Q:What is a solar map?**
   A: A solar map shows the intensity and availability of solar radiation across different regions of a country or the world.
5. **Q:Mention two states in India with high solar potential.**
   A: Rajasthan and Gujarat have high solar potential.

6 Q:What is the principle of a solar PV system?
A: It works on the **photovoltaic effect**, where sunlight is converted directly intoelectricity using semiconductor materials.

7 Q:Mention the main components of a PV power plant.
A: Solar panels, charge controller, inverter, battery bank, and distribution system.

8 Q:What type of current is produced by a solar panel?
A: Direct Current (DC).

9 Q:What is a rooftop solar PV system?
A: It is a solar power setup installed on the roof of buildings to generate electricity forlocal consumption or grid connection.

10. **Q:What is a Concentrated Solar Power (CSP) plant?**
    A: A CSP plant uses mirrors or lenses to concentrate sunlight onto a receiver, which converts it into heat to produce steam for driving a turbine.
11. **Q:Name four types of CSP technologies.**
    A: Power Tower, Parabolic Trough, Parabolic Dish, and Linear Fresnel Reflectors.
12. **Q: What is the working fluid used in CSP plants?**
    A: Typically, synthetic oil, molten salt, or steam is used as a working fluid.
13. **Q: State one advantage of CSP plants**.
    A: CSP plants can include thermal energy storage, allowing power generation even at night.

05 Marks Questions

1. **Q:Explain the layout of a solar PV power plant.**
   A:

Photovoltaic (PV) Panel

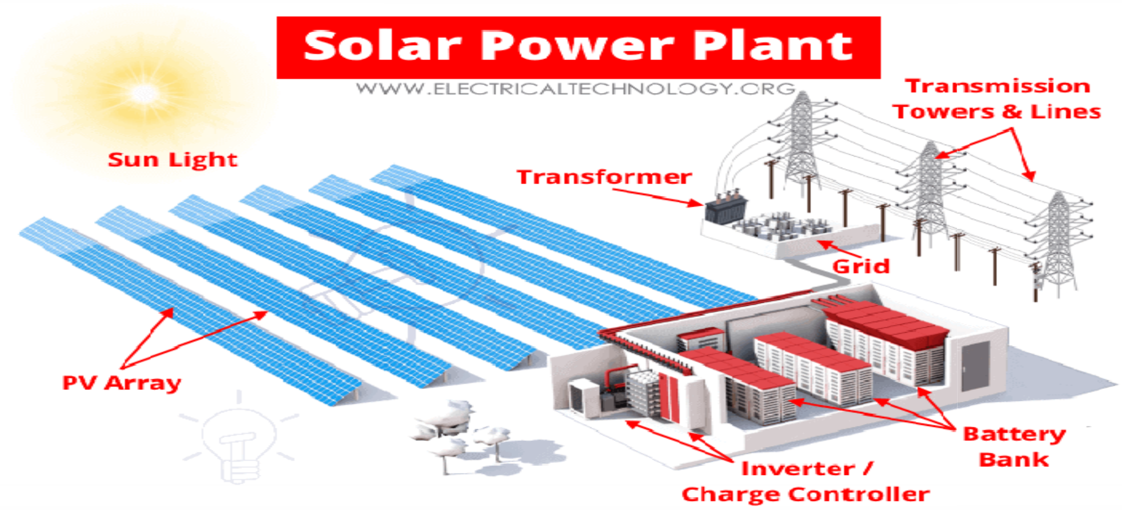
PV panels or Photovoltaic panel is a most important component of a solar power plant. It is made up of small solar cells. This is a device that is used to convert solar photon energy into electrical energy.

Generally, silicon is used as a semiconductor material in solar cells. The typical rating of silicon solar cells is 0.5 V and 6 Amp. And it is equivalent to 3 W power. The number of cells is connected in series or parallel and makes a module. The number of modules forms a solar panel. According to the capacity of po v er plants, a number of plates are mounted and a group of panels is also known as Photovoltaic (PV) array.

Inverter

The output of the solar panel is in the form of DC. The most of load connected to the power system network is in the form of AC. Therefore, we need to convert DC output power into AC power. For that, an **inverter** is used in solar power plants.

For a large-scaled grid-ti ɛ d power plant, the inverter is connected with special protective devices. And a transformer is also connected with the inverter to assu



res the output voltage and frequency as per the standard supply.

Energy storage devices

The batteries are used to store electrical energy generated by the solar power plants. The storage components are the most important component in a power plant to meet the demand and variation of the load. This comp onent is used especially when the sunshine is not available for few days.

The capacity of a battery is that how much amount of electrical power it can store. The capacity of batteries is measured in Ampere-hours (AH) rating.

Charge Controller

A charge controller is used to control the charging and discharging of the battery. The charge controller is used to avoid the overcharging of the battery. The overcharging of a battery may lead to corrosion and redu ce plate growth. And in the worst condition, it may damage the electrolyte of the battery.

Sometimes, the charge controller is termed a solar battery charger. There are many technologies used to make a charge controller. For example, the most popular technique is the MPPT charge controller that is known as "Maximum Power Point Tracking". This algorithm is used to optimize the production of PV cells.

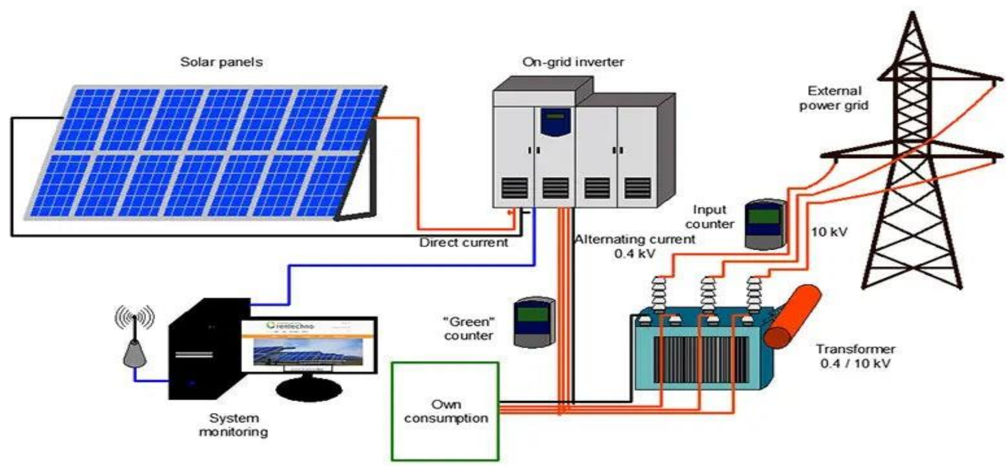
Blocking diode

The solar PV panels are connected with a battery. And these panels are used to charge the battery during sunlight is available. During charging of the battery, the current flows from panel to battery. But when the sunlight is not available, the current can be flow in a reverse direction and it may harm the solar panel. So, the blocking diode is a diode that is connected between the battery and panel to avoid reversal current from battery to panel.

Voltage regulator

The output of solar panels depends on sunlight. And the sunlight is not constantly available. It is continuously varying. Similarly, the output of the solar panel is also varying with respect to sunlight. This results in fluctuation in load current. The voltage regulators are used to maintain fluctuation within an acceptable range.

2. **Q:Describe the working of a rooftop solar PV system**.
   A:



A rooftop solar photovoltaic (PV) system is a solar power system with electricity-generating panels installed on a building's roof, consisting of solar panels, mounting structures, an inverter, and other electrical components. These systems convert sunlight into DC electricity, which is then converted to AC by an inverter to be used for power. Common types include grid-connected systems that feed excess power back to the grid, hybrid systems with battery backup, and off-grid systems that are not connected to the grid and rely entirely on batteries.

Components of a rooftop solar PV system

- **Solar PV modules:** The panels that convert sunlight into DC electricity.
- **Inverter (or PCU):** Converts the DC power from the panels into usable AC power.
- **Mounting structures:** The framework that secures the solar panels to the roof.
- **Cables:** Connect the various components of the system.
- **Energy meter:** Measures the electricity generated and/or consumed.
- **Protection equipment:** Devices for earthing, lightning, and surge protection.
- **Distribution boxes:** Boxes for distributing power (both AC and DC)

Types of systems

- **Grid-connected**:
  The most common type, connected to the electrical grid. Excess power can be sent to the grid for credit, and power can be drawn from the grid when solar production is low.
- **Hybrid**:
  A grid-connected system that also includes a battery backup. The battery provides power during grid outages.
- **Off-grid**:
  Not connected to the grid. These systems require a battery bank to store power for use when the sun isn't shining and are often used in remote areas.

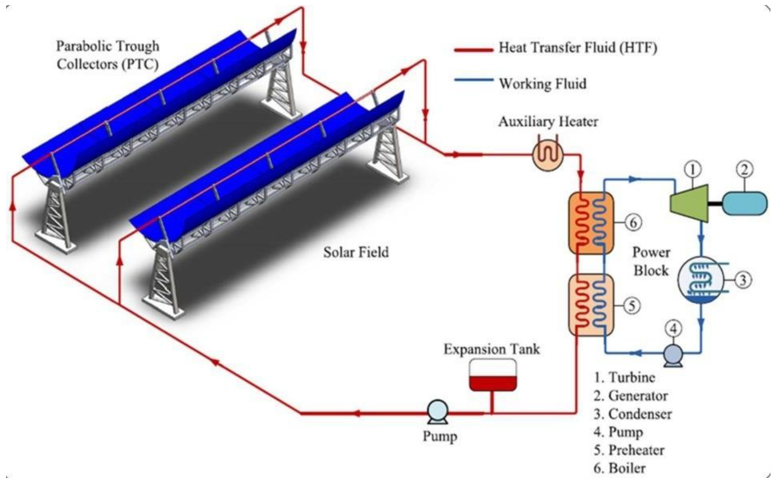
3 Q:Differentiate between on-grid and off-grid PV systems.

A:

Aspect	On-Grid Solar System	Off-Grid Solar System
Grid Connection	Connected to the electricity grid	Not connected to the grid
Energy Source at Night	Uses electricity from the grid when solar power isn't available	Uses energy stored in batteries
Battery Requirement	No batteries needed	Needs batteries to store solar power
Installation Cost	Less expensive	More expensive due to batteries and extra parts
Maintenance	Easier to maintain	Needs regular battery maintenance
Power Backup	Loses power during grid failures	Keeps running even during blackouts
Suitability	Ideal for cities with good grid access	Best for remote areas with no grid connection
Excess Energy Usage	Sends extra power to the grid and earns credits (net metering)	Stores extra power in batteries
System Size	Usually smaller and simpler	Often larger due to storage needs
Government Incentives	May benefit from net metering and subsidies	May have fewer subsidies or different incentives

Environmental Impact	Lower overall footprint	Uses more materials (batteries), so slightly higher impact
Energy Independence	Depends on the grid	Completely independent from the grid

4. Q:Explain the construction and working of a Parabolic Trough system.
A:



A parabolic trough system uses a parabolic reflector to focus direct sunlight onto a receiver tube running along its focal line, where a heat transfer fluid is heated to high temperatures (up to 550∘C). The system is constructed with a parabolic mirror, a receiver tube containing a heat transfer fluid, and a support structure, all mounted on a single-axis solar tracker to follow the sun throughout the day. The heated fluid is then used for industrial processes or to generate electricity.

Construction

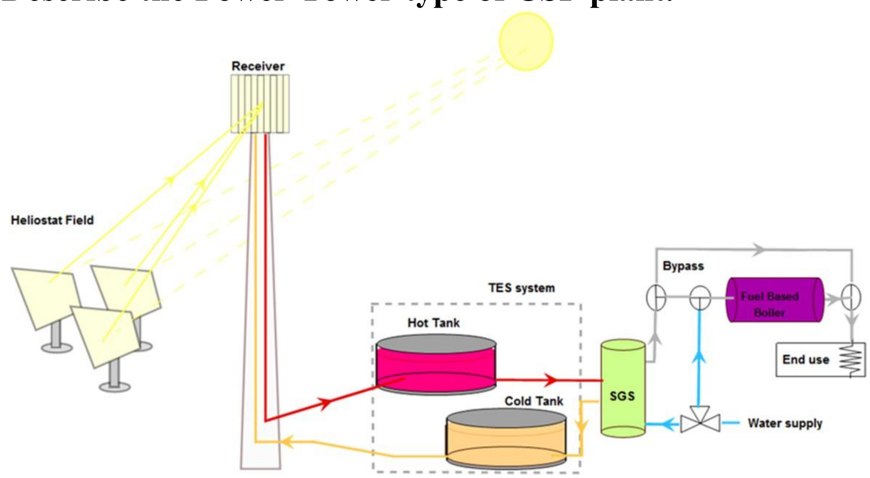
- **Parabolic reflector:** A large, curved mirror with a precise parabolic shape, typically made of a mirror-coated substrate mounted on an aluminum or steel frame. Its shape focuses sunlight onto a single focal line.
- **Receiver tube:** A tube that runs along the focal line of the parabola. It is often coated with a selective surface to absorb as much solar energy as possible and has a transparent glass cover to reduce heat loss to the environment.
- **Support structure:** A rigid frame that holds the reflector and receiver in place, providing stability against wind and other loads.
- **Tracking system:** A single-axis solar tracker that constantly adjusts the position of the parabolic trough to keep it pointed directly at the sun, maximizing the amount of sunlight captured.

Working

a. Sunlight strikes the parabolic reflector.
b. The reflector's shape causes the sunlight to be reflected and concentrated onto the narrow receiver tube located at the focal line.
c. A heat transfer fluid, such as synthetic oil or molten salt, circulates through the receiver tube.

d. The concentrated sunlight heats the fluid inside the tube to high temperatures.
e. The heated fluid is then pumped out of the collector and sent to a power block or industrial application. In power plants, this hot fluid is used to generate steam to drive a turbine and produce electricity.

5. Q:Describe the Power Tower type of CSP plant.



A:

Concentrated Solar Power (CSP) construction involves using mirrors to concentrate sunlight onto a receiver, while its working principle is to convert this concentrated light into heat, which then generates electricity. Key components include a collector (mirrors or heliostats), a receiver, a heat transfer fluid, and a power block with a turbine and generator. The concentrated heat can also be stored, allowing the plant to produce electricity even after sunset. Example: **Ivanpah Solar Power Facility (USA).**

Construction and components

- **Collectors:** Large fields of mirrors (heliostats) or parabolic dishes are used to reflect and concentrate sunlight onto a single point or line.
- **Receiver:** A receiver is positioned at the focal point of the collectors to absorb the concentrated solar energy. This receiver contains a heat transfer fluid.
- **Heat Transfer Fluid (HTF):** A fluid, such as oil, water, or molten salt, is heated in the receiver and circulates through the system.
- **Thermal Storage:** Some CSP plants include a storage system, often using tanks of molten salt, to store heat for later use.
- **Power Block:** This is the conventional power generation unit, typically a steam turbine connected to a generator. The hot fluid from the receiver (or the storage system) is used to produce steam, which drives the turbine.

Working principle

a) **Concentration:** The mirrors or heliostats are positioned to track the sun and focus sunlight onto a smaller area on the receiver.

b) **Heating:** The heat transfer fluid circulating through the receiver absorbs the intense solar energy and heats up to high temperatures.

c) **Heat transfer:** The superheated fluid is pumped to the power block.

d) **Electricity generation:** In the power block, the heat from the fluid is used to create steam, which turns a turbine. The spinning turbine drives a generator, producing electricity.

e) **Storage and discharge:** If the system has a storage system, the hot fluid can be directed there for later use. When needed, the stored heat is used to produce steam and generate electricity, enabling a continuous power supply even when the sun isn't shining.

6Q:List advantages and disadvantages of CSP plants.

A:

Advantages of CSP plants

- **Energy storage:** CSP can store thermal energy, allowing it to generate electricity even when the sun isn't shining, providing a more stable and reliable power source than solar photovoltaics (PV).
- **Clean energy:** CSP plants use a renewable energy source and do not emit carbon dioxide during operation, contributing to a reduction in greenhouse gas emissions.
- **Complementary to other renewables:** CSP can be hybridized with fossil fuels and can complement other renewable sources like wind and solar PV by providing power at different times, improving grid stability.
- **Flexible applications:** In addition to electricity, CSP can generate heat for industrial applications or be used to assist in oil recovery.
- **High efficiency:** CSP plants can achieve high energy efficiency, especially when using technologies like two-axis tracking,

Disadvantages of CSP plants

- **High costs:** CSP plants have a high upfront capital cost due to complex technology and expensive materials, and they are often more expensive to build than solar PV plants.
- **Large land requirements:** They require a significant amount of land, making them impractical for densely populated areas and potentially impacting local ecosystems.
- **High water consumption:** Traditional CSP designs require large amounts of water for cooling, which is problematic as they are best suited for arid regions where water is often scarce.
- **Location dependence:** Their efficiency is highly dependent on locations with strong, direct sunlight, limiting where they can be built.
- **Environmental impact on wildlife:** The concentrated light can attract and kill birds and other animals, and the construction and infrastructure can fragment habitats.
- **Complexity and maintenance:** The complex systems of mirrors and collectors require specialized, high-temperature materials and ongoing maintenance

7. Q: Explain the importance of the solar map of India.

A:

The importance of the solar map of India lies in its role in planning and developing the country's solar energy sector. It helps identify high-potential areas for solar development, supports government policy-making for renewable energy targets, guides investment decisions, and aids in designing and optimizing solar projects.

Key roles of the solar map

a. **Identifies high-potential areas**: Solar maps use data like solar irradiance to highlight regions that receive the most sunlight, allowing developers to pinpoint the best locations for solar power plants.
b. **Supports government policy**: The data helps the government set national and state-level renewable energy targets and design appropriate policies, including subsidies and incentives. The National Solar Mission, for example, aims to establish India as a global solar leader, and the solar map is a key tool for achieving this.
c. **Guides investment**: By showing which areas have the most reliable solar resources, the maps help investors and financial institutions direct capital toward regions with the highest potential for a return on investment.
d. **Aids project design**: Detailed maps provide essential input data for the precise design and performance assessment of solar technologies, such as photovoltaic systems. For instance, mapping solar potential on buildings can help identify the best surfaces for Building-Integrated Photovoltaics (BIPV).
e. **Enables resource assessment**: India's solar radiation atlases, like the one launched by the National Institute of Wind Energy (NIWE), provide detailed information on solar radiation resources across the country, supporting a wide range of solar energy activities.
f. **Helps track progress**: Maps detailing the commissioned and pipeline capacity of solar projects are used to monitor the growth of the sector at both the national and state levels, which is crucial for achieving long-term energy goals.

8. Q:Describe the global solar power radiation over India.

A: India receives abundant global solar radiation, with an average of 4–7 $kWh/m^2/day$ across most regions, totaling over 5,000 trillion kWh annually, equivalent to 2300–3200 hours of sunshine per year. The highest solar insolation is found in the northwest and inland peninsular regions, such as the Thar Desert, while the northeastern states receive less due to cloud cover.

This consistent solar energy makes India a prime location for solar power generation, though air pollution can reduce solar panel efficiency.

State	Total annual GHI ($kWh/m^2/year$)
Andhra Pradesh	1796
Delhi	1741
Gujarat	1797
Himachal Pradesh	1520
Karnataka	1809
Kerala	1866
Madhya Pradesh	1798
Maharashtra	1736
Manipur	1580
Meghalaya	1371
Odisha	1654
Rajasthan	1854
Tamil Nadu	1725
Telangana	1814
West Bengal	1491

Solar radiation intensity

- **Average:** India receives an average of 4–7 $kWh/m^2/day$ across most of the country, with annual sunshine hours ranging from 2300 to 3200.
- **Highest:** The highest solar radiation is concentrated in the northwest and inland peninsular regions, with some areas in Rajasthan exceeding 5.5–6.0 $kWh/m^2/day$.
- **Lowest:** Northeastern states, like Meghalaya and Arunachal Pradesh, experience lower levels due to increased cloud cover and rainfall.

Factors affecting solar radiation

- **Seasonality:** Solar radiation is generally highest during the pre-monsoon season and decreases during the monsoon period due to cloud cover.
- **Atmospheric conditions:** Increased atmospheric turbidity and cloudiness reduce the amount of solar radiation reaching the surface.
- **Air pollution:** Rising levels of air pollution, particularly suspended particulate matter, can scatter sunlight and reduce the efficiency of solar panels, especially in areas like the northwest.

10 Marks Question

Q1 :Explain the solar map of India and describe the global solar radiation distribution.

Answer: The solar map of India shows that most parts of the country receive abundant solar energy, with daily global horizontal irradiance (GHI) ranging from 4.0 to 7.0 kWh/m² and 2,500 to 3,200 sunny hours per year. Globally, solar radiation is highest in the tropics and subtropical deserts due to the angle of incidence, but it decreases towards the poles, with the equator receiving less than other tropical regions.

Solar map of India

- **Abundant potential**: India receives over 5,000 trillion kWh of solar energy annually, with an equivalent potential of about 6,000 million GWh.
- **Geographical variation**: While most of the country has a high solar potential, there are regional variations.
  - Western regions often receive higher daily GHI, around 7.0 kWh/m².
  - The north-eastern and hilly areas have lower daily GHI, around 4.0-5.0 kWh/m².
- **Sunny days**: Most of India experiences 250 to 300 clear, sunny days per year.
- **Diffuse irradiance**: The annual diffuse irradiance component is estimated to be between 25-30% in most Indian locations.

Global solar radiation distribution

- **High in tropics**: The highest levels of solar radiation are received in the tropics, particularly in subtropical deserts, due to a combination of high sun angles and lower cloud cover.
- **Decreases towards poles**: Solar radiation levels decrease significantly at higher latitudes as the sun's rays hit the Earth's surface at a lower angle.
- **Equator vs. tropics**: The equator receives less sunlight than the surrounding tropical regions because the sun is directly overhead for only part of the year, and the more direct, overhead sunlight of the tropics is more intense.
- **Land vs. water**: At the same latitude, land areas generally receive more solar radiation than ocean areas.
- **Seasonal variation**: Higher latitudes receive much less solar radiation during winter compared to summer.

Solar radiation intensity

- **Average:** India receives an average of 4–7 kWh/m²/day across most of the country, with annual sunshine hours ranging from 2300 to 3200.
- **Highest:** The highest solar radiation is concentrated in the northwest and inland peninsular regions, with some areas in Rajasthan exceeding 5.5–6.0 kWh/m²/day.
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Factors affecting solar radiation

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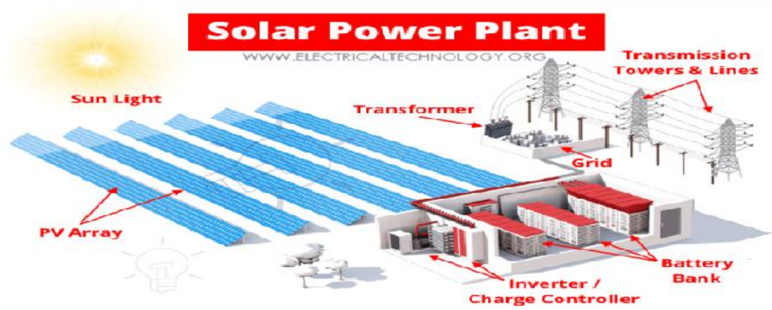
- **Air pollution:** Rising levels of air pollution, particularly suspended particulate matter, can scatter sunlight and reduce the efficiency of solar panels, especially in areas like the northwest.

2. Q:Explain the construction, components, and working of a solar PV power plant with neat layout diagram.And also write the advantages and applications. Answer:



Photovoltaic (PV) Panel

PV panels or Photovoltaic panel is a most important component of a solar power plant. It is made up of small solar cells. This is a device that is used to convert solar photon energy into electrical energy.

Generally, silicon is used as a semiconductor material in solar cells. The typical rating of silicon solar cells is 0.5 V and 6 Amp. And it is equivalent to 3 W power. The number of cells is connected in series or parallel and makes a module. The number of modules forms a solar panel. According to the capacity of power plants, a number of plates are mounted and a group of panels is also known as Photovoltaic (PV) array.

Inverter

The output of the solar panel is in the form of DC. The most of load connected to the power system network is in the form of AC. Therefore, we need to convert DC output power into AC power. For that, an **inverter** is used in solar power plants.

For a large-scaled grid-tied power plant, the inverter is connected with special protective devices. And a transformer is also connected with the inverter to assures the output voltage and frequency as per the standard supply.

Energy storage devices

The batteries are used to store electrical energy generated by the solar power plants. The storage components are the most important component in a power plant to meet the demand and variation of the load. This component is used especially when the sunshine is not available for few days.

The capacity of a battery is that how much amount of electrical power it can store.

The capacity of batteries is measured in Ampere-hours (AH) rating.

Charge Controller

A charge controller is used to control the charging and discharging of the battery. The charge controller is used to avoid the overcharging of the battery. The overcharging of a battery may lead to corrosion and reduce plate growth. And in the worst condition, it may damage the electrolyte of the battery.

Sometimes, the charge controller is termed a solar battery charger. There are many technologies used to make a charge controller. For example, the most popular technique is the MPPT charge controller that is known as "Maximum Power Point Tracking". This algorithm is used to optimize the production of PV cells.

Blocking diode

The solar PV panels are connected with a battery. And these panels are used to charge the battery during sunlight is available. During charging of the battery, the current flows from panel to battery. But when the sunlight is not available, the current can be flow in a reverse direction and it may harm the solar panel. So, the **blocking diode** is a diode that is connected between the battery and panel to avoid reversal current from battery to panel.

Voltage regulator

The output of solar panels depends on sunlight. And the sunlight is not constantly available. It is continuously varying. Similarly, the output of the solar panel is also varying with respect to sunlight. This results in fluctuation in load current. The voltage regulators are used to maintain fluctuation within an acceptable range.

Grid Integration / Storage:

The electricity is either supplied to the **utility grid** or used to **charge batteries** in standalone systems.

Monitoring & Control:

System performance is continuously monitored, and safety devices ensure stable and protected operation.

Advantages

- Renewable and pollution-free
- Low operating cost
- Scalable and modular
- Suitable for remote/off-grid areas.

Applications

- Residential rooftop systems
- Solar farms
- Remote telecommunication stations
- Water pumping systems.

3. Q: Discuss advantages, disadvantages, and applications of solar PV systems.

Answer

Solar PV systems have advantages like being a renewable, eco-friendly energy source with low operating costs, but face disadvantages such as high initial investment, intermittency depending on sunlight, and space requirements. Their applications range from small-scale residential use and remote power to large utility-scale power plants.

Advantages

- **Renewable and clean energy:** Sunlight is an abundant, inexhaustible resource, and PV systems produce no greenhouse gas emissions or pollutants during operation.
- **Low operating and maintenance costs:** After the initial installation, maintenance is minimal (e.g., occasional cleaning), and there are no fuel costs.
- **Energy independence:** Solar PV can reduce reliance on the grid and fossil fuels, especially in remote areas where grid connections are difficult.
- **Scalability:** Systems can be installed in various sizes, from small rooftop installations to large power plants.
- **Silent operation:** PV panels operate without any noise pollution.

Disadvantages

- **High initial cost:** The upfront investment for equipment and installation can be significant, though costs have decreased significantly over time.
- **Intermittent power source:** Energy generation is dependent on sunlight, meaning output is reduced on cloudy days and nonexistent at night.
- **Space requirements:** A significant amount of land or roof space is needed to generate a large amount of electricity.
- **Energy storage costs:** To provide power when sunlight isn't available, batteries or other storage systems are required, which adds to the overall expense.
- **Environmental impact of manufacturing:** The manufacturing and recycling of solar panels require energy and can involve hazardous materials, creating an environmental footprint.

Applications

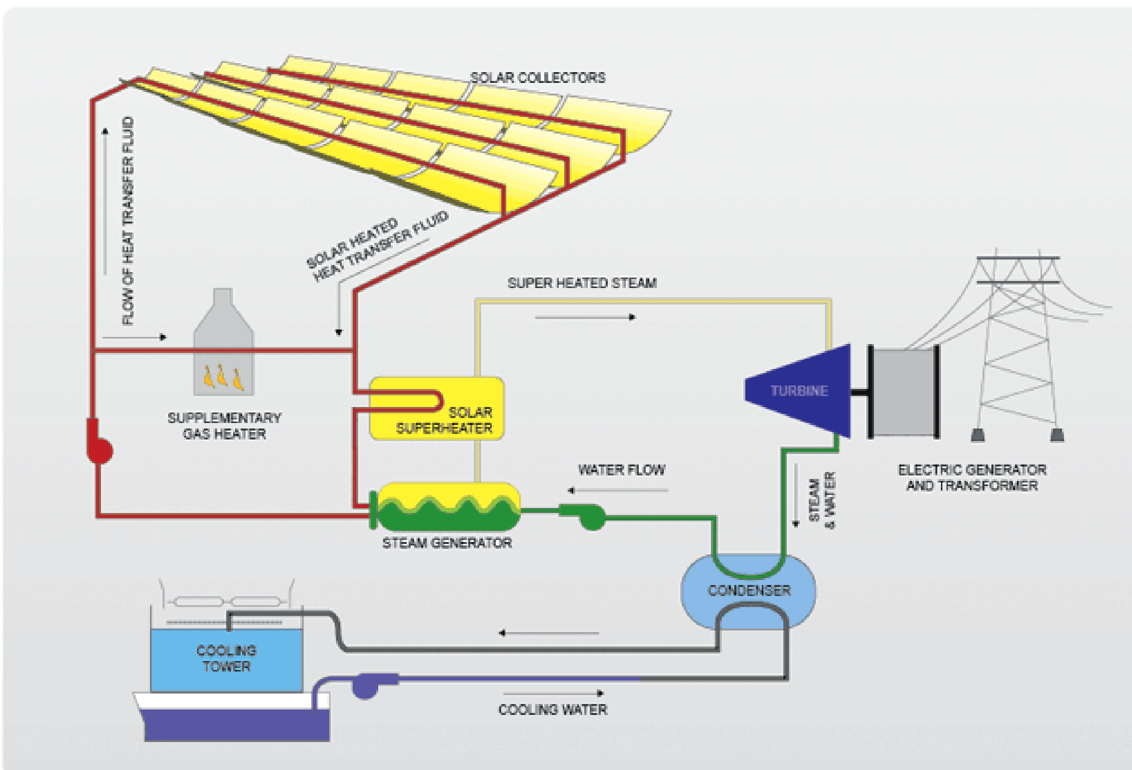
- **Residential:** Rooftop solar panels to power homes, reduce electricity bills, and provide energy independence.
- **Commercial and industrial:** Large-scale rooftop systems or ground-mounted plants for businesses to lower energy costs and meet sustainability goals.
- **Utility-scale power plants:** Large solar farms that feed electricity directly into the national grid, comparable to traditional power plants.
- **Remote and off-grid locations:** Powering homes, villages, and infrastructure in areas without access to a traditional electrical grid.
- **Transportation and infrastructure:** Powering solar-powered vehicles, street lights, and traffic signals.
- **Agriculture:** Running solar pumps for irrigation.

4. Q: With neat diagrams, explain the construction and working of any two types of CSP systems.
Answer Outline:

Concentrated Solar Power (CSP) systems use mirrors or lenses to concentrate a large area of sunlight into a small area, where the concentrated light is converted to heat. This thermal energy is then used to generate electricity via a conventional steam turbine.

Two primary types of CSP systems are the **Parabolic Trough System** and the **Solar Power Tower System** (or Central Receiver System).

a. Parabolic Trough System



Construction

A parabolic trough system consists of long, U-shaped (parabolic) mirrors or reflectors, typically arranged in parallel rows across a large area known as the collector field. A receiver tube, often covered with a glass envelope to reduce heat loss, runs along the focal line of each parabolic mirror.

The entire assembly typically uses a single-axis tracking system to follow the sun's movement from east to west during the day, ensuring the sunlight is continuously focused onto the receiver tube.

Working Principle

i. **Concentration:** The curved parabolic mirrors reflect and concentrate the direct normal irradiance (DNI) from the sun onto the receiver tube at the focal line.

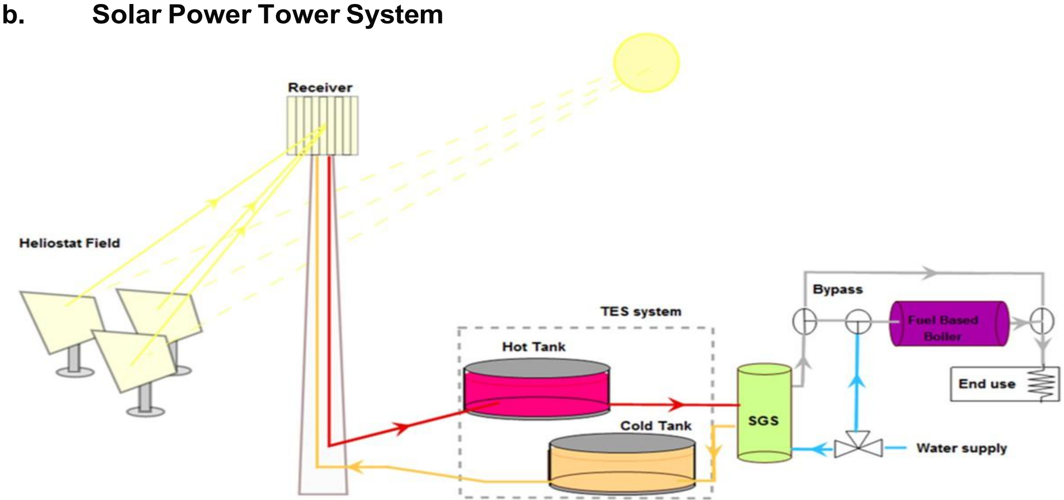
ii. **Heat Transfer:** A heat transfer fluid (HTF), such as thermal oil or molten salt, flows through the receiver tube and is heated to high temperatures, typically between 150°C and 400°C.

iii. **Steam Generation:** The hot HTF is circulated to a central power block where it passes through a series of heat exchangers. This heat transfers to water, producing high-pressure, superheated steam.

iv. **Power Generation:** The steam drives a conventional steam turbine connected to a generator, which produces electricity.

v. **Cycle Completion:** The spent steam is condensed and pumped back to the heat exchangers to repeat the cycle. Thermal energy storage systems (using molten salt tanks) can be integrated to store excess heat for use during the night or on cloudy days.

b. Solar Power Tower System



Construction

A power tower system (also known as a central receiver system) uses a field of large, flat, sun-tracking mirrors called **heliostats**, which surround a tall, central tower. A receiver is located at the top of this tower. Each heliostat has its own dual-axis tracking mechanism, controlled by a computer, to reflect sunlight precisely onto the receiver.

Working Principle

i. **Concentration:** Thousands of heliostats focus a large amount of solar energy onto the central receiver atop the tower.

ii. **Heat Transfer:** A heat transfer medium (often molten salt, but sometimes water/steam, liquid sodium, or air) inside the receiver absorbs the highly concentrated solar radiation, heating up to very high temperatures (typically 565°C to over 1000°C).

iii. **Steam Generation:** The heated fluid (e.g., hot molten salt from a "hot" storage tank) generates high-pressure steam in a heat exchanger located at the base of the tower.

iv. **Power Generation:** This high-temperature, high-pressure steam drives a steam turbine/generator to produce electricity.

v. **Energy Storage:** The major advantage of this system is its high temperature and ability to store thermal energy efficiently in large molten salt tanks, enabling the plant to generate electricity 24/7 or on demand, even without direct sunlight.

5. Q What is PV Cell and Explain the Construction & working principle of PV Cell.

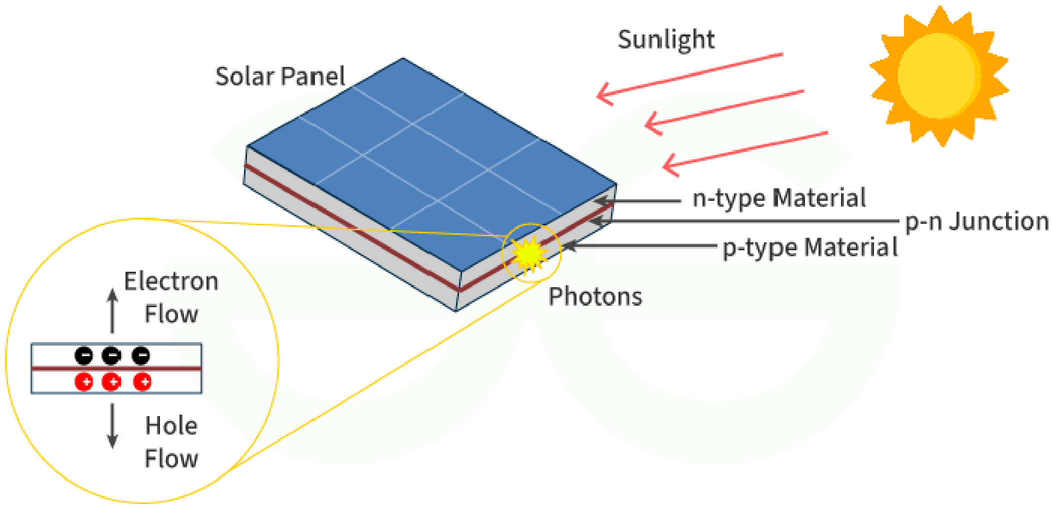
Ans :

A photovoltaic cell is a specific type of PN junction diode that is intended to convert light energy into electrical power. These cells usually operate in a reverse bias environment. Photovoltaic cells and solar cells have different features, yet they work on similar principles.

Construction of Photovoltaic Cell

The construction of a photovoltaic cell involves several key components and materials. A detail of such components and method is discussed below:

- **Semiconductor Material:** Photovoltaic cells are typically made from silicon, a semiconductor material that has the ability to absorb photons of sunlight and release electrons. **Silicon** is chosen for its availability, stability, and efficiency in converting sunlight into electricity.
- **P-N Junction:** The basic structure of a PV cell involves a P-N (positive-negative) junction. This junction is created by doping the silicon with specific impurities. The P side is doped with a material that introduces positive charge carriers (holes), while the N side is doped with a material that introduces negative charge carriers (electrons).
- **Absorption Layer:** Above the P-N junction, there is a thin layer known as the absorption layer. This layer is crucial for capturing photons from sunlight. When photons strike the absorption layer, they energize electrons, causing them to break free from their atomic bonds.
- **Metal Contacts:** Metal contacts are placed on the top and bottom surfaces of the PV cell to allow the flow of electrons. The metal contacts form an electrical circuit, capturing the freed electrons and providing a pathway for them to be utilized as electrical power.
- **Antireflection Coating:** To enhance the absorption of sunlight, an antireflection coating is often applied to the surface of the PV cell. This coating minimizes the reflection of sunlight, ensuring that more photons penetrate the cell and contribute to the generation of electricity.
- **Encapsulation:** Photovoltaic cells are often encapsulated to protect them from environmental factors such as moisture and mechanical stress. Encapsulation materials can include glass or transparent plastics that allow sunlight to reach the cell while providing a protective barrier.
- **Back Surface Field:** Some advanced PV cells may incorporate a back surface field to enhance the collection of electrons and improve overall efficiency.



Photovoltaic Cell

Working of Photovoltaic Cell

The working principle of a photovoltaic (PV) cell involves the conversion of sunlight into electricity through the photovoltaic effect. Here's how it works:

- **Absorption of Sunlight:** When sunlight (which consists of photons) strikes the surface of the PV cell, it penetrates into the semiconductor material (usually silicon) of the cell.
- **Generation of Electron-Hole Pairs:** The energy from the absorbed photons is transferred to electrons in the semiconductor material, allowing them to break free from their atomic bonds and create electron-hole pairs. Electrons are negatively charged and move freely, while the holes are positively charged.
- **Separation of Charges:** Due to the built-in electric field within the PV cell (created by the junction between different semiconductor layers), the newly generated electron-hole pairs are separated. Electrons are pushed towards the n-type (negative) side of the cell, while holes are pushed towards the p-type (positive) side.
- **Flow of Electrons:** The separated electrons are collected by metal contacts on the surface of the cell, forming an electric current. This current can be harnessed for external use.
- **External Load:** When an external electrical load (such as a light bulb or a battery) is connected to the PV cell, the flow of electrons through the load generates electrical power, which can be used to power various devices or stored in batteries for later use.

As long as sunlight is available, the photovoltaic cell continues to generate electricity through this process, providing a sustainable and renewable source of energy.

UNIT 2 – LARGE WIND POWER PLANTS

2 Marks Questions

1. **Q:What is wind power density?**
   A: Wind power density is the amount of power available in the wind per unit area, expressed in watts per square meter (W/m^2).
2. **Q:Define lift and drag forces.**
   A:
   - **Lift:** Force acting perpendicular to the wind direction.
   - **Drag:** Force acting parallel to the wind direction.
3. **Q:What is the unit of wind power density?**
   A: It is measured in **W/m^2** (watts per square meter).
4. **Q:What is meant by a wind map?**
   A: A wind map shows the distribution of average wind speeds and wind power density over different regions of a country.
5. **Q:Mention any two states with high wind potential in India**.
   A: Tamil Nadu and Gujarat.
6. **Q:What is the function of a gearbox in a wind turbine?**
   A: A gearbox increases the low rotational speed of the turbine shaft to a higher speed suitable for the generator.
7. **Q:What is a direct drive wind turbine?**
   A: A direct drive wind turbine eliminates the gearbox and connects the rotor directly to a low-speed generator.
8. **Q:Mention two advantages of direct drive turbines**.
   A: High reliability and reduced maintenance.
9. **Q:Name two main components common to all wind turbines.**
   A: Rotor blades and generator.
10. **Q:What is a constant-speed generator?**
    A: A generator that operates at a nearly constant speed irrespective of wind variation.
11. **Q:Name two types of constant speed wind generators.**
    A: Squirrel Cage Induction Generator (SCIG) and Wound Rotor Induction Generator (WRIG).
12. **Q:Why are induction generators commonly used in wind turbines?**
    A: They are robust, low-cost, and self-protective during grid faults.
13. **Q:What type of excitation does an induction generator require?**
    A: It requires reactive power excitation from the grid or capacitors.
14. **Q:What is a variable speed generator?**
    A: A generator that can operate efficiently over a range of rotor speeds depending on wind velocity.
15. **Q:Name any two types of variable speed generators**.
    A: DFIG (Doubly Fed Induction Generator) and PMSG (Permanent Magnet Synchronous Generator).
16. **Q:What does DFIG stand for?**
    A: Doubly Fed Induction Generator.
17. **Q:What is the advantage of variable speed operation?**
    A: It improves energy capture and reduces mechanical stress.

05 Marks Questions

1 Q: **Explain the importance of the wind map of India**.

A: The wind map of India is a crucial tool for **identifying, assessing, and strategically planning the utilization of wind resources** across various sectors, most notably renewable energy and structural engineering. Its importance spans economic, environmental, and safety domains.

Key Importance and Applications

a. <u>Renewable Energy Development</u>

- **Site Selection:** The maps, developed by agencies like the National Institute of Wind Energy (NIWE), help identify optimal locations for wind farm installation by highlighting areas with high wind power potential (e.g., coastal areas in Gujarat, Tamil Nadu, and Maharashtra).
- **Potential Assessment:** High-resolution wind atlases provide data on wind speeds at various altitudes (100m, 120m, 150m) to estimate the total installable wind power potential, enabling policymakers and investors to make informed decisions and set realistic targets.
- **Resource Planning:** By quantifying available wind resources, the maps facilitate long-term energy planning, helping India transition to a sustainable energy system, reduce dependence on fossil fuels, and enhance energy security.
- **Investment Certainty:** The data reduces investment risk for private developers by offering greater certainty about a project's viability, leading to lower project costs and expedited development.
- **Hybrid Systems:** Wind maps also show co-location opportunities for wind-solar hybrid projects, optimizing the use of renewable energy resources for better grid stability.

b. <u>Structural Design and Safety</u>

- **Building Codes:** The wind speed maps are incorporated into the Indian Standard (IS:875 Part-3) which provides guidelines for the design of buildings and structures.
- **Design Basis:** They specify basic wind velocities and risk zones based on historical data and return periods (e.g., 50 years) to ensure structures can withstand extreme wind events, including cyclonic storms.
- **Hazard Mitigation:** The maps help identify cyclone-prone coastal areas, allowing for specialized building requirements and preparedness plans in high-risk zones.

c. <u>Environmental and Meteorological Studies</u>

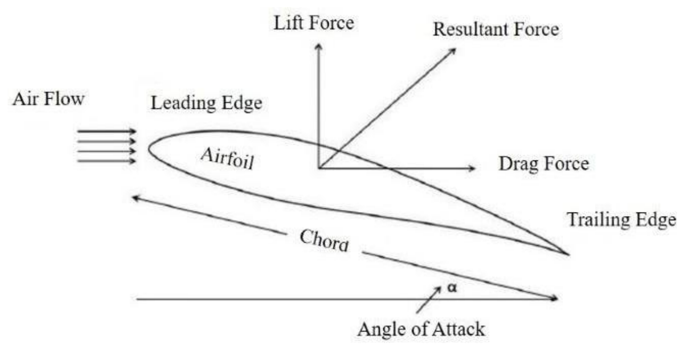
- **Air Quality:** Wind roses and wind direction data are used in environmental studies to understand prevailing wind patterns, which are crucial for assessing the dispersion of pollutants from industrial sites and urban areas.
- **Climate Monitoring:** The maps contribute to ongoing meteorological research, helping scientists monitor climate patterns and predict harsh weather conditions.

In essence, the wind map of India is a foundational resource that supports the nation's energy transition goals, ensures the safety and resilience of infrastructure, and aids in vital environmental planning.

- Helps identify areas with high wind energy potential.
- Aids in site selection for wind farms.
- Assists in planning and investment decisions.
- Encourages state-level renewable energy policies.
- Promotes optimal use of wind resources.

2. Q: Explain the principle of wind energy conversion using lift and drag.

A:



- Wind energy is converted into mechanical energy by wind turbine blades.
- **Lift Force:** Created due to pressure difference across the blade surfaces, causes rotation.
- **Drag Force:** Acts opposite to motion, should be minimized.
- Lift-type turbines (like modern wind turbines) are more efficient than drag-type.

Wind turbines use the principle of lift and drag to convert the wind's kinetic energy into rotational energy, which then drives a generator to produce electricity. The turbine's blades, shaped like an airplane wing, create lift as wind flows over them, causing the rotor to spin. Lift is a force perpendicular to the wind's direction that is stronger than the drag, the force parallel to the wind.

How it works

- **Lift and drag creation**: The airfoil shape of the blade causes air to travel faster over one side than the other, which creates a pressure difference. This difference generates both lift (pulling the blade forward) and drag (pushing against the wind).
- **Rotation**: The lift force is greater than the drag force, and this imbalance creates a net force that causes the rotor to spin.
- **Electricity generation**: The spinning rotor is connected to a shaft and a gearbox, which increases the rotation speed to a level suitable for a generator. The generator then converts this rotational mechanical energy into electrical energy.

- **Efficiency**: The design of the blade's airfoil is crucial for efficiency. A high lift-to-drag ratio is ideal, meaning the lift force is maximized while drag is minimized. This is achieved through careful design and by controlling the blade's angle of attack.

3. Q: Derive the expression for wind power density.

Step 1: Energy in Moving Air

The **kinetic energy** of air moving with velocity v is:

$$E = \frac{1}{2}mv^2$$

where

- m = mass of air (in kilograms),
- v = wind speed (in meters per second).

Step 2: Rate of Energy Flow (Power)

Power is the rate at which energy passes through an area A:

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt}v^2$$

Step 3: Mass Flow Rate

The **mass flow rate** $\frac{dm}{dt}$ is the amount of air (mass) passing through area A per second:

$$\frac{dm}{dt} = \rho A v$$

where

- ρ = air density ($\approx$ 1.225 kg/m^3 at sea level),
- A = cross-sectional area the wind passes through (m^2).

Step 4: Substitute Mass Flow Rate

Plug this into the power expression:

$$P = \frac{1}{2}(\rho A v)v^2 = \frac{1}{2}\rho A v^3$$

✅ Step 5: Fundamental Formula for Wind Power

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

This represents the **total power available** in the wind passing through an area A.

The **formula for wind power density** is given by:

$$\textbf{Power Density (P)} = 1/2 \times \rho \times A \times v^3$$

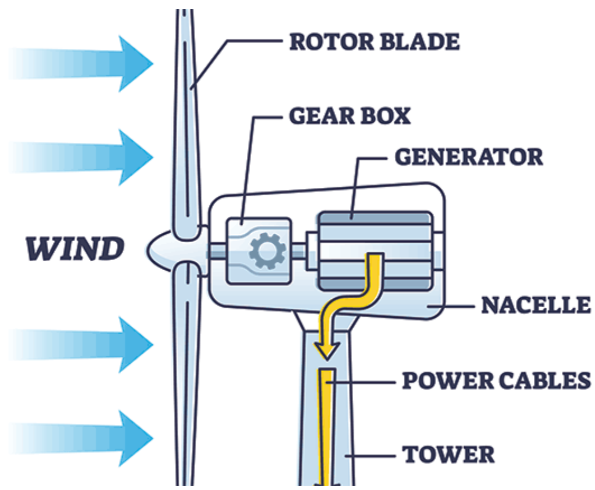
Where:

ρ (rho) = density of air (kg/m^3)
A = cross-sectional area of the wind (m^2)
v = wind velocity (m/s)

This formula calculates the power available in the wind, which is essential for understanding win d energy potential.

4. Q:Explain the working of a geared type wind power plant.

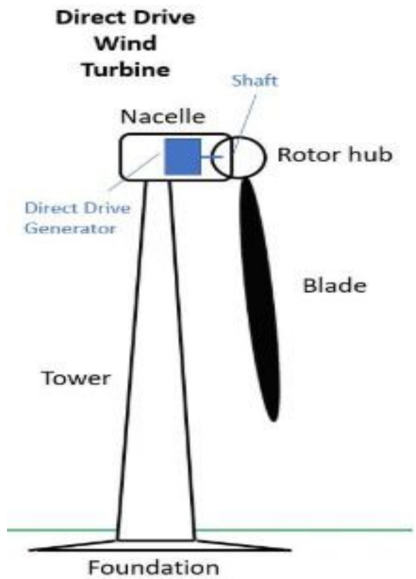
A:



A geared wind turbine converts wind's kinetic energy into electricity by using a gearbox to increase the speed of a rotor's rotation to a rate that a generator can use. Wind pushes the turbine's blades, which turn a low-speed shaft. This shaft connects to a gearbox, which uses a system of gears to drastically increase the rotational speed, and the now fast-spinning shaft spins a generator. The generator then produces electricity, which can be sent to the grid or stored in batteries.

a. **Wind captures energy:** Wind blows and pushes the large blades of the turbine.
b. **Rotor and low-speed shaft turn:** The force of the wind causes the blades to rotate, which turns the rotor and the connected low-speed shaft.
c. **Gearbox increases speed:** The low-speed shaft is connected to a gearbox that uses gears to significantly increase the speed of rotation, converting low-speed, high-torque rotation into high-speed, low-torque rotation.
d. **Generator is powered:** The high-speed shaft coming out of the gearbox spins the generator.
e. **Electricity is produced:** The generator converts this mechanical energy into electrical energy.
f. **Power is transmitted:** This electricity is then sent to the power grid for use or to batteries for storage.

6. Q: Describe the construction and working of a direct drive wind turbine.
A:



A direct drive wind turbine converts wind energy into electricity by eliminating the gearbox, so the rotor is connected directly to a low-speed generator. The main components include the rotor (blades and hub), a direct-drive generator, and a tower. The construction involves mounting the blades on a hub, which connects directly to a large-diameter, low-speed generator housed in a nacelle atop a tall tower; the generator uses the rotor's slow rotation to produce electricity, which is then sent to the power grid.

Construction

- **Rotor:** Consists of large blades attached to a central hub. The blades are aerodynamically shaped to capture wind energy and cause the rotor to spin.
- **Nacelle:** The housing at the top of the tower that contains the generator, control systems, and other equipment. In a direct drive system, it specifically contains the large, low-speed generator.
- **Generator:** A large-diameter, low-speed generator. Unlike geared turbines, this generator is directly coupled to the rotor's shaft, meaning it spins at the same speed as the blades. It typically consists of a stator with coils and a rotor with permanent magnets.
- **Tower:** The structure that supports the nacelle and rotor. The tower's height is crucial, as wind speed increases with altitude, allowing taller towers to capture more energy.

Working

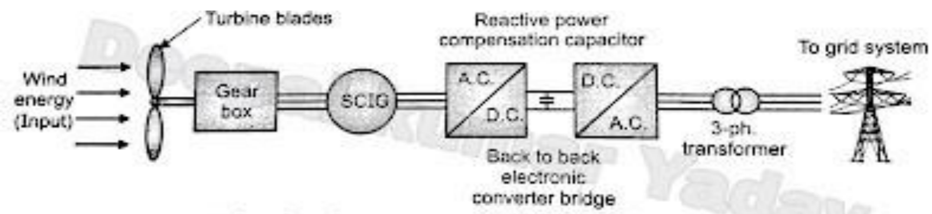
i. **Energy capture:** Wind blows across the blades, creating a pressure difference that makes them spin.
ii. **Direct mechanical coupling:** The spinning blades turn the rotor hub and shaft at a relatively low speed (e.g., 15-20 rpm).
iii. **Direct drive generation:** The shaft is connected directly to the large-diameter generator, so the generator's rotor also turns at this low speed.
iv. **Electricity production:** The motion of the rotor magnets passes through the stator coils, inducing an alternating voltage and producing electricity.

v. **Power transmission:** The generated electricity travels through cables down the tower to a transformer and then to the power grid.

vi. **Control systems:** During operation, control systems monitor wind speed and may adjust the blade pitch or use electromagnetic braking to regulate the rotor speed and prevent damage from high winds.

7. Q: Explain the working of a Squirrel Cage Induction Generator (SCIG) used in wind turbines.

A:



Block Diagram of Squirrel Cage Induction Generator (SCIG)

A Squirrel Cage Induction Generator (SCIG) in a wind turbine converts wind energy into electrical energy by spinning faster than the grid's synchronous speed. The wind turns the turbine blades, which spin the generator's rotor. This rotor speed must exceed the synchronous speed to force the generator into a power-producing state, after which it produces electricity and feeds it into the grid. The SCIG requires external reactive power for excitation, which is often supplied by a capacitor bank.

How it works

- **Mechanical input:** The wind rotates the turbine's rotor blades, which are connected to the generator's rotor shaft.
- **Rotor and magnetic field:** The generator's stator is connected to the grid, which creates a rotating magnetic field.
- **Generating mode:** To generate electricity, the wind must spin the rotor faster than this rotating magnetic field. This difference in speed is called "negative slip".
- **Electrical output:** This "negative slip" induces currents in the rotor bars, creating a torque that opposes the wind's rotation, pushing the rotor and the generator's output into the grid.
- **Grid connection:** The SCIG is directly connected to the grid, which forces its speed to be very close to the synchronous speed.
- **Reactive power compensation:** Induction generators consume reactive power to operate. To avoid this and improve power factor, a capacitor bank is installed to provide the necessary reactive power.
- **Fixed-speed operation:** Because the generator is directly connected to the grid, its speed is nearly constant and can only vary slightly above synchronous speed.
- **Wind fluctuations:** When wind speed fluctuates, the rotor speed changes slightly, and the output power also fluctuates with the wind.

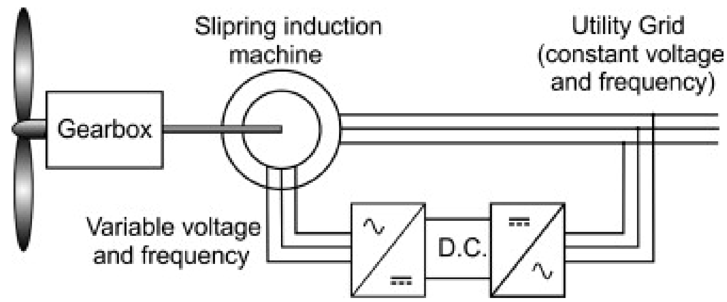
8. Q: State differences between SCIG and WRIG.
A:

Feature	Squirrel Cage Induction Generator (SCIG)	Wound Rotor Induction Generator (WRIG)
Complexity	Simpler and more robust, with a solid rotor made of bars.	More complex due to the rotor windings and slip rings.
Speed Operation	Traditionally fixed-speed, though can be adapted for variable speed with a full-scale converter.	Primarily used for variable-speed operation, providing better control over the generator.
Controllability	Limited; speed variations are restricted by slip.	Higher, as external resistance can be added to the rotor circuit to adjust speed and power output.
Maintenance	Lower maintenance due to the simple, robust rotor design.	Higher maintenance requirements due to the brushes and slip rings on the rotor.
Cost	Lower initial cost.	Higher initial cost.

10 Marks Questions

01 Q: Explain the working of a Doubly Fed Induction Generator (DFIG).

A:



A Doubly Fed Induction Generator (DFIG) generates power by using both its stator and rotor windings, which are connected to the grid. The stator connects directly to the grid, while the rotor is connected via a partial-scale back-to-back converter. This converter allows control over the rotor's speed, frequency, and active and reactive power by manipulating the rotor's electrical current. This system enables the turbine to operate efficiently over a range of wind speeds by controlling the slip and adjusting the rotor's magnetic field to match the grid frequency.

How it works

i. **Stator connection**: The stator windings of the DFIG are directly connected to the power grid, providing a constant frequency and voltage supply.

ii. **Rotor connection**: The rotor has three-phase windings and is connected to the grid through a back-to-back converter. This converter is comprised of a rotor-side converter and a grid-side converter.

iii. **Power generation**: As wind turns the turbine blades, the rotor spins. This rotation induces a current in the rotor windings, creating a rotating magnetic field. This field interacts with the stator's magnetic field, generating torque and producing electricity.

iv. **Speed control**: The converter controls the rotor's speed relative to the grid's synchronous speed. By adjusting the frequency and magnitude of the rotor current, the system can:

   a) **Operate at sub-synchronous speeds**: The rotor is slower than synchronous speed, and the rotor-side converter draws active power from the grid to supplement the mechanical power.

   b) **Operate at super-synchronous speeds**: The rotor is faster than synchronous speed, and the rotor-side converter feeds active power back to the grid.

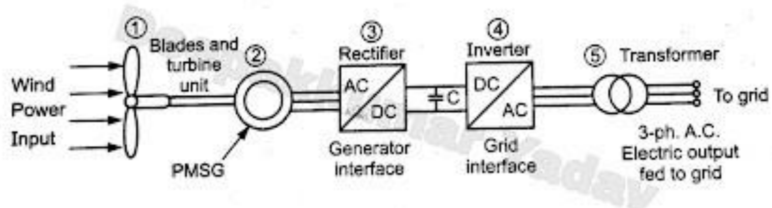
Grid integration:

a. The rotor-side converter controls the rotor's power exchange with the grid.

b. The grid-side converter handles the power flow between the rotor-side converter and the grid, ensuring a stable and constant frequency output to the grid.

c. The two converters work together to ensure that the DFIG provides consistent power at the grid's standard frequency, regardless of fluctuations in wind speed.

02 Q: **Describe the working of a Permanent Magnet Synchronous Generator (PMSG).**



Block Diagram of Permanent Magnet Synchronous Generator

A:

Main Components of a Permanent Magnet Synchronous Generator

A **Permanent Magnet Synchronous Generator (PMSG)** converts **mechanical energy** from a prime mover (like a wind turbine rotor) into **electrical energy** using **permanent magnets** on the rotor instead of field windings.

a. Rotor (with Permanent Magnets)

- The rotor carries permanent magnets made of materials like NdFeB (Neodymium-Iron-Boron) or SmCo (Samarium-Cobalt).
- These magnets create a constant magnetic field — eliminating the need for external excitation.
- Types:
  - Surface-mounted rotor – magnets fixed on rotor surface.
  - Interior-mounted rotor – magnets embedded inside the rotor core.

b. Stator

- Stationary part of the generator.
- Contains three-phase armature windings placed in stator slots.
- When the rotor's magnetic field rotates past the stator, alternating voltage (AC) is induced in the windings.

c. Shaft

- Connects the mechanical prime mover (e.g., wind turbine rotor) to the generator rotor.
- Transmits mechanical energy for conversion into electrical energy.

d. Bearings

- Support the rotor and allow smooth rotation with minimal friction.
- Maintain alignment between the rotor and stator.

e. Frame / Housing

- Provides mechanical support and protection to internal components.
- Ensures heat dissipation and structural rigidity.

f. Cooling System (Optional)

- Used in large PMSGs to remove heat generated in stator windings and rotor.
- May be air-cooled or liquid-cooled.

Working in short of Permanent Magnet Synchronous Generator :

- Wind power rotates rotor of wind turbine, it rotates rotor of permanent magnet type synchronous generator. The field of rotor rotates with rotor and stator stationary coils cut the flux of rotor magnet and emf Is Induced in stator coils.
- Rectifier/ Inverter unit converts variable voltage and variable frequency output into constant frequency (50-60 Hz) and constant magnitude voltage. This stable voltage from stator goes to grid circuit to connect the power from this wind power station to grid system.

Advantages of Permanent Magnet Synchronous Generator :

- Construction is simple.
- It is robust.
- Cheaper In cost.
- No excitation system is required (as permanent magnets).
- High frequency.
- Low loss.
- No gear box is needed.
- Power converters regulate voltage and active and reactive power flow.
- Power factor is controlled.

Disadvantages of Permanent Magnet Synchronous Generator :

- Difficulty of non-availability of large size permanent magnets, so useful for small/ medium size wind power plants only.
- Possibility of de-magnetisation permanent magnet.
- Complicated structural dynamics.
- Need cooling system to maintain temperatures within limits.

03 :Write differences between DFIG and PMSG.

Feature	**Doubly Fed Induction Generator (DFIG)**	**Permanent Magnet Synchronous Generator (PMSG)**
Generator Type	Wound rotor induction generator	Permanent magnet synchronous generator
Converter	Partial-power converter (20–30% of rated power)	Full-rated back-to-back converter
Gearbox	Typically requires a gearbox	Can be direct-driven (gearless)
Maintenance	Higher maintenance due to slip rings and brushes	Lower maintenance due to brushless design
Efficiency	Less efficient due to gearbox and slip rings, but good efficiency within its operating range	High efficiency due to direct-drive potential and lack of gearbox and brushes
Cost	Lower initial cost due to partial-power converter	Higher initial cost due to the full-rated converter and permanent magnets
Grid Control	Can control power factor	Offers more complete control over both real and reactive power
Fault Ride-Through (FRT)	More complex to implement, especially during grid faults	Better grid fault ride-through capability
Feature	DFIG	PMSG
Rotor	Wound with slip rings	Permanent magnets

UNIT – III Small Wind Turbine (HAWT)

2 Marks Questions

1. **What is a horizontal axis small wind turbine?**
Ans: A horizontal axis small wind turbine (HAWT) has blades that rotate around a horizontal axis parallel to the wind direction. It resembles a traditional windmill and is commonly used for small-scale power generation.

2. **What is the function of a gearbox in a wind turbine?**
Ans: The gearbox increases the rotational speed of the turbine shaft to match the required speed of the generator for electricity production.

3. **What is a vertical axis wind turbine?**
Ans: A vertical axis wind turbine (VAWT) has blades that rotate around a vertical axis, allowing it to capture wind from any direction.

4. **Name two common types of vertical axis turbines**.
Ans: Darrieus type and Savonius type.

5. **What is the main advantage of a vertical axis wind turbine?**
Ans: It can accept wind from any direction and does not require yaw control.

6. **Name two types of generators used in small wind turbines.**
Ans: (i) Permanent Magnet Synchronous Generator (PMSG)
(ii) Induction Generator

7. **Why are permanent magnet generators preferred in small wind systems?**
Ans: They offer high efficiency, compact size, and require no external excitation.

8. **What is the function of a generator in a wind turbine?**
Ans: It converts mechanical rotational energy from the turbine shaft into electrical energy.

9. **What are the types of towers used for small wind turbines?**
Ans:

i. Guyed tower: Supported by guy wires; economical and lightweight.
ii. Free-standing (monopole) tower: No guy wires, suitable for small spaces.
iii. Tilt-up tower: Can be lowered for maintenance.
iv. Lattice tower: Steel frame construction offering rigidity.

10. **What is the main disadvantage of geared vertical axis turbines?**
Ans: They have higher mechanical losses and require more maintenance due to moving parts.

(5 Marks Questions)

1. **Explain the working of a Permanent Magnet Synchronous Generator (PMSG) used in small wind turbines.**
   Answer:

A **Permanent Magnet Synchronous Generator (PMSG)** is commonly used in **small wind turbines** because of its high efficiency and brushless operation.

Working Principle:

- The **rotor** of the PMSG has **permanent magnets** that create a constant magnetic field.
- The **stator** has a three-phase winding where electricity is generated.
- When **wind blows**, it rotates the **turbine blades**, which are directly coupled to the **rotor shaft**.
- As the rotor turns, the **magnetic field** from the permanent magnets **cuts the stator conductors**, inducing an **alternating voltage** according to **Faraday's law of electromagnetic induction**.
- The **frequency** of the generated voltage depends on the **rotor speed** and **number of poles**:

$$f=(N\times P)/120$$

where f= frequency, N= speed in rpm, P = number of poles.

Power Conversion:

- The generated voltage is **variable in frequency and amplitude** due to changing wind speed.
- Hence, the output is passed through **power electronic converters (rectifier and inverter)** to produce a **stable AC supply** for use or grid connection.

Advantages:

- No external excitation (uses permanent magnets).
- High efficiency and reliability.
- Compact, lightweight, and requires low maintenance.

2. **Compare PMSG and Induction Generators.**
   Ans:

Feature	PMSG	Induction Generator
Excitation	Permanent magnets	Requires external or self-excitation
Efficiency	High	Moderate
Cost	Higher	Lower
Maintenance	Low	Moderate
Applications	Small/standalone systems	Grid-connected systems

3. **List and explain the components of a vertical axis small wind turbine.**
   Ans:

Main Components and Their Functions:

i. Rotor Blades:
   - Capture the kinetic energy of the wind and convert it into rotational motion.
   - Common types: Savonius (drag type) and Darrieus (lift type).
   - Made of lightweight materials like fiberglass or aluminum.

ii. Rotor Shaft:
   - Connects the blades to the generator.
   - Transfers mechanical rotational energy from the rotor to the generator.

iii. Generator (Alternator or PMSG):
   - Converts mechanical energy from the rotor shaft into electrical energy.
   - In small turbines, a Permanent Magnet Synchronous Generator (PMSG) is often used.

iv. Support Tower / Mast:
   - Holds the rotor assembly at a suitable height to capture wind efficiently.
   - Provides mechanical support and stability to the turbine.

v. Base and Bearings:
   - The base anchors the turbine to the ground or roof.
   - Bearings reduce friction and allow smooth rotation of the rotor.

vi. Optional Components:
   Controller: Regulates voltage and current output.
   Battery / Inverter: Stores and converts generated power for use.

4. **Explain the components of a direct drive horizontal axis small wind turbine.**
   Ans:
   A Direct-Drive Horizontal Axis Wind Turbine (HAWT) has a horizontal rotor shaft facing the wind and is directly coupled to the generator, eliminating the need for a gearbox. It is widely used in small-scale wind power systems for its simplicity and high efficiency.

Main Components and Their Functions:

i. Rotor Blades:
   - Aerodynamically shaped blades that capture wind energy and convert it into rotational mechanical energy.
   - Usually made of lightweight materials like fiberglass or carbon fiber.

ii. Hub:
   - Connects the rotor blades to the shaft.
   - Transmits the rotational motion from the blades to the main shaft.

iii. Main Shaft (Rotor Shaft):
   - Transfers mechanical power directly from the rotor to the generator (no gearbox in direct-drive design).
   - Simplifies construction and reduces energy loss.

iv. Generator (PMSG or Synchronous Generator):
   - Converts the mechanical rotation from the shaft into electrical energy.
   - In direct-drive systems, Permanent Magnet Synchronous Generators (PMSGs) are commonly used for high efficiency.

v. Nacelle and Tower:
   - Nacelle: Houses the generator, shaft, and control components, protecting them from weather.
   - Tower: Supports the nacelle and blades at a height where wind speed is higher and more consistent.

5. **Differentiate between direct drive and geared type horizontal axis small wind turbines.**
Answer:

Feature	Direct Drive	Geared Type
Transmission	Direct coupling between rotor and generator	Gearbox between rotor and generator
Maintenance	Low	High
Efficiency	High at low speeds	Moderate
Cost	Higher initial cost	Relatively lower
Applications	Small-scale systems	Medium-scale systems

(10 Marks Question)

1. What is Horizontal Axis Wind Turbine : Working & Its Applications

Ans:

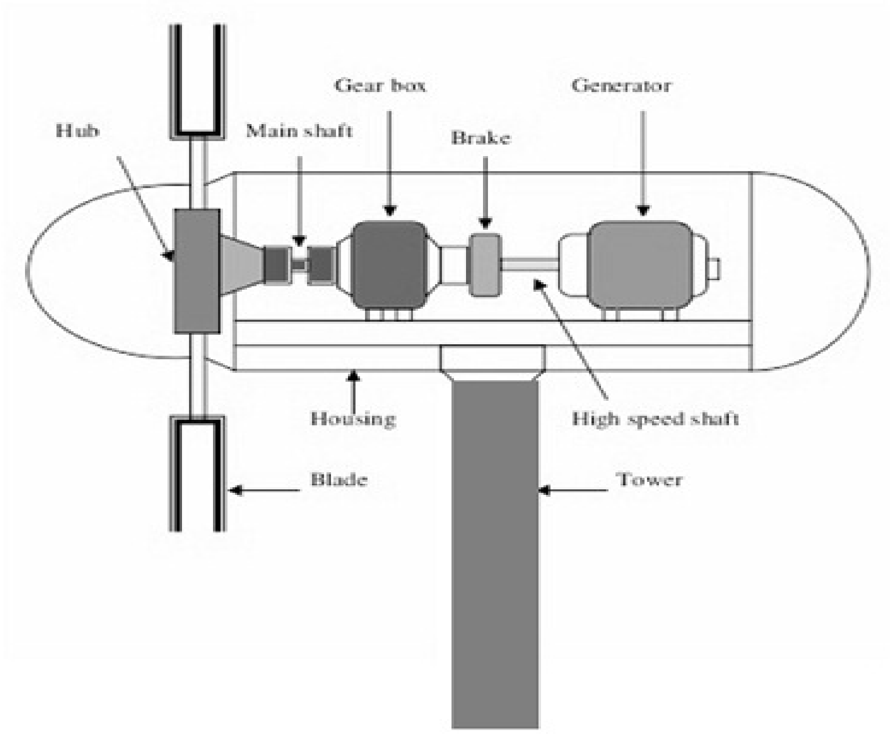
A wind turbine is a rotating mechanical device, used to change wind energy from kinetic to electrical. These are available in different sizes with either vertical or horizontal axes. The wind turbine is an essential device in a wind power station or wind park. So, the selection of this turbine for the development of wind park projects can be done based on different parameters like physical dimensions, nominal power, available area, wind potential, etc. Wind turbines are available in two types like **horizontal axis wind turbine** & vertical axis wind turbine. This article gives an overview of a horizontal axis wind turbine.

Horizontal Axis Wind Turbine

Horizontal Axis Wind Turbine Construction and Working

The construction of a horizontal axis wind turbine can be done with different components. So the horizontal axis wind turbine components mainly include foundation, nacelle, generator, tower, and rotor blades.
Horizontal axis wind turbines include the rotor shaft & electric generator which are arranged at the top of the tower. Small wind turbines use a simple wind vane, whereas larger wind turbines use wind sensors that are connected through an auxiliary motor. Most wind turbines contain a

gearbox, which is used to change the blade rotation from slow to fast, so used to operate an electric generator.



Construction of HAWT

Foundation

For any wind turbine, the foundation gives support to the tower because the wind turbine includes different parts which weigh in tonnes.

Tower

A tower is used to give support to the rotor hub and nacelle on the top of the window turbine. The materials used to make this are concrete, tubular steel, or steel lattice. While designing this turbine, the height of the tower is very important because wind speed enhances with height. So taller towers allow these turbines to capture a huge amount of energy & produce more electricity.

Generally, the output power of a wind turbine enhances by increasing its height & also decreasing the turbulence within the wind. There are different wind turbine towers available like tubular, lattice, guyed wind, tilt upwind & free standing.

Wind Turbine Blades

These blades are mainly used to remove the kinetic energy (KE) of wind & change it to mechanical energy. These types of blades are designed with wood-epoxy or fiberglass-reinforced polyester. These turbines include a minimum of one and maximum multiple blades depending on the design.

Most of the horizontal axis wind turbines include three blades that are connected to the rotor hub. In earlier days, multiple blades based turbines are used as a single blade, two-blade and three blades for grinding & pumping water, etc.

Nacelle

The nacelle includes different components which are used to operate the wind turbine efficiently like the gearbox, brakes, controller, low & high-speed shafts & generator. It is arranged at the top of a tower & a wind vane is arranged on the nacelle.

Hub

A rotor hub is used to connect a shaft and rotor blade of the wind turbine. The hub includes blade bearings, bolts, internals & a pitch system. These are designed with cast iron, welded sheet steel & forged steel. These are available in two types like Hinge-less hub & Teetering hub.

Gear Box

In wind turbines, a gearbox is used to change high toque power with low-speed which is received from a rotor blade to low torque power with high speed. This power is used for the generator. The gearbox is connected in between the generator and main shaft for enhancing rotational speeds from 30 – 60 rpm to 1000 – 1800 rpm.

Gearboxes are made with different materials like superior quality alloys, aluminum cast iron, stainless steel, etc. In wind turbines, there are three types of gearboxes are used like Planetary, Helical, and Worm.

Generator

The rotating mechanical energy of the gearbox is given to the generator through the shaft. It works on 'Faraday's law of electromagnetic induction principle. So it changes the energy from mechanical to electrical.

Horizontal Axis Wind Turbine Working

Once the wind blows, a wind turbine changes the kinetic energy from the motion of the wind into mechanical through the revolution of the rotor. After that, this converted energy can be transmitted through the shaft & the gear train toward the generator. Further, this generator converts the energy from mechanical to electrical to generate electricity.

The wind flows on both faces of the airfoil-shaped blade although flows faster on the upper face of the airfoil to create a low-pressure region on the airfoil. The pressure difference between both the top & bottom surfaces results within the aerodynamic lift.

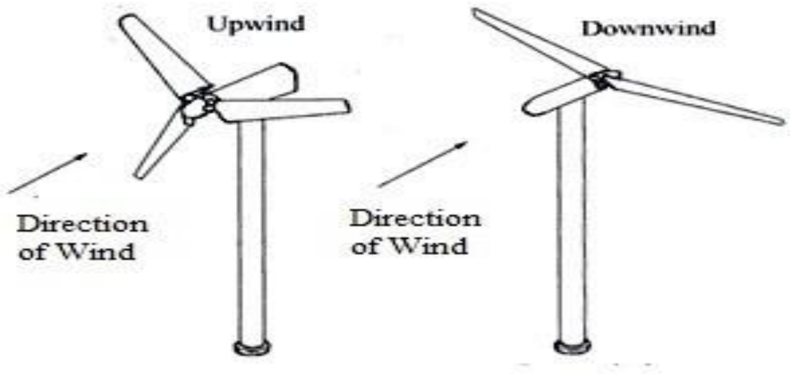
As the blades of a wind turbine are constrained to move in a plane with the hub as the center, the lift force causes rotation about the hub. In addition to the lift force, a drag force perpendicular to the lift force prevents rotor rotation.

The horizontal axis wind turbine design mainly includes a high lift to drag ratio, especially for the blades. So this ratio can change through the blade's length to optimize the output energy for the wind turbine at different speeds of wind. The generator & rotor shaft are arranged within the box at the top of the array.

Horizontal Axis Wind Turbine Types

The horizontal axis wind turbines are available in two types like the following.

- Upwind Turbine
- Downwind Turbine



Types of Horizontal Axis Wind Turbines
Upwind Turbine

In an upwind wind turbine, the rotor is arranged at the upside of the tower. The main function of this turbine is to avoid the shadow of wind on the backside of the tower. At present, this design is used in most HAWTs because it is nonflexible & arranged at some distance from the tower.

Downwind Turbine

In a downwind turbine, the rotor is arranged at the downside of the tower. In this turbine, firstly the wind is faced toward the tower, then to the blades of the rotor. This wind turbine faces some differences within wind power because of the passage of the rotor through the wind shade of the tower. Here, the rotor is behind the nacelle of the tower which causes fluctuations within wind power.

Advantages and Disadvantages

The advantages of a horizontal axis wind turbine include the following.

- It includes high output power as compared to the vertical wind turbine.
- A tall tower gets stronger winds once the wind shear alters.
- High efficiency.
- It is not expensive as compared to vertical type turbine.
- It has high reliability.
- It has a high rate of capacity.
- Its rotational speed is high.
- It is more consistent.
- These turbines are self-starting.
- In this turbine, the vanes are located one face of the turbine center of gravity, which improves stability.
- It can bend the blades so that the turbine blades have the best attack angle.
- The blade can also tilt the rotor during a storm to reduce damage

The disadvantages of horizontal axis wind turbine include the following.

- These are available in large size.
- Weight is high.
- We cannot move easily.
- Installation is difficult.
- High noise.
- To design this wind turbine, large machinery is needed.
- Its maintenance is difficult as compared to other wind turbines.

Applications

The applications of horizontal axis wind turbines include the following.

- These are the most frequently used wind turbines for commercial and industrial purposes due to their large power output and high efficiency.
- These are mostly used in wind farms

- Horizontal axis wind turbines achieve better power output & higher energy efficiency, so used in large-scale wind power plants & also for electricity generation.
- In industrial plants, large-scale wind farms, or national projects, these wind turbines are most frequently seen. So they are the perfect solution for the production of mass electricity.

2. Describe various types of electric generators used in small wind power plants and explain their advantages, disadvantages, and suitability.

Answer:

Types of Electric Generators Used in Small Wind Power Plants

Small wind power plants (up to about 100 kW) use different types of electric generators depending on the design, speed range, and control system. The main types are:

i. Permanent Magnet Synchronous Generator (PMSG)

Working Principle:
A PMSG uses permanent magnets on the rotor to produce a constant magnetic field. The stator has windings where AC voltage is induced when the rotor spins with the wind turbine.

Advantages:

- High efficiency (no field winding losses)
- Compact and lightweight design
- Suitable for **direct-drive** systems (no gearbox)
- Better performance at low wind speeds

Disadvantages:

- High initial cost due to rare-earth magnets
- Difficult to control voltage and frequency variations
- Demagnetization risk at high temperature

Suitability:
Ideal for **small and medium-sized direct-drive wind turbines** where low maintenance and high efficiency are required.

ii. Induction Generator (Asynchronous Generator)

There are two types — **Squirrel Cage Induction Generator (SCIG)** and **Wound Rotor Induction Generator (WRIG).**

Working Principle:
It works on the principle of electromagnetic induction; the rotor current is induced by the stator's rotating magnetic field. It requires an external reactive power source (capacitor bank or grid).

Advantages:

- Rugged and low-cost construction
- Simple and reliable operation
- Self-protection against short circuits and overloads

Disadvantages:

- Needs external excitation (not self-excited unless capacitors used)
- Lower efficiency than synchronous machines
- Not suitable for variable speed without power electronic converters

Suitability:
Used in **small grid-connected wind turbines** or **stand-alone systems** with capacitor excitation.

iii. Doubly Fed Induction Generator (DFIG)

Working Principle:
Both stator and rotor are connected to electrical circuits; the rotor is fed through slip rings and a variable frequency converter allowing variable speed operation.

Advantages:

- Variable-speed operation with constant frequency output
- Reduced converter size (30% of rated power)
- High efficiency and power factor control

Disadvantages:

- Complex construction and control
- Requires slip rings (higher maintenance)
- Not preferred for very small turbines due to cost

Suitability:
Common in **medium to large wind turbines (50 kW and above)** but less used in small systems.

iv. DC Generator (Permanent Magnet DC or Separately Excited)

Working Principle:
A rotating armature cuts the magnetic field, inducing DC voltage directly or after rectification.

Advantages:

- Simple construction
- Easy voltage regulation
- Suitable for battery charging applications

Disadvantages:

- Brushes and commutator require frequent maintenance
- Lower efficiency
- Not suitable for large-scale or grid-tied systems

Suitability:
Used in **very small wind turbines** for **battery charging** or **remote power supply** (off-grid).

Comparison Table:

Type	Efficiency	Cost	Maintenance	Speed Range	Typical Use
PMSG	High	High	Low	Variable	Direct-drive small turbines
SCIG	Moderate	Low	Low	Fixed	Grid-connected small turbines
DFIG	High	Moderate	Medium	Variable	Medium turbines
DC Generator	Low	Low	High	Fixed	Battery charging

UNIT-IV BIOMASS-BASED POWER PLANTS

02 Marks Questions

1. **What is biomass?**
   Ans: Biomass is organic material derived from plants and animals that can be used as a renewable source of energy.
2. **Give two examples of solid biomass fuels.**
   Answer: Bagasse and rice husk.
3. **What is biodiesel?**
   Ans: Biodiesel is a **mono-alkyl ester of long-chain fatty acids** produced through a chemical process called **transesterification**, in which oil or fat reacts with an alcohol (usually methanol) in the presence of a catalyst (like NaOH or KOH) to produce **biodiesel and glycerin.**
4. **What is gobar gas?**
   Ans: Gobar gas is biogas produced from the anaerobic digestion of cattle dung, rich in methane and carbon dioxide.
5. **What is the basic principle of a biochemical-based biomass power plant?**
   Ans:A biochemical-based biomass power plant works on the principle of **energy conversion through biological processes**, where **microorganisms (bacteria, fungi, or enzymes)**break down**organic matter (biomass)** such as agricultural waste, animal manure, or food waste to produce **biogas** or other biofuels. This **biogas** (mainly methane, CH_4, and carbon dioxide, CO_2) is then **burned to produce heat and electricity.**
6. **Name the main gas produced in a biogas plant.**
   Ans:The main gas produced in a biogas plant is Methane (CH_4).
7. **What is thermo-chemical conversion?**
   Ans: The **thermo-chemical conversion** is a process in which **biomass or organic materials** are converted into **useful fuels, gases, or chemicals** by applying **heat and chemical reactions.**

   In this process, the **chemical energy stored in biomass** is released or transformed through **high-temperature reactions**, often in the **presence or absence of oxygen**.

8. **Give two example of a thermo-chemical process.**
   Ans: Two examples of **thermo-chemical processes** are:

i. **Gasification** – Conversion of biomass into a **combustible gas mixture (producer gas)** by heating it at high temperature (700–1000°C) with **limited supply of oxygen or air**.
   - **Main products:** Carbon monoxide (CO), hydrogen (H_2), methane (CH_4).

ii. **Pyrolysis** – Decomposition of biomass by **heating in the absence of oxygen** (300–600°C) to produce **bio-oil, syngas, and charcoal**.
   - **Main products:** Bio-oil (liquid fuel), syngas (gas), and biochar (solid).

9. **What is the main raw material for agro-chemical-based biodiesel plants?**
   Ans: The **main raw material** for **agro-chemical-based biodiesel plants** is **vegetable oil** obtained from **oil-bearing crops** such as **Jatropha, Soybean, Sunflower, Mustard, or Palm oil.**
10. **What is the by-product of biodiesel production?**
    Answer: The **main by-product** of **biodiesel production** is **Glycerin (Glycerol).**

During the **transesterification process**, vegetable oil or animal fat reacts with alcohol (usually methanol) in the presence of a catalyst (NaOH or KOH) to produce:

- Biodiesel (Fatty acid methyl esters) — main product
- Glycerin ($C_3H_8O_3$) — by-product

11. **List the main units of a municipal solid waste-based power plant.**
    Answer:
    i. Waste collection and segregation unit
    ii. Shredder and drying unit
    iii. Combustion/gasification chamber
    iv. Boiler and turbine
    v. Generator and control system
12. **List the main units in a biodiesel (agro-chemical-based) power plant.**
    Answer:
    i. Feedstock preparation (oil extraction)
    ii. Transesterification reactor
    iii. Separation and washing unit
    iv. Drying unit
    v. Storage tank and engine-generator

5 Marks Questions

1. **State the properties of Jatropha oil as a biomass fuel.**
   Ans:

Properties of Jatropha Oil as a Biomass Fuel

Jatropha oil is a non-edible vegetable oil obtained from the seeds of the *Jatropha curcas* plant. It is widely used as a raw material for biodiesel production due to its favorable fuel properties.

i. Calorific Value:
- About 39–41 MJ/kg, which is comparable to diesel fuel.
- Indicates good energy content for combustion and power generation.

ii. Viscosity:
- Higher than diesel (about 40–50 cSt at 40°C).
- High viscosity can cause poor atomization in engines, so it is often converted into biodiesel to reduce viscosity.

iii. Density:
- Around 0.91–0.93 g/cm^3, slightly higher than diesel.
- Provides good fuel handling and energy storage characteristics.

iv. Flash Point:
- High flash point (around 240°C), making it safe to store and handle compared to petroleum diesel.

v. Sulfur Content:
- Very low (<0.02%), hence environment-friendly, producing less SO_2 emissions during combustion.

vi. Carbon Residue:
- Moderate carbon residue; complete combustion possible when used as biodiesel.

2. **Compare biodiesel and gobar gas.**
Ans:

Property	**Biodiesel**	**Gobar Gas**
State	Liquid	Gas
Source	Vegetable oil (e.g., Jatropha)	Animal waste (cow dung)
Calorific Value	~37–40 MJ/kg	~20–23 MJ/m^3
Production Process	Transesterification	Anaerobic digestion
Use	Engines, generators	Cooking, electricity generation

3. **List the properties of bagasse as a biomass fuel.**
Ans:

Properties of Bagasse as a Biomass Fuel
Bagasse is the fibrous residue left after extracting juice from sugarcane. It is widely used as a biomass fuel in sugar mills and cogeneration plants.

i. Moisture Content:
- Typically 40–50% (depending on drying).
- High moisture lowers its calorific value, so drying improves combustion efficiency.

ii. Calorific Value:
- Around 7,000–9,000 kJ/kg (7–9 MJ/kg) on a wet basis.
- Moderate heating value suitable for boiler fuel in sugar industries.

iii. Volatile Matter:
- Approximately 45–55%.
- Indicates good combustibility and ease of ignition.

iv. Ash Content:
- Low, around 1–3%, meaning less residue after burning and less pollution.

v. Density:
- Bulk density ranges between 100–200 kg/m^3, depending on compaction and moisture.
- Low density requires larger storage space.

vi. Composition:
- Mainly composed of cellulose (≈45%), hemicellulose (≈28%), and lignin (≈20%), which contribute to its fuel value.

4. **Compare wood chips and municipal solid waste as biomass fuels.**
Answer:

Property	Wood Chips	Municipal Waste
Source	Forest residue	Urban waste
Moisture	15–30%	30–50%
Calorific Value	3500–4000 kcal/kg	1500–2500 kcal/kg
Ash Content	Low	High
Pollution	Low	High (needs control)

5. **List the main components of a biogas power plant**.
Ans:

Main Components of a Biogas Power Plant
A biogas power plant converts organic waste into biogas (mainly methane) through anaerobic digestion and then uses it to generate electricity and heat. The main components are as follows:
i. Biomass Feedstock Storage Unit:

- Stores organic materials such as cow dung, agricultural waste, or food waste before feeding into the digester.
- Ensures a steady and uniform supply of feedstock.

ii. Anaerobic Digester (Fermentation Tank):

- The heart of the plant, where microorganisms decompose biomass in the absence of oxygen.
- Produces biogas (mainly CH_4 and CO_2) and slurry (digestate).

iii. Gas Holder (Gas Storage Tank):

- Collects and stores the biogas produced in the digester.
- Maintains constant gas pressure for uniform supply to engines or burners.

iv. Gas Cleaning and Conditioning Unit:

- Removes impurities such as hydrogen sulfide (H_2S), moisture, and CO_2.
- Ensures clean biogas suitable for use in engines or turbines.

v. Biogas Engine / Generator Set:

- Uses the cleaned biogas to run an internal combustion engine connected to a generator, producing electricity.

vi. Slurry Outlet / Manure Pit:

- Collects the digestate (spent slurry) from the digester.
- Used as a bio-fertilizer in agriculture.

6. **Explain the transesterification process in biodiesel production.**
Ans:

Transesterification Process in Biodiesel Production
Transesterification is the main chemical process used to produce biodiesel from vegetable oils or animal fats. It converts triglycerides (fats/oils) into methyl esters (biodiesel) and glycerol (by-product) by reacting them with an alcohol (usually methanol) in the presence of a catalyst such as sodium hydroxide (NaOH) or potassium hydroxide (KOH).

i. Chemical Reaction:

$$\text{Triglyceride} + 3\text{Methanol} \xrightarrow[\text{NaOH / KOH3}]{} \text{Methyl Esters (Biodiesel)} + \text{Glycerol}$$

ii. Steps Involved:

a) Preparation of Reactants:
   - Oil or fat is mixed with methanol and a catalyst (NaOH or KOH).

b) Chemical Reaction:
   - The mixture is stirred and heated (50–60°C).
   - The triglycerides in oil react with methanol to form fatty acid methyl esters (biodiesel) and glycerin.

c) Separation:
   - After the reaction, the mixture settles into two layers:
     - Upper layer: Biodiesel (lighter)
     - Lower layer: Glycerin (heavier)

d) Purification:
   - Biodiesel is washed and dried to remove impurities and excess methanol.

iii. Products:

- Main Product: Biodiesel (Fatty Acid Methyl Esters – FAME)
- By-product: Glycerin (used in soap and pharmaceutical industries)

iv. Advantages of the Process:

- Reduces oil viscosity
- Produces high-quality biodiesel suitable for diesel engines
- Simple and efficient chemical conversion method

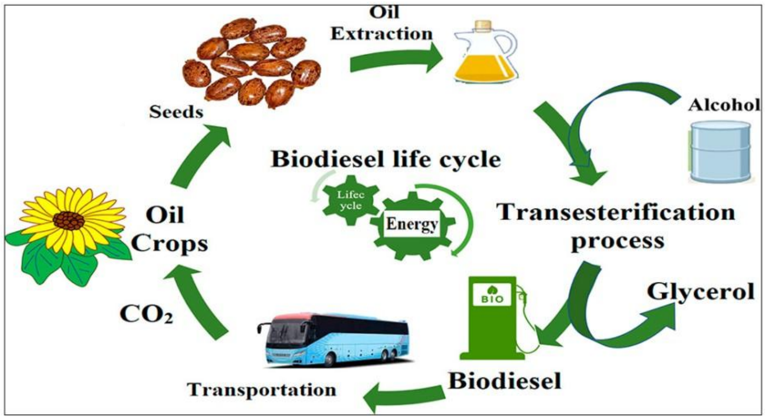
7. **Explain the properties and significance of solid biomass fuels like bagasse, wood chips, rice husk, and municipal waste for power generation.**

Answer:

- **Bagasse:** Fibrous residue from sugarcane; used in co-generation; renewable and reduces waste.
- **Wood Chips:** Obtained from forestry residues; easy to handle; used in gasifiers and boilers.
- **Rice Husk:** By-product of rice milling; calorific value ~3000 kcal/kg; high ash content.
- **Municipal Waste:** Mixture of organic and inorganic waste; processed for energy recovery; helps in waste management.

  Significance: Reduces fossil fuel dependence, utilizes agricultural residues, supports rural economy, and contributes to sustainable energy generation.

8. **Draw and explain the layout and working of an agro-chemical-based (biodiesel) power plant.**
Ans:



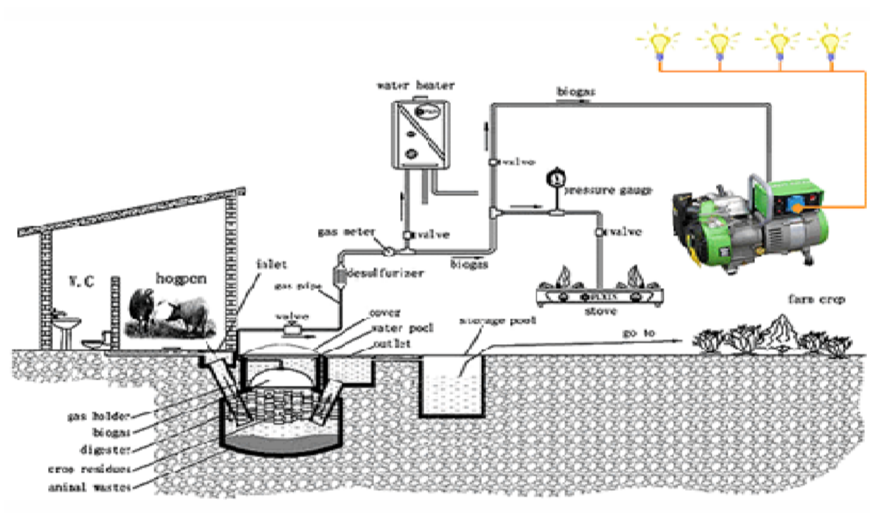
Layout Components:

i. **Oil extraction unit:** Extracts oil from seeds (e.g., Jatropha).
ii. **Reactor:** Carries out transesterification using methanol and catalyst.
iii. **Separation tank:** Separates biodiesel and glycerin layers.
iv. **Purification unit:** Removes impurities and water.
v. **Storage tank:** Stores purified biodiesel.
vi. **Diesel engine-generator:** Converts chemical energy into electrical power.
Working: Oil is processed chemically into biodiesel, which is then used in a diesel engine connected to a generator for electricity production.

10 Marks Questions

1. **Draw and explain the layout and working of a biochemical-based (biogas) power plant.**

Answer:



Layout Components:

11 **Feedstock preparation unit:** Organic waste mixed with water.
12 **Anaerobic digester:** Converts biomass into biogas via microbial action.
13 **Gas storage:** Dome or floating drum.
14 **Gas cleaning unit:** Removes CO_2 and H_2S.
15 **Gas engine and generator:** Converts gas energy into electrical power.
16 **Slurry outlet:** By-product used as fertilizer.

Working: Biomass is decomposed anaerobically, biogas is collected, purified, and used in an engine-generator set to produce electricity.

Biogas Power Plant converts wet biomass into biogas by the proc ss of anaerobic fermentation. Biogas Power Plants are very popular in rural areas where biomass (cow dung, agricultural waste, etc.) are abundant.

The biomass (cow dung) is mixed with water to form slurry in mixing tank. The slurry is stored in the inlet chamber. From the inlet chamber the biomass is fed into the digester where the biomass undergoes anaerobic fermentation and then the biogas (methane) is released as a result of biomass decomposition.
The slurry fed in the plant comprises mainly of cow dung mixed with other biodegrable waste. The slurry when confined in a place without air, gives rise to mainly two types of bacteria – Acid forming bacteria and Gasifying bacteria. Volatile acids are formed from carbohydrates, fats and proteins by the acid forming bacteria and carbondioxides are formed by gasifying bacteria. This phase is called as liquification phase. After this phase, the methane bacteria work upon the volatile acid, producing methane and carbon dioxide with the help of introcell ar enzyme. This phase is called **gasification pha e**.
The whole process is governed by factors like temperature of slurry, loading rate, detention period, pH value, nutrients conc ntration, solid concentration, toxic substance, etc.

The Biogas produced consists of 55-60% methane and 40-45% carbonmonoxide with little amount of hydrogen and hydrogen sulphide.
The gas being lighter in weight rises to the top of the digester and stored there. A dome structure is made at the top to prevent the biogas from escaping out into the atmosphere. The plant has a strong foundation made up of concrete.
The slurry move to the outlet chamber after being fermented. The moving of slurry is due to difference in the gas pressure. The slurry at the outlet can be used as manure.
A gas outlet pipe is provided on the dome structure which is governed by a valve. When the biogas is required, the valve is opened and when not required, it is closed.
The biogas from the outlet pipe is supplied for various uses like cooking, domestic heating and lighting, I.C engine, etc.
The I.C engine is coupled to a generator which produce the electricity. The biogas need to be upgraded before using it in an I.C engine by removing CO_2 and heating the gas in order to make the gas free from moisture.

Advantages of Biogas Power Plant:

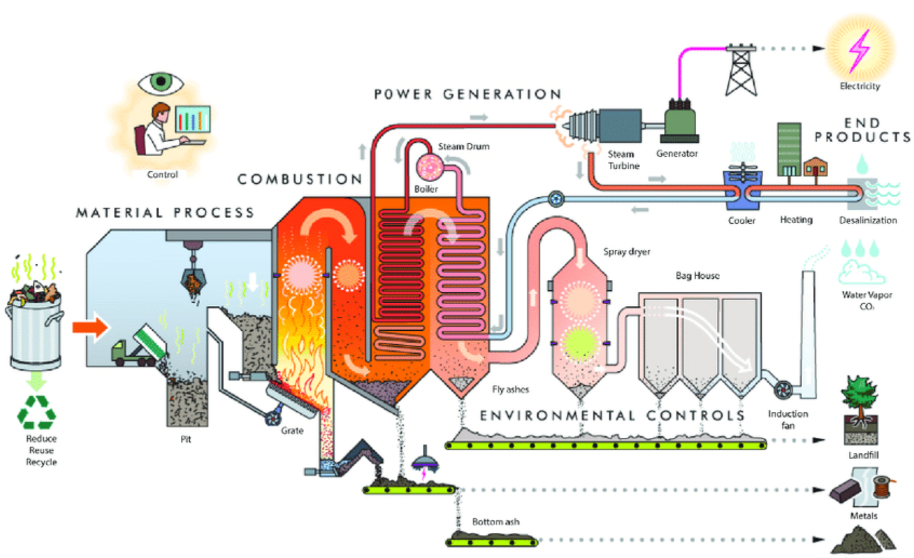
- Generation of renewable, green electricity.
- Low operating costs.
- Underground construction minimizes land use.
- Long life span.
- Reduces greenhouse gases.
- Increases family income by selling back electric energy to the electric power grid.
- No maintenance problems due to the absence of moving parts.
- No corrosion problems.

Disadvantages:

- Requires expert design, skilled construction and expert maintenance required.
- Biogas production below 15°C, is no longer economically feasible.
- High capital costs.
- Variable gas pressure.
- Scum formation.

2. **Describe the layout and working of a thermo-chemical-based (municipal waste) power plant.**

Answer:



Thermo-Chemical-Based (Municipal Waste) Power Plant
A thermo-chemical-based municipal waste power plant converts solid municipal waste (such as plastics, paper, wood, and organic materials) into useful energy—heat and electricity—by thermal decomposition processes such as combustion, gasification, or pyrolysis.

i. Layout of Thermo-Chemical-Based Power Plant
Main Components:

a. **Waste Collection and Segregation Unit:**
   - Municipal solid waste (MSW) is collected and sorted to remove non-combustible materials (like metals, glass, and stones).
   - Organic and combustible materials are shredded for uniform size.

b. **Drying and Feeding System:**
   - Moisture content of waste is reduced.
   - Dried waste is conveyed to the combustion or gasification chamber.

c. **Combustion / Gasification Chamber:**
   - The prepared waste is **burned (combustion)** or **partially oxidized (gasification)** at **high temperatures (700–1000°C)**.
   - Produces **hot flue gases** or **producer gas** rich in CO, H_2, and CH_4.

d. **Heat Recovery Boiler:**
   - Hot gases pass through a **boiler**, where heat is transferred to **water** to generate **steam**.

e. **Steam Turbine and Generator:**
   - The **steam** drives a **steam turbine**, which in turn rotates a **generator** to produce **electricity**.

f. **Flue Gas Cleaning System:**
   - Exhaust gases are treated in **electrostatic precipitators (ESP)**, **scrubbers**, and **filters** to remove dust and pollutants before releasing into the atmosphere.

g. **Ash Handling System:**
   - The **bottom ash and fly ash** are collected and either **disposed of safely** or **used in construction materials**.

h. **Control and Monitoring System:**
   - Controls temperature, air supply, and pollution levels for efficient and safe operation.

iii. Layout Diagram (Description):

Municipal Waste → Sorting → Shredding → Combustion/Gasification → Boiler → Steam Turbine

Generator
↓
Electricity

Flue Gas → Cleaning → Chimney
↓
Ash → Disposal/Reuse

iv. Working Principle:

a) **Waste Preparation:**
Collected municipal waste is sorted, dried, and shredded.

b) **Thermo-Chemical Conversion:**
The processed waste is subjected to **high temperature** in limited or excess oxygen:
   - **Combustion:** Complete oxidation producing heat directly.

- **Gasification:** Partial oxidation producing combustible syngas.
- **Pyrolysis:** Thermal breakdown in absence of oxygen producing gas, oil, and char.

c) **Energy Conversion:**
The **heat energy** from combustion or gasification is used to **produce steam**, which drives a **turbine-generator set** to produce **electric power**.

d) **Emission Control:**
Exhaust gases are treated to remove harmful particles and gases before release.

e) **By-products:**
- **Electricity and heat** (main output)
- **Ash and slag** (solid residue) which can be used for road construction.

v. Advantages:
- Reduces municipal waste volume by up to **80–90%**.
- Produces **renewable electricity and heat**.
- Reduces dependence on fossil fuels.
- Minimizes **landfill usage** and **environmental pollution**.

vi. Disadvantages:
- High initial and maintenance cost.
- Requires proper segregation of waste.
- Emission control is essential to prevent air pollution.

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