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RENEWABLE ENERGY SOURCES AND APPLICATIONS (21MEO112T)

ASSIGNMENT-1

Q1. List and explain the different forms of energy with examples.

Ans. Forms of Energy

Energy is the fundamental capacity to perform work or cause change in physical systems. While it manifests in numerous ways throughout nature and human-made systems, all forms of energy can be broadly categorized into two primary types: **kinetic energy** (energy of motion) and **potential energy** (stored energy). According to the law of conservation of energy, energy cannot be created or destroyed—only transformed from one form to another.

Primary Categories of Energy

Kinetic Energy

Kinetic energy is possessed by objects in motion and depends on both mass and velocity. The relationship is expressed as $KE = \frac{1}{2}mv^2$, where m represents mass and v represents velocity. Any moving object—whether a rolling ball, flowing river, or speeding vehicle—contains kinetic energy. The faster an object moves or the more mass it has, the greater its kinetic energy.

Potential Energy

Potential energy is stored energy based on an object's position, configuration, or state relative to other objects. It is expressed as $PE = mgh$, where m is mass, g is gravitational acceleration, and h is height. Objects possess potential energy when they are capable of doing work but are not currently in motion.

Specific Forms of Energy

Mechanical Energy

Mechanical energy is the sum of kinetic and potential energy in a system. It represents the energy an object possesses due to its motion or position. In an idealized system without friction or air resistance, mechanical energy remains constant as it continuously transforms between kinetic and potential forms.

Thermal (Heat) Energy

Thermal energy is produced when temperature increases cause atoms and molecules to move faster, vibrate, and collide with each other. The hotter the substance, the more its particles move and the higher its thermal energy.

Chemical Energy

Chemical energy is potential energy stored in the bonds between atoms and molecules. When chemical bonds are formed, energy is stored; when bonds are broken, energy is released.

Gasoline contains long chains of carbon and hydrogen atoms that, when heated and broken, release heat, light, and kinetic energy while forming carbon dioxide and water. Food stores chemical energy that our bodies convert into motion and heat. Batteries, biomass, petroleum, natural gas, and coal all contain chemical energy.

Electrical Energy

Electrical energy results from the movement of electrons through conductors. It is the energy associated with electric charges and their motion through electric fields.

Electrical energy is highly versatile because it can be easily transformed into light (light bulbs), heat (toasters), sound (radios), or motion (electric motors). Power plants generate electrical energy by converting mechanical, thermal, or nuclear energy, then distribute it through power grids.

Nuclear Energy

Nuclear energy is stored in the nucleus of atoms—the energy that binds the nucleus together. Large amounts of energy can be released when nuclei are combined (fusion) or split apart (fission).

Nuclear power plants extract energy from large uranium atoms by bombarding them with protons and neutrons, causing them to become unstable and break apart. This releases massive amounts of thermal energy used to heat water, generate steam, turn turbines, and produce electricity.

Radiant Energy

Radiant energy is electromagnetic energy that travels in waves. It encompasses various forms of electromagnetic radiation including visible light, X-rays, ultraviolet light, and radio waves.

The sun produces abundant radiant energy transmitted to Earth as light and heat.

Light Energy

Light energy is a specific type of electromagnetic radiation visible to the human eye. It consists of photons produced when an object's atoms heat up and travel in waves.

A burning campfire converts chemical energy into light energy and thermal energy. Light bulbs convert electrical energy into light energy, allowing us to see in darkness. Sunlight provides natural light energy essential for photosynthesis in plants.

Sound Energy

Sound energy is kinetic energy that moves through substances (air, water, solids) in the form of waves created by vibrations. Only frequencies between 20 Hz and 20 kHz are audible to humans; below this range is infrasonic and above is ultrasonic.

When you clap your hands, the sudden motion vibrates nearby air molecules, creating pressure waves that propagate outward as sound.

Gravitational Energy

Gravitational energy is potential energy held by an object due to its position in a gravitational field. The higher an object's position, the greater its gravitational potential energy.

A water balloon dropped from a few feet has relatively low gravitational energy and may not break on impact, but the same balloon thrown from high in the air contains much more gravitational energy (and kinetic energy from motion) and will almost certainly break.

Elastic Energy

Elastic energy is potential energy stored in objects when they are stretched, compressed, or deformed. Compressed springs, stretched rubber bands, and bent diving boards all store elastic potential energy.

When a bow is drawn, elastic potential energy is stored in the bent bow; upon release, this energy converts to kinetic energy and transfers to the arrow. A trampoline stores elastic energy when compressed by a jumper's weight, then releases it to propel the jumper upward.

Energy Transformation and Conservation

Energy continuously transforms between different forms while the total amount remains constant. A cyclist converts chemical energy from food into kinetic energy to accelerate, then that kinetic energy converts to gravitational potential energy when climbing a hill. When coasting downhill, potential energy converts back to kinetic energy. If the cyclist applies brakes, kinetic energy dissipates as thermal energy through friction.

Q2. Describe the solar spectrum, solar constant, and extra-terrestrial radiation on a horizontal surface.

Ans. The solar spectrum includes all electromagnetic radiation emitted by the Sun, the solar constant quantifies the energy received per unit area at Earth's average distance, and extra-terrestrial radiation on a horizontal surface describes solar energy outside the atmosphere projected onto the horizontal plane.

Solar Spectrum

The solar spectrum refers to the range of electromagnetic radiation emitted by the Sun, stretching from ultraviolet (UV) to infrared (IR). The key regions of the solar spectrum are:

- **Ultraviolet (UV):** 290–400 nm, about 2% of total solar energy, generally divided into UVC, UVB, and UVA subcategories. Most UV, especially UVC and UVB, is absorbed by Earth's atmosphere.
- **Visible:** 400–700 nm, about 40–47% of the solar energy, comprising the light visible to the human eye, peaking around 500 nm (green-yellow).
- **Infrared (IR):** 700–2500 nm, about 51% of solar energy, responsible for most of the heat felt from sunlight.

The solar spectrum closely resembles a blackbody spectrum with a temperature of about 5800 K, peaking near 500 nm.

Solar Constant

The solar constant is the average amount of solar electromagnetic energy received per unit time per unit area on a surface perpendicular to the Sun's rays at Earth's mean distance from the Sun (one astronomical unit). Its value is approximately:

- **1.361–1.366 kW/m²** (or 1361–1366 watts per square meter).
This value includes all types of solar radiation, not just visible light. The solar constant is measured above Earth's atmosphere to exclude effects of absorption and scattering, and it varies slightly due to Earth's orbital changes and solar activity.

Extra-Terrestrial Radiation on a Horizontal Surface

Extra-terrestrial radiation is the solar radiation received on a horizontal surface at the top of Earth's atmosphere, i.e., before atmospheric absorption or scattering takes place. Unlike the solar constant (which is measured on a perpendicular surface), extra-terrestrial radiation on a horizontal surface requires mathematical projection, considering the solar zenith angle (the angle between the Sun and the vertical):

- **Intensity calculation:** The received power decreases with the cosine of the solar zenith angle, so at noon, when the Sun is overhead (zenith angle = 0°), the horizontal surface receives the maximum value equal to the solar constant. At other times, the effective radiation is less due to the larger angle.

- **Daily average:** Calculated by integrating the incident energy from sunrise to sunset, factoring in the changing zenith angle throughout the day. The average value per day or month can be found using radiometric equations that include the solar constant, zenith angle, declination, and hour angle.

This extra-terrestrial radiation forms the basis for calculating theoretical solar input before atmospheric losses and is vital for solar energy applications, climate models, and satellite measurements.

Q3. Differentiate between beam, diffuse, and global radiation. Illustrate with neat sketches.

Ans. Beam, diffuse, and global radiation are distinct types of solar radiation measured at Earth's surface. Each type has unique characteristics based on how sunlight interacts with the atmosphere, and their contributions are fundamental for solar energy systems.

Beam Radiation

A pyrheliometer used on a solar tracker to measure Direct Normal Irradiance

Beam (direct) radiation refers to solar radiation received in a direct path from the Sun without scattering by atmospheric particles. It is highly directional and reaches the surface as a sharp, well-defined shadow under clear skies. Beam radiation can be measured using a pyrheliometer, which points directly at the Sun and measures the direct solar irradiance.

- Example: The sunlight that creates sharp, distinct shadows on a clear day is primarily beam radiation.
- Measured as "Direct Normal Irradiance (DNI)" on a surface perpendicular to the solar rays.

Diffuse Radiation

Diffuse radiation is sunlight that has been scattered by molecules, aerosols, clouds, and other atmospheric constituents before reaching the surface. This radiation arrives from all directions of the sky and is responsible for brightening the sky, even on cloudy days when the Sun is not directly visible.

- Example: The general daylight available under overcast skies, or the light illuminating shaded areas, comes from diffuse radiation.
- Measured as "Diffuse Horizontal Irradiance (DHI)" on a horizontal surface using a pyranometer, often with a shading device to block the direct beam.

Global Radiation

Global radiation is the total solar irradiance received on a horizontal surface and is the sum of both beam (projected onto the horizontal plane) and diffuse components:

$$\begin{aligned}
 &\text{Global Horizontal Irradiance (GHI)} \\
 &= \text{Diffuse Horizontal Irradiance (DHI)} \\
 &+ \text{Direct Normal Irradiance (DNI)} \times \cos(\theta_z)
 \end{aligned}$$

where θ_z is the solar zenith angle.

- Example: The total sunlight measured by a pyranometer in an open area, including both direct sunlight and scattered light from the sky.

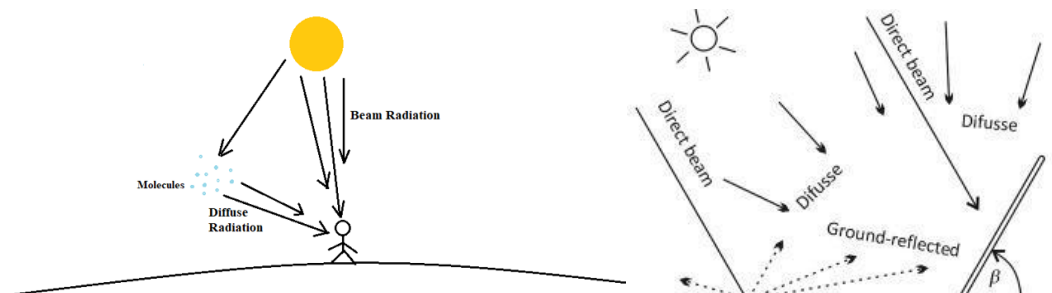
Summary Table

Type	Description	Measurement	Example Scenario
Beam Radiation	Direct sunlight, no scattering	Pyrheliometer (DNI)	Sharp shadow, clear sky
Diffuse Radiation	Scattered sunlight from atmosphere	Pyranometer (DHI)	Bright sky under clouds
Global Radiation	Total sunlight (Beam + Diffuse)	Pyranometer (GHI)	Total light on horizontal plate

Illustration

The following sketches visually represent beam, diffuse, and global radiation:

- **Beam (Direct):** A single arrow from the Sun to the surface, not deviating; creates a shadow.
- **Diffuse:** Multiple arrows arriving from all directions of the sky to the same surface point.
- **Global:** Combination of direct (from Sun) and diffuse (from sky) reaching the surface.



Q4. Define concentration ratio and angle of acceptance with neat diagrams.

Ans. The concentration ratio defines the degree of solar energy focusing in a concentrator system, while the angle of acceptance represents the range of incident sunlight angles that can be effectively captured and directed to the absorber.

Concentration Ratio

The **concentration ratio (CR)** is the ratio of the area of the aperture (entry point for sunlight) to the area of the absorber or receiver in a solar concentrator. It quantifies how much sunlight is focused onto the absorber, and is given by:

$$CR = \frac{\text{Aperture Area (A}_1\text{)}}{\text{Absorber Area (A}_2\text{)}}$$

A higher CR means more intense solar flux at the receiver, enabling higher temperatures and more efficient energy conversion. Concentrators can be classified as low, medium, or high concentration based on CR value:

- Low: ≤ 10 suns
- Medium: 10–100 suns
- High: 100–2000 suns
- Ultra-high: > 2000 suns

Diagram: A rectangle (aperture) with sunlight entering and being focused by mirrors/lenses onto a smaller rectangle (absorber)—showing the ratio.

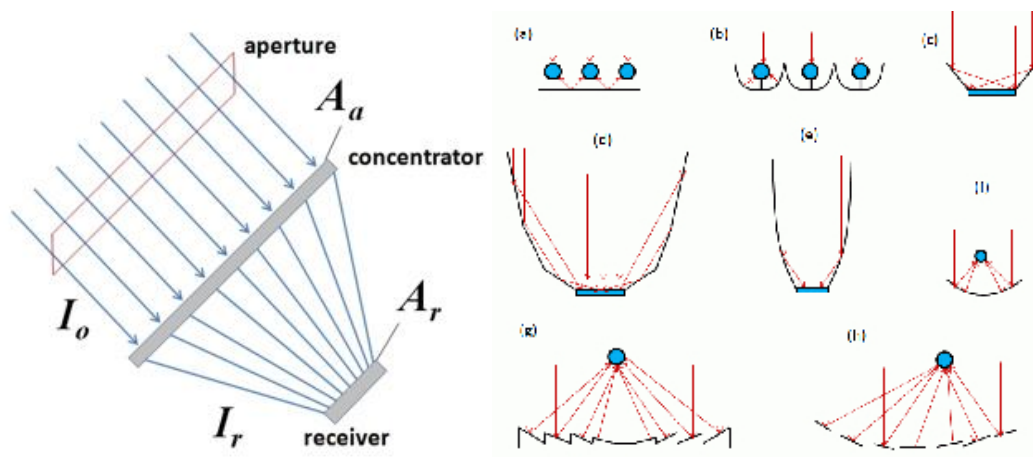
Angle of Acceptance

Aerial view of the Khi Solar One concentrated solar power plant in South Africa, October 2016

The **angle of acceptance** is the maximum angle relative to the concentrator's axis at which incoming rays can still be redirected to the absorber. It determines the effectiveness of the concentrator throughout the day or year, especially for non-tracking designs. Beyond this angle, stray or oblique rays are not collected by the receiver.

Diagram: Show a concentrator (parabolic or V-trough) with lines representing incident sunlight coming from different angles; rays within the acceptance angle are directed to the absorber, those outside are not.

These concepts are critical for designing solar concentrators with high performance and efficiency.



Q5. Identify and evaluate the drawbacks and real field issues in solar thermal systems. Suggest possible remedies.

Ans. Solar thermal systems are a promising renewable energy technology, but they face several drawbacks and real-world challenges that can limit their efficiency and reliability. Here is an evaluation of these issues along with potential remedies:

Drawbacks and Field Issues

1. High Initial Costs

- Solar thermal systems require significant investment in collectors, storage tanks, and installation.
- **Remedy:** Invest in mass production and economies of scale to reduce costs. Government subsidies and incentives can also promote adoption.

2. Dependence on Weather Conditions

- Efficiency is highly affected by cloudy weather, night-time, and seasonal variations, leading to inconsistent energy supply.
- **Remedy:** Integrate with thermal storage systems (like phase change materials or large tanks) to store excess heat and ensure supply during non-sunny periods.

3. Thermal Losses

- Heat losses occur due to conduction, convection, and radiation from Collector surfaces and piping, especially during storage or at night.
- **Remedy:** Use insulation materials with low thermal conductivity, design better insulation around pipes and storage tanks, and employ selective coating for collectors to minimize losses.

4. Corrosion and Scaling

- Water or heat transfer fluids can corrode system components or cause scaling, reducing efficiency and lifespan.
- **Remedy:** Use corrosion-resistant materials, anti-corrosion coatings, and proper water treatment or migration to eco-friendly heat transfer fluids.

5. Maintenance and Durability

- Field conditions can cause wear and tear, dust accumulation, and damage to collectors, reducing efficiency over time.
- **Remedy:** Implement regular maintenance schedules, use self-cleaning coatings, and design modular, easy-to-maintain systems.

6. Limited Space and Land Use Constraints

- Large surface area requirements for collectors may not be feasible in densely populated or land-scarce areas.
- **Remedy:** Use high-efficiency, compact collector designs such as evacuated tube collectors or dish Stirling engines.

7. Environmental Impact

- Manufacturing and disposal of collectors involve environmental concerns, especially with certain glass or metal components.
- **Remedy:** Promote recycling, use environmentally benign materials, and develop sustainable manufacturing processes.

8. Economic Viability and Grid Integration

- Economic competitiveness against traditional energy sources remains a challenge in some regions.
- **Remedy:** Enhance policy support, improve system efficiencies, and develop hybrid systems combining solar thermal with other renewables or conventional energy sources.

Summary

While solar thermal systems hold great promise, overcoming these field issues requires technological improvements, policy support, and innovative design strategies to optimize their performance, durability, and cost-effectiveness in real-world conditions.

Q6. Explain the basic working principle, components, and applications of solar photovoltaic (PV) systems.

Ans. Solar photovoltaic (PV) systems convert sunlight directly into electricity using the photovoltaic effect. The basic working principle, components, and common applications of solar PV systems are summarized below:

Working Principle of Solar Photovoltaic Systems

Solar PV systems operate on the **photovoltaic effect**, where semiconductor materials—typically silicon—absorb sunlight photons and generate an electric current. Key aspects include:

- PV cells consist of layers of semiconductor material forming a PN junction.
- When sunlight hits the cell, photons transfer energy to electrons, freeing them from atoms and creating electron-hole pairs.
- An internal electric field drives these electrons to flow as current, generating direct current (DC) electricity.
- This DC electricity is then converted to alternating current (AC) by an inverter for household or grid use.

Main Components

1. Solar PV Panels (Modules)

- Composed of many interconnected PV cells arranged in series and parallel to achieve desired voltage and current levels.
- Panels absorb sunlight and generate DC electricity.

2. Inverter

- Converts the DC electricity generated by panels into usable AC electricity for homes or industries.

3. Charge Controller (optional)

- Regulates power going to batteries from PV panels to prevent overcharging and damage.

4. Battery Bank (optional)

- Stores excess energy for use during nighttime or cloudy conditions, enhancing reliability.

5. Mounting Structures

- Securely position panels at optimal tilt and orientation for maximum solar exposure.

6. Electrical Wiring and Protection Devices

- Connect components and ensure safety with circuit breakers, surge protectors, and grounding.

7. Utility Meter and Grid Connection (for grid-tied systems)

- Measure power generated and feed excess electricity back to the grid or draw power when needed.

Applications of Solar Photovoltaic Systems

- **Residential and Commercial Electricity Supply**

Solar PV provides clean power for homes, offices, and businesses, reducing dependence on fossil fuels.

- **Remote Power Systems**

Ideal for off-grid locations such as rural areas, telecommunications towers, and remote weather stations.

- **Agricultural Uses**

Powering irrigation pumps, greenhouses, and farm equipment where grid access is limited.

- **Utility-Scale Solar Power Plants**

Large solar farms generate electricity for distribution to the grid, supporting renewable energy targets.

- **Portable Devices**

Small-scale PV cells power calculators, watches, and portable chargers.

Solar photovoltaic systems offer a versatile, scalable, and sustainable solution for electricity generation by directly converting sunlight into usable electrical energy without moving parts or emissions.

