1. Derive the expression for total power in wind.

The total power contained within the wind can be computed using the concept of kinetics, as the windmill works on the principle of converting the **kinetic energy** of the wind into mechanical energy.

The power in the wind depends on the **density of the air ()**, the **rotor area (A)**, and the **wind speed (V)**.

The standard expression for the total power () available in the wind is given by the formula:

Derivation Steps (Based on Kinetic Principles):

1. **Mass Flow Rate ():** The mass of air passing through the swept area (A) of the rotor per unit time (mass flow rate) is defined as: Since Volume Flow Rate is the area (A) multiplied by the velocity (V) of the wind:

2. **Kinetic Energy (KE):** The kinetic energy of any moving body is proportional to its mass. The kinetic energy of the wind mass () is given by:

3. **Power (P):** Power is the rate of energy transfer, meaning the kinetic energy contained in the mass flow rate () of the wind:

4. **Substituting Mass Flow Rate:** Substitute the expression for from step 1 into the power equation:

5. **Final Expression:** The expression for the total power in the wind is derived as:

Constraints and Efficiency:

• The power available in the wind is proportional to the **cube of the wind velocity ()**.

• Only **60% of the available energy** in the wind can theoretically be converted into mechanical energy.

• In practice, the **maximum power efficiency is 45%**.

• Well-designed blades typically extract of the theoretical maximum, but overall wind turbine efficiency may decrease to **35%** due to losses in the gearbox, transmission system, and generator or pump.

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2. Classify and explain about wind turbines.

Wind Energy Conversion Systems (WECS) are broadly classified into two major types based on the orientation of their axis of rotation. They can also be classified by size, output, and rotational speed.

A. Classification by Axis of Rotation (Main Types)

1. Horizontal Axis Machines (HAWTs)

The axis of rotation and the aeroturbine plane are horizontal, with the aeroturbine plane vertical, facing the wind. HAWTs have emerged as the **most successful type** for commercial energy generation.

Feature	Description
Principle Force	**Lift force is more dominating**. The blades utilize an airfoil cross-section.
Orientation	Requires a **yaw control** system (tail vane or yaw drive) to orient the rotor into the changing wind direction.
Component Placement	The **electrical generator and gearbox are placed at the top of the tower**.
Efficiency/Speed	Generally have **better performance** and a **high power coefficient**. They are well suited for electricity generation due to much **higher rotational speeds** (high tip-speed ratios, around 10).
Examples	Two aerodynamic blades, single blade propeller type, multi-bladed type, Dutch type, and Sail type.

2. Vertical Axis Machines (VAWTs)

The axis of rotation is vertical. They receive wind from any direction and therefore **do not require a yawing system**.

Feature	Description
Principle Force	**Drag force is more dominating** (though Darrieus uses lift).
Orientation	Operates in all wind directions, **needs no yaw adjustment**.
Component Placement	The **generator and gearbox can be placed near the ground** (at the bottom of the tower), simplifying installation and maintenance.
Efficiency/Speed	Generally **not self-starting** (a major disadvantage) and have a **low power coefficient**.
Examples	**Savonius Rotor** (low speed, self-starting, low efficiency, uses drag); **Darrieus Rotor** (high speed, high efficiency, not self-starting, uses lift).

B. Classification by Size (Electrical Power Output)

1. **Small Scale (up to 2 kW):** Used on farms, remote applications, and other places requiring relatively low power.

2. **Medium Size Machines (2–100 kW):** Used to supply less than 100 kW rated capacity, typically to several residences or for local use.

3. **Large Scale (100 kW and up):** Used to generate power for distribution in central power grids.

C. Classification by Output Power

1. **DC Output:** Generated using a DC generator or an alternator rectifier.

2. **AC Output:** Can be variable frequency/variable or constant voltage AC, or constant frequency/variable or constant voltage AC.

D. Classification by Rotational Speed

1. **Constant Speed** with variable pitch blades (implies use of a synchronous generator with constant frequency output).

2. **Nearly Constant Speed** with fixed pitch blades (implies an induction generator).

3. **Variable Speed** with fixed pitch blades.

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

I cannot provide a diagram, but the process of extracting energy from the wind involves converting the kinetic energy of moving air into rotary mechanical energy, and then into electricity.

Energy Extraction Process

The system operation of a Wind Energy Conversion System (WECS) involves several stages and components:

1. Energy Capture and Conversion (Rotor/Aero Turbine):

• The **rotor**, consisting of blades attached to a hub, is the portion that collects energy from the wind.

• The blades, which typically have an **airfoil cross-section**, convert the force of the wind into a **torque (turning force)** acting on the rotor.

• This conversion occurs primarily through **lift force** (perpendicular to the wind flow). This causes the rotor to rotate at a relatively low speed (40 rpm to 400 rpm).

2. Mechanical Interface and Speed Up (Transmission):

• The low rotational speed of the rotor is transmitted via a mechanical drive train (low-speed shaft) to the **gearbox**.

• Generators typically require much higher speeds (1,200 rpm to 1,800 rpm). Therefore, the gearbox acts as a **step-up gear** to increase the rotational speed required for efficient electricity production.

3. Electrical Conversion (Generator):

• The **high-speed shaft** drives the **electrical generator**.

• The generator converts the turning mechanical motion into electricity by rotating coils of wire in a magnetic field.

• The output of this generator is connected to the load or power grid.

4. Control and Protection (Controller and Yaw/Pitch Mechanisms):

• For HAWTs, a **yaw control** mechanism (motor or tail vane) rotates the entire nacelle about the vertical axis to face the blades into the wind, maximizing the swept area.

• The **pitch control** system varies the pitch of the rotor blades to control the power output and is used for shutdown in very high winds (cut-out speed).

• A comprehensive **control system** monitors wind speed, direction, shaft speed, and torque, providing control signals necessary for matching the electrical output to the wind energy input and protecting the system from extreme conditions.

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4. Explain the working of biogas digester with the help of diagram.

I cannot provide a diagram, but I can explain the working principle and provide details for the two main digester types used in India. Biogas is produced by the **anaerobic digestion** of organic matter (fermentation).

Working Principle (Anaerobic Digestion)

Biogas is produced by the bacterial decomposition of wet sewage sludge, animal dung, or green plants **in the absence of oxygen**. The process takes place in a container known as the **digester** and involves three main steps:

1. **Enzymatic Hydrolysis:** Complex organic matter (like starch, protein, fat, carbohydrates) are broken down into simpler structures using **anaerobic micro-organisms**.

2. **Acid Formation:** The simple structures are further reacted upon by **anaerobic and facultative micro-organisms** (which thrive in both the presence and absence of oxygen) to **generate acids**.

3. **Methane Formation:** The organic acids are converted to **methane () and** by strict **anaerobic micro-organisms** (anaerobes).

The resulting biogas mainly consists of **50–55% methane** and **30–35%** . The residue left after digestion is a valuable, nitrogen-rich fertilizer.

Types of Biogas Digesters (Physical Layout)

Biogas plants can be classified as single-stage or two-stage, and continuous or batch processes. Two major models used in India are:

1. Indian Digester (KVIC / Floating Drum Type)

• **Structure:** It consists of a digester pit for fermentation and a **floating drum** for gas collection. The digester has a partition wall that submerges in the slurry.

• **Input/Output:** Raw material (e.g., dung mixed with water at a 4:5 ratio) is loaded through the inlet pipe, and the fermented material flows out through the outlet pipe to a compost pit.

• **Gas Collection:** The **gas holder** is a mild steel drum that fits into the digester. When gas is generated, the holder rises and **floats freely** on the surface of the slurry.

• **Pressure:** The pressure of the collected gas is relatively low, varying between **7 and 9 cm of water column**.

• **Maintenance:** The floating drum requires periodical maintenance.

2. Janata Type (Chinese Fixed Dome Type)

• **Structure:** This plant is made entirely of brick and cement, meaning **no steel is used**, and it has **no moving parts**, leading to low maintenance costs. It consists of an underground well-like digester with a **dome-shaped roof** that remains below ground level.

• **Gas Collection:** Biogas collects in the restricted space of the **fixed dome**.

• **Pressure:** Because the gas is collected in a fixed space, the pressure is much **higher**, around **90 cm of water column**.

• **Cost/Adoption:** The Deenbandhu model, a low-cost variation of the fixed dome, accounts for about **90% of biogas plants in India**.

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5. With a neat sketch explain the devices employed for wave energy.

I cannot provide a sketch, but I can explain the working principles of three devices employed for converting wave energy, which relies on the up-and-down motion of waves to generate electricity.

Wave Energy Conversion Devices

1. Float Wave Power Machine

• **Principle:** Uses the vertical movement of a float driven by the waves to compress air, which then drives an air turbine.

• **Operation:**

1. A **float** moves up and down in the water.
2. The float is attached to a **piston** inside a cylinder, which is stationary.
3. The **downward motion** of the piston draws air into the cylinder through an inlet valve.
4. The **upward motion** of the piston compresses the air and sends it through an outlet to **storage tanks**.
5. The compressed air stored in the tanks is used to drive an **air turbine** that, in turn, drives an electrical generator.
6. The electricity is transferred to storage areas via underground cables.

2. Hydraulic Accumulator Wave Machine

• **Principle:** Uses wave motion to create high-pressure fluid, which is stored in an accumulator before being fed to a hydraulic turbine.

• **Operation:**

1. **Pressure Amplifier:** Waves enter a cylinder at the bottom and move a main piston. This amplifies the pressure of a closed-loop fluid to about 5 bar.
2. **Hydraulic Accumulator:** The high-pressure fluid is conducted through a one-way valve to a **hydraulic accumulator**. This accumulator uses air cushions to maintain a **constant pressure**.
3. **Turbine Generation:** Part of the high-pressure fluid flows through a **Pelton wheel or Francis hydraulic turbine** that drives an electrical generator.
4. **Continuous Operation:** The capacity of the hydraulic accumulator must be large enough to permit **continuous turbine operation**, even though the waves themselves are cyclic.

3. The Dolphin-Type Wave-Power Machine

• **Principle:** Utilizes both the rolling and vertical motion of a float to drive separate generators.

• **Operation:**

1. The system involves a **dolphin** (structure) and a **float** connected by a rod.
2. **Rolling Motion:** The float undergoes a **rolling motion** about its own fulcrum. This motion is amplified and converted into continuous rotary motion using gears, which drives one electrical generator.

3. **Vertical Motion:** The float also has a **vertical motion**. This motion is separately amplified and converted into rotary motion to drive a second set of gears and a second electrical generator.

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6. What is geothermal energy? Explain about different types of geothermal resources.

What is Geothermal Energy?

Geothermal energy is heat from within the Earth. This heat is continuously generated in the Earth's core by the slow decay of **radioactive particles**. The heat is conducted upward to igneous rock, which in turn heats ground water that finds its way down through fissures. Geothermal energy sources are fundamentally systems that take advantage of the Earth as a natural heat source to drive power plants.

Geothermal steam is generally of two kinds:

1. **Magmatic steam:** Originates from the magma itself.

2. **Meteoritic steam:** Originates from ground water heated by the magma, and this is the **largest source** of geothermal steam.

Different Types of Geothermal Resources (Classification)

Geothermal sources are classified into three basic kinds, based on the presence, phase, and temperature of the water/steam, or the condition of the rock.

1. Hydrothermal Systems

In these systems, water is heated by contact with hot rock. These are the only systems currently in commercial operation. They are subdivided based on the phase of the fluid produced:

• **a. Vapor-Dominated Systems (Dry Steam)**

◦ **Description:** Produce relatively dry steam at around (), rarely above 8 bar.

◦ **Suitability:** This steam is the **most suitable for use in turboelectric power plants**, offering the least cost.

◦ **Rarity:** They are the rarest form of geothermal energy, accounting for only about 5% of geothermal resources.

◦ **Examples:** The Geysers plant in the U.S. and Larderello in Italy.

• **b. Liquid-Dominated Systems (Hot Water)**

◦ **Description:** Hot water (brine) is trapped underground at a temperature range of to (to). When tapped, the drop in pressure causes the water to partially flash to a two-phase mixture.

◦ **Abundance:** They are **much more plentiful** than vapor-dominated systems.

◦ **Challenge:** They contain relatively large concentrations of dissolved solids (salinity), which **precipitate and cause scaling** in pipes and heat exchangers, reducing flow and heat transfer.

◦ **Conversion Methods:**

▪ **Flashed-Steam System:** Suitable for the higher temperature range, where the water is flashed into steam to drive a turbine.

▪ **Binary Cycle System:** Suitable for moderate temperatures (to), where the hot water transfers its heat to a separate organic working fluid (like isobutane or Freon-12) in a closed Rankine cycle.

2. Geopressured Systems

• **Description:** Sources of water or brine trapped in very **deep underground aquifers** (to ft deep) under **very high pressure** (more than 1,000 bar).

• **Temperature/Energy:** The temperature is relatively low (about or).

• **Key Feature:** The water is **saturated with natural gas (mostly methane)**. This methane provides significant potential energy that is drawing attention, as drilling for the low thermal potential alone is not economically justified due to the great depth.

3. Petrothermal Systems (Hot Dry Rock/HDR)

• **Description:** Hot, dry, largely impermeable rock where **no underground water exists**.

• **Resource Size:** This energy represents by far the **largest resource base** of geothermal energy, accounting for about **85%** of the geothermal resource base of the United States. The estimated ratio of resources is steam:hot water:HDR at 1:10:1000.

• **Extraction Method:** To extract heat, water (or other fluid) must be pumped into the rock and back out to the surface. This requires **fracturing the rock** (e.g., using high-pressure water or nuclear explosives) to create a permeable structure with a large heat-transfer surface.