a. Define cut-out velocity.

Cut-out speed is the wind speed at which most wind turbines cease power generation and **shut down**. This speed is typically between **72 and 128 kmph**. Having a cut-out speed is a **safety feature** that protects the wind turbine from damage. Shut down can occur in several ways, such as an automatic brake activated by a wind speed sensor, or by machines twisting or **"pitching" the blades to spill the wind**.

b. What is Pitch control?

Pitch control involves **varying the pitch of the rotor blades** to control the power output of the rotor. It is a necessary function for the proper operation of horizontal or wind axis machines (aero turbines).

- For horizontal axis wind turbines, the blades may be twisted or "pitched" to spill the wind, which is a method used for system shutdown at high wind speeds (cut-out speed).

- Pitch control mechanisms are sometimes housed in the windmill head, alongside the rotor bearings, and used as a safety device.

- Constant Speed wind turbines often employ **variable pitch blades**.

- The function of pitch control is part of the overall control system required by modern large wind turbine generators.

- The Savonius Rotor (a vertical axis machine) does **not** need pitch controls to operate in high winds.

c. What is Betz's limit?

The sources provided mention the calculation of wind power and conversion efficiencies, but they do **not** explicitly define or refer to **"Betz's limit"**.

- The sources do state that, in practice, the **maximum power efficiency is 45%**.

- Furthermore, they note that only 60% of the available energy in the wind can be converted into mechanical energy.

d. Define tidal range.

The **tidal range** is defined as the **vertical difference between high tide and low tide**. Tides, which have a wave form, are caused by the interactions between the ocean, Sun, and Moon, where the crest of the waveform is the high tide and the trough is the low tide.

e. What is aerobic digestion?

Aerobic digestion is **not** explicitly defined in the sources as a process in the context of biogas generation.

The sources primarily focus on **anaerobic digestion**, which is the process where complex organic compounds are broken down into biogas (methane and CO_2) by micro-organisms **in the absence of oxygen**. The three steps of biogas digestion (enzymatic hydrolysis, acid formation, and methane formation) are performed using **anaerobic** and **facultative** (thrive in both presence and absence of oxygen) micro-organisms.

f. What are the limitations of geothermal energy?

The limitations (disadvantages) of geothermal energy, according to the sources, are:

1. **Limited Availability**
2. **High Cost**
3. **Corrosion and Scaling**
4. **Mineral Precipitation**
5. **Environmental Problems**
6. **Subsidence**
7. **Low Temperature/High Depth Challenges (Geopressured Systems)**
8. **Nuclear Explosion Risks (Petrothermal Systems)**

2. Illustrate operation of a wind turbine with the help of a schematic diagram.

The operation of a wind turbine is the process of converting the kinetic energy of the moving air into usable electrical energy.

Operational Flow and Energy Conversion

The system operation is summarized as follows: **Aero Turbines convert energy in moving air to rotary mechanical energy**, which is then transmitted via a mechanical interface to an electrical generator, and the output is connected to the load or power grid.

Stage	Component	Function/Process
1. Energy Capture	**Rotor/Blades**	The rotor collects energy from the wind. The wind's force acts on the airfoil-shaped blades, generating **lift force** (perpendicular to wind flow). This force is converted into a **torque** (turning force) acting on the rotor blades, resulting in low-speed rotational motion (40 rpm to 400 rpm).

2. Speed Transformation	**Transmission/Gearbox**	Since the rotor rotation speed is low (e.g., 40–400 rpm) and electrical generators require much greater rates of rotation (e.g., 1,200 to 1,800 rpm), the mechanical interface uses a **step-up gear** to efficiently increase the rotational speed.
3. Energy Conversion	**Electrical Generator**	The high-speed shaft drives the generator. Inside, coils of wire are rotated in a magnetic field to convert the turning motion into electricity. The generator output is connected to the load or power grid.

Main Components and Control Mechanisms

The primary components of a Wind Energy Conversion System (WECS) or a modern wind power system include the tower, rotor, mechanical drive train (shafts and gearbox), electrical generator, and sophisticated controls.

1. Rotor Assembly (Blades and Hub)

The rotor is the portion that collects energy from the wind. For electrical generation, the blades use a **lift design**, which is characterized by airfoil-type cross sections and achieves much higher rotational speeds (tip-speed ratios around 10) compared to drag designs. The blades are attached to the **hub**, which is attached to the main shaft.

2. Nacelle and Drive Train

The **Nacelle** is the housing located at the top of the tower, which contains several critical components:

• **Low-speed shaft and High-speed shaft:** Part of the mechanical drive train.

• **Gearbox:** A step-up gear mechanism necessary to increase the low rotor RPM (40–400) to the high RPM (1,200–1,800) required by the generator.

• **Generator:** Converts the mechanical energy into electricity. In HAWTs, the generator and gearbox are placed at the top of the tower.

3. Control Systems

For proper operation, HAWTs require control systems to match the electrical output to the wind energy input and protect the system:

• **Yaw Control:** This system ensures the rotor is oriented into the wind (azimuth or yaw). Since HAWTs are **yaw active**, a tail vane (in small turbines) or a servomechanism and motor (in larger machines) rotates the turbine slowly about the vertical axis to face the blades directly into the wind, maximizing the swept area.

• **Pitch Control:** This controls the power output and protects the system. It involves varying the pitch of the rotor blades. For safety, machines may twist or "pitch" the blades to spill the wind during high speeds (cut-out speed).

4. Supporting Structure (Tower)

The **Tower** supports the entire system. It is essential not just for support but also for raising the turbine to higher elevations (40 to 70 meters for large turbines) where the winds are stronger, thus increasing energy production. HAWTs are mounted on towers to be above the level of turbulence and other ground-related effects.

3. Discuss in detail the advantages and disadvantages of horizontal 6 M CO3 L1 axis and vertical axis wind mills.

Horizontal Axis Wind Turbines (HAWTs)

HAWTs are the common type of wind turbine where the axis of rotation and the aeroturbine plane are horizontal, with the plane facing the wind.

Advantages of HAWTs

1. **High Performance and Efficiency:** HAWTs generally have **better performance** and **show a high power coefficient** compared to VAWTs.

2. **Commercial Success:** They have emerged as the **most successful type of turbines** and are widely used for commercial energy generation globally.

3. **Efficiency for Electricity:** The lift-type blade design commonly used in HAWTs is **well suited for electricity generation** because it results in much higher rotational speeds (tip-speed ratios around 10).

4. **Low Cut-in Speed:** HAWTs typically have a **low cut-in wind speed**.

5. **Easy Furling:** They possess the characteristic of **easy furling**.

6. **Structural Strength (for Severe Storms):** In a conventional horizontal-axis wind electric machine with the generator aloft, the strength of the structure required to carry the added weight of the generator is **small compared with that needed to survive a severe storm**.

Disadvantages of HAWTs

1. **Complex and Expensive Design:** Their design is **more complex and expensive** compared to VAWTs.

2. **Generator/Gearbox Placement:** The **generator and gearbox are placed at the top of the tower**, which complicates installation and maintenance compared to VAWTs.

3. **Yaw System Required:** A **tail vane or yaw drive must be installed to orient them in the wind direction**. This yaw control is required for proper operation.

4. **Flexing and Fatigue Life:** When in operation, the rotor blades are continuously flexed by unsteady aerodynamic, gravitational, and inertia loads. If the blades are made of metal, this flexing **reduces their fatigue life**.

5. **Vibration Issues:** If the vibrational modes of the rotor happen to coincide with one of the natural modes of the tower, the **system may shake itself to pieces**.

6. **Need for Step-Up Gear:** Because HAWT rotor speeds (40 to 400 rpm) are typically low, they **require a gear-box transmission** to increase the rotational speed for efficient electricity production by the generator (1,200 to 1,800 rpm).

Vertical Axis Wind Turbines (VAWTs)

VAWTs are known as cross-wind axis machines where the axis of rotation is perpendicular to the direction of the wind. Examples include the Savonius Rotor and the Darrieus Rotor.

Advantages of VAWTs

1. **No Yawing System Needed:** The main advantage is that they **receive wind from any direction, and hence the yawing system is not required**.

2. **Ground-Level Components:** The **generator, gearbox, etc., can be installed at the bottom of the tower** (near the ground). This simplifies the tower design and installation.

3. **Easier Maintenance:** Installation, inspection, and **maintenance are easier** because heavy components are near the ground.

4. **Cost and Weight:** VAWTs are generally **lighter in weight and cheaper in cost**.

5. **Simpler High-Wind Operation (Savonius):** For specific VAWT types like the Savonius Rotor, yaw and pitch controls are **not needed** to operate in high winds.

6. **Low Wind Velocity Operation (Savonius):** The Savonius rotor performs effectively even at **low-wind velocity ranges** and has a **low cut-in speed** (producing power in winds as slow as 8 km/hour).

7. **Self-Starting (Savonius):** The Savonius Rotor is **self-starting**.

8. **Minimized Bending Stresses (Darrieus):** The Darrieus machine supports its blades in a way that minimizes bending stresses in normal operation.

Disadvantages of VAWTs

1. **Not Self-Starting (General and Darrieus):** VAWTs are **generally not self-starting** and require a mechanism to start from a stationary position. (Note: The Savonius rotor is an exception and *is* self-starting).

2. **Low Power Coefficient:** VAWTs typically have a **low power coefficient**, which is a major disadvantage.

3. **Risk of Over-Speeding:** There is a possibility of running the blades at a **very high speed and causing damage to the system**.

4. **Material/Weight Issue (Savonius):** The Savonius rotor is described as **"too solid,"** having excessive material surface compared with the intercepted wind, leading to **excessive weight** for a large installation.

5. **Vulnerability to Storms (Savonius):** Due to the solid structure of the Savonius rotor, there is **no way to reduce the effective area**, leaving the machine **at the mercy of severe storms**.

6. **Tall Installation Challenges:** VAWTs are **not useful for very tall installations** because of issues with long drive shafts and the awkward bracing required for the topmost bearing.

7. **Low Speed/Efficiency (Savonius):** The Savonius Rotor is characterized by **low speed** and **low efficiency**.

4. Illustrate working principle of simple single pool tidal system.

The working principle of a simple single basin tidal system, specifically the **Single basin-One-way cycle** system, involves separating a basin from the sea using a dam or barrage and utilizing the natural rise and fall of the tides to generate power intermittently.

Here is an illustration of its operational principles:

1. Structure and Components

The system requires the construction of a **dam or barrage**. This structure separates a natural basin (or pool) from the open sea. The barrage must provide channels for the turbines, gates, and locks. The operation also relies on **sluice ways** (gate-controlled devices) used to fill or empty the basin.

2. Operational Cycle (One-Way)

The single basin, one-way cycle is the **simplest form of tidal power plant**. It is designed so that water flows in only one direction through the turbine to generate power.

A. Filling Phase (Flood Tide): During the **flood tide** (when the sea level is rising and above the mean sea level), the sea is allowed to fill the basin.

• This is typically achieved by opening **gates** and using **sluice ways** to let the water flow from the sea into the basin.

• The basin becomes filled with water, storing potential energy.

B. Storage Phase (High Tide): Once the high tide is reached, the water level in the basin is maintained by closing the gates, creating a **difference in the water level (tidal range)** between the water stored in the basin and the lowering level of the sea.

C. Generation Phase (Ebb Tide): Power generation occurs only during the **ebb tide** (when the sea level is falling and below the mean sea level).

• The water flows from the high-level basin back out to the sea.

• This flow passes through the **turbine** (which is directly coupled to an alternator).

• The **potential energy of the stored water** in the basin is used to drive the turbine, which in turn generates electricity.

3. Power Characteristics and Limitations

• **Intermittent Power:** The main characteristic of this system is that **power is available only for a short duration during ebb tide**.

• **Dependence on Tides:** The power produced depends mainly on the **range of the tide** and the tidal flow that can be stored during the cycle.

• **Need for Storage:** Because the supply of power is **not continuous** and depends on the timing of tides, more complex arrangements (like double basin or pump storage) are often required to ensure continuous power supply, which increases capital cost.

(Note: Large size turbines are needed for tidal systems due to the small hydraulic head available, necessitating large power house structures.)

5. Describe working principle of closed cycle OTEC power plant.

The working principle of a **Closed Cycle Ocean Thermal Energy Conversion (OTEC) power plant**, also known as the **Anderson Cycle**, is based on utilizing the temperature difference between warm surface seawater and cold deep seawater to drive a heat engine using a separate working fluid.

1. Thermodynamic Basis and Components

The operation of an OTEC plant relies on the thermodynamic principle that a temperature gradient between a high-temperature heat source and a low-temperature heat sink can be used to convert part of the heat into mechanical and then electrical energy.

• **Heat Source:** Warm surface water (often exceeding in the tropics).

• **Heat Sink:** Cold deeper water (around at 1 km depth or more). A temperature difference of at least **()** is required to produce a significant amount of power.

• **Working Fluid:** The closed cycle requires a separate fluid, such as **ammonia, propane, or a Freon**, which operates within the system.

• **Key Components:** The system depends on two critical heat exchangers: the **evaporator (boiler)** and the **surface condenser**.

2. Working Principle and Cycle Description

The closed cycle operates as a **conventional closed Rankine cycle system**:

A. Evaporation (Heat Absorption): Warm surface water is circulated through the **evaporator (boiler)**. The separate working fluid (e.g., ammonia) is pumped through the evaporator, where it **receives heat** from the warm water, causing it to vaporize.

• The working fluid, which has a low boiling point (e.g., isobutane, Freon-12, propane, or ammonia), operates at relatively high saturation pressures at the boiler temperature (roughly).

• The hot water or brine from the underground reservoir (if discussing the geothermal binary cycle analogy) circulates through a heat exchanger and is pumped back to the ground after transferring its heat.

B. Expansion and Power Generation: The high-pressure vaporized working fluid drives a **turbine**.

• The turbine extracts energy from the fluid, converting the heat into rotary mechanical energy, which is used to generate electrical power.

• Turbines used in the closed cycle are **much smaller and less costly** than the extremely large turbines required for the low-pressure steam utilized in the open cycle.

C. Condensation (Heat Rejection): The spent vapor from the turbine is then channeled into the **surface condenser**. Cold, deep-sea water is pumped up and circulated through the condenser to **reject heat** from the working fluid. This process causes the working fluid to condense back into a liquid (condensate).

D. Recirculation: The liquid working fluid condensate is then pumped back to the evaporator to complete the closed cycle. This distinguishes the closed cycle from the open cycle, where the condensate (desalinated water) may be discharged.

3. Characteristics and Advantages

The closed cycle offers several key advantages over the open cycle for near-future development:

• **Avoids Vacuum Problems:** Because the working fluids operate at higher pressures and have much lower specific volumes (comparable to steam in conventional power plants), the closed cycle avoids the need to harness extremely low-pressure steam, which complicates the open cycle.

• **Smaller, Cheaper Turbines:** The resulting pressures and specific volumes allow for the use of turbines that are **much smaller and less costly**.

• **Reduced Turbine Cost:** The cost of the closed-cycle system for producing significant megawatts is generally regarded as being **significantly less** than for the open-cycle system.

• **Avoids Contamination Issues:** The cycle avoids the need for degasifiers (deaerators) required in the open cycle to remove gases dissolved in seawater, which would otherwise cause large losses in efficiency.

• **Working Fluid Selection:** Ammonia is noted as having better operating characteristics than propane, despite being noxious. Ammonia has been used as the working fluid in successful tests of the closed cycle concept.