Renewable-Energy-Module-3-Important-Topics-PYQs(Theory)

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This includes only theory questions

Important Topics and PYQs (Theory)

1. Block diagram of wind energy conversion system

Windmills can be mainly classified into two types: **Horizontal Axis Wind Turbines (HAWT)** and **Vertical Axis Wind Turbines (VAWT)**

1. Horizontal Axis Wind Turbine (HAWT)

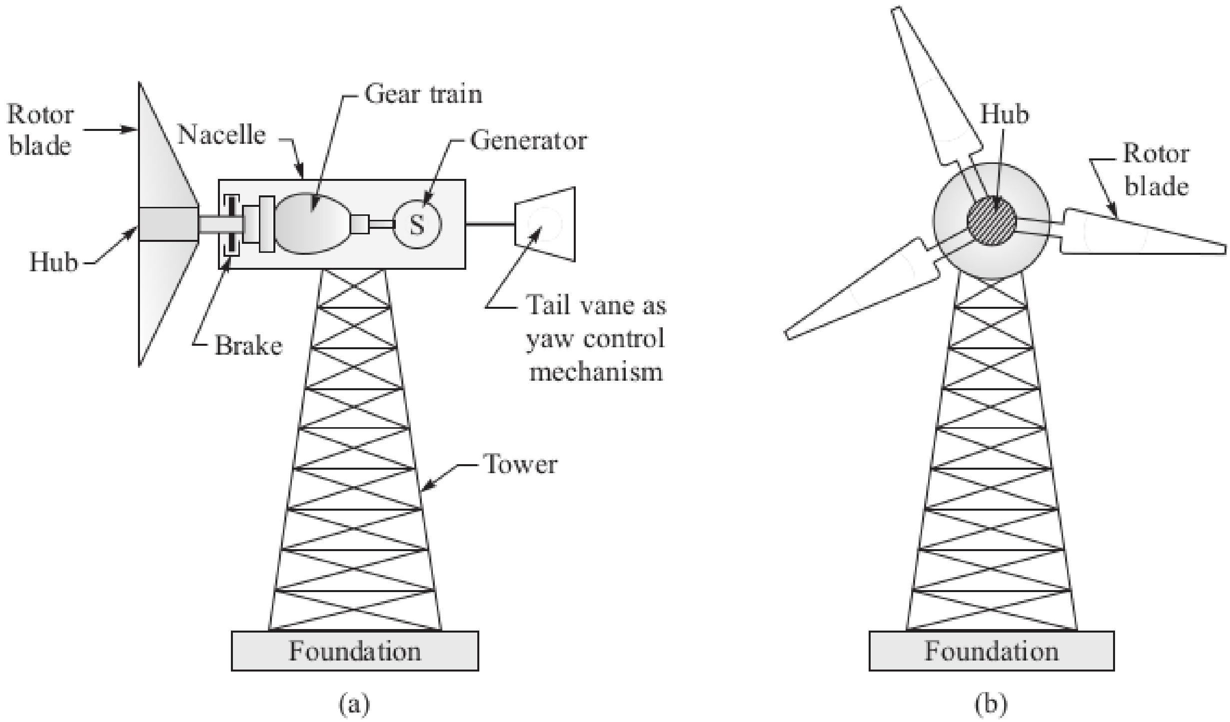

Figure 6.14 Wind turbine (a) Side view of the wind turbine, (b) Front view of the wind turbine.

- **Axis Orientation**: In HAWTs, the axis of rotation (the part that spins) is parallel to the wind direction. This means that the turbine blades rotate like the blades of a propeller.
- **Common Design**: HAWTs are the most commonly used type of wind turbine and typically have two or three blades that resemble those on an airplane propeller.
- **Advantages**:
  - They are efficient and can generate more power at higher wind speeds.
  - The blades are designed to have an aerofoil shape, which helps capture wind energy effectively.
- **Components**:
  - **Blades**: These extract energy from the wind and are usually made of lightweight materials.
  - **Hub**: The central part where the blades are attached.
  - **Nacelle**: This is the housing at the top of the tower that contains the gearbox, generator, and control systems.
  - **Tower**: Supports the nacelle and the rotor and is usually tall to access stronger winds.
- **Yaw Control System**: This system helps rotate the nacelle to keep the blades facing into the wind for maximum efficiency.

2. Vertical Axis Wind Turbine (VAWT)

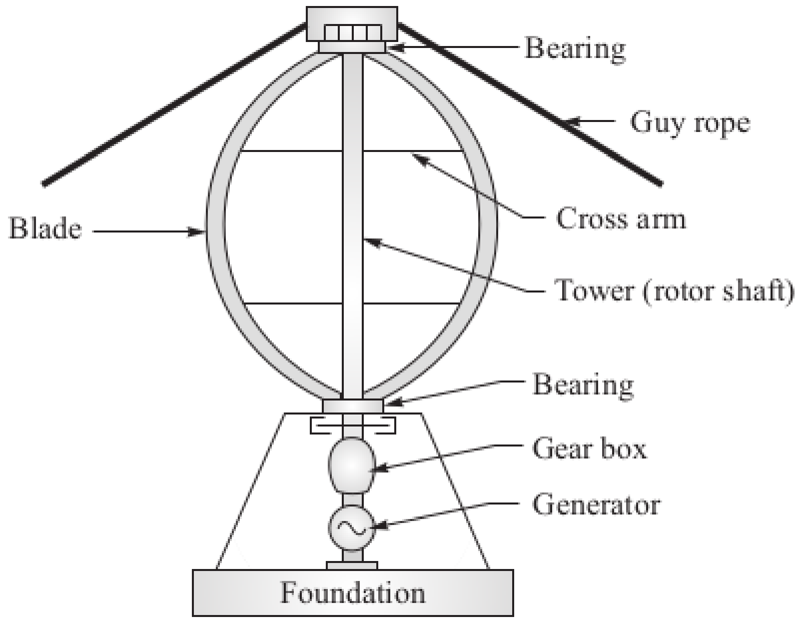

Figure 6.16 Vertical axis wind turbine.

- **Axis Orientation**: In VAWTs, the axis of rotation is perpendicular to the wind direction. This means the blades spin up and down, similar to an eggbeater.
- **Advantages**:
  - VAWTs can capture wind from any direction, eliminating the need for a yaw control system.
  - The gearbox and generator can be placed at ground level, making maintenance easier and reducing the overall height of the turbine.
- **Components**:
  - **Blades**: These are usually curved and designed to handle the wind's forces efficiently.
  - **Tower**: The structure supports the blades and components and can be quite tall, often reaching up to 100 meters.
  - **Support Structure**: This helps hold the blades and other components in place.
- **HAWT** is the traditional design, efficient at high speeds and requires facing the wind directly.
- **VAWT** is more versatile, can accept wind from any direction, and is easier to maintain due to its ground-level components.

2. Discuss the advantages and disadvantages of horizontal and vertical axis wind mills.

Horizontal Axis Wind Turbines (HAWT)

Advantages:

1. **More Efficient:** HAWTs extract more power from the wind because they are designed to use lift force, which is more efficient than drag force.
2. **Smooth Output:** They produce a more consistent and smooth output, making them ideal for power generation.
3. **Higher Power Output:** Due to their efficient design, they can generate more power compared to VAWTs.
4. **Technological Development:** HAWTs are well-developed and commonly used in large-scale wind farms.
5. **Better for Moderate Winds:** They operate efficiently in moderate wind speeds, making them versatile for various wind conditions.
6. **Less Fatigue:** HAWTs experience less fatigue due to wind action compared to VAWTs, leading to longer operational lifespans.
7. **Less Noise:** They are generally quieter than VAWTs.

Disadvantages:

1. **Yaw Control Needed:** The rotor must face into the wind, requiring a yaw mechanism, which adds complexity and cost.
2. **Difficult Maintenance:** Maintenance and inspection are more challenging since the nacelle and generator are located at the top of a tall tower.
3. **Costly:** They are generally more expensive to build and maintain due to the need for a tall, strong tower and yaw mechanism.
4. **Lower Starting Torque:** HAWTs have lower starting torque compared to VAWTs, making them less efficient at low wind speeds.

Vertical Axis Wind Turbines (VAWT)

Advantages:

1. **Can Accept Wind from Any Direction:** VAWTs can accept wind from any direction, eliminating the need for a yaw control system.

2. **Simpler Construction:** The tower and nacelle can be positioned on the ground, making installation and maintenance simpler and cheaper.
3. **Lower Cost:** VAWTs are typically less costly to construct and install.
4. **Self-Starting:** Some VAWTs, like the Evans rotor, are self-starting, meaning they don't require external power to begin operating.
5. **Operate in Low Wind Speeds:** They can generate power even at low wind speeds, making them useful in areas with less consistent winds.
6. **Easier Inspection and Maintenance:** With the generator and gearbox located on the ground, maintenance is much easier.

Disadvantages:

1. **Less Efficient:** VAWTs are less efficient because they primarily use drag force, which is not as effective as lift force.
2. **Fluctuating Output:** The power output can fluctuate because the wind doesn't always strike the blades at the optimal angle.
3. **More Fatigue on Parts:** The components experience more fatigue due to wind action, leading to potentially shorter lifespans.
4. **Limited Power Output:** VAWTs generally produce lower power output compared to HAWTs.
5. **No Pitch Control:** The blade pitch cannot be adjusted, which limits control over performance at high wind speeds.

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3. What is meant by pitch control in a wind turbine? What is its importance?

Pitch control in a wind turbine refers to the ability to adjust the angle (or pitch) of the rotor blades to control the amount of wind they capture. By changing the angle of the blades, the turbine can either capture more wind to generate more power or reduce the wind it captures to prevent damage during high wind speeds.

Importance of pitch control:

- **Maintains optimal performance**: By adjusting the blade angle, pitch control helps the turbine run efficiently, producing the most power possible based on current wind conditions.

- **Prevents damage**: In very high winds, pitch control can reduce the blade angle to avoid excessive spinning that could damage the turbine.
- **Ensures stability**: It helps maintain a constant turbine speed, making the turbine more reliable and efficient, regardless of changing wind speeds.

4. List 3 important criteria for the selection of site for a WECS

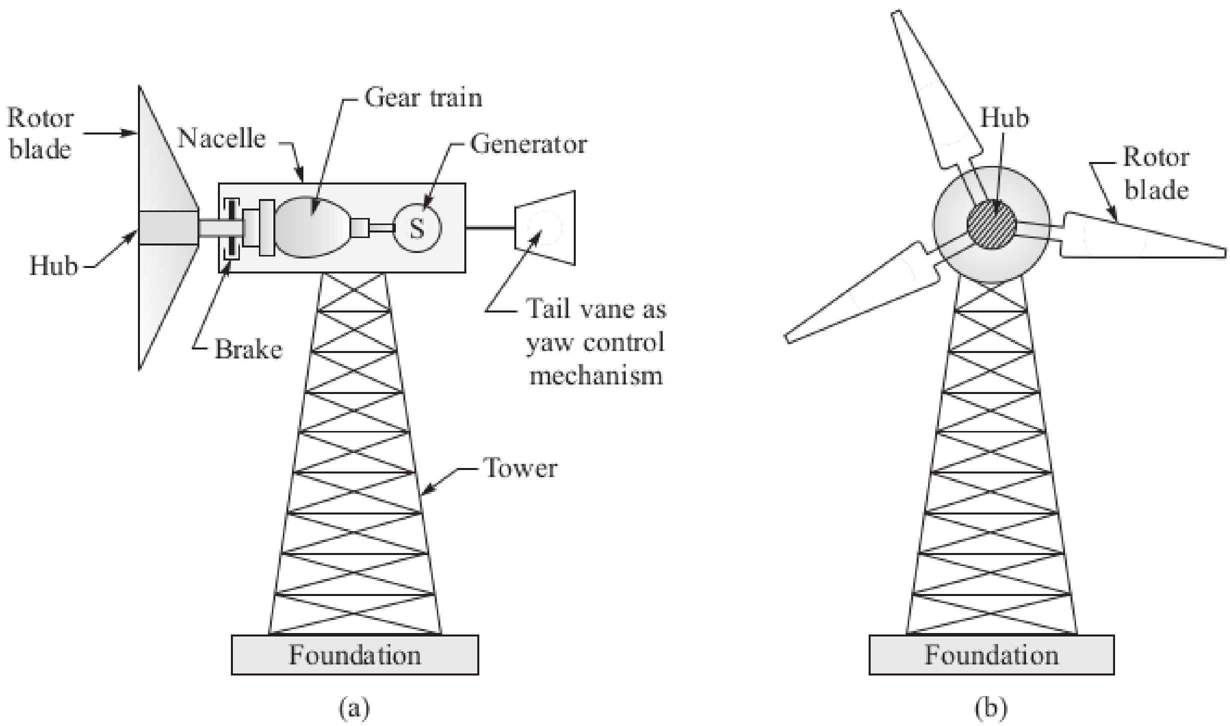
1. **High Wind Speed**: The location should have strong winds throughout the year. The more wind there is, the more energy the wind turbine can produce, since wind power increases rapidly with wind speed.
2. **No Obstructions**: There should be no tall buildings or trees within 3 kilometers of the wind turbine. Anything that blocks the wind can reduce its effectiveness.
3. **Open Area**: Ideal sites are open plains or shorelines where strong winds are common. These areas allow wind to flow freely without interruption.
4. **Height**: Wind speeds are usually higher at greater heights. Placing the turbine on a hill or ridge can help take advantage of these stronger winds.
5. **Proximity to Water**: Being near a lake or ocean is beneficial because water heats up and cools down differently than land, creating winds that can be harnessed for energy.

5. Compare between the horizontal and vertical axis wind turbines.

Feature	HAWT (Horizontal Axis Wind Turbine)	VAWT (Vertical Axis Wind Turbine)
Axis of Rotation	Parallel to the wind	Perpendicular to the wind
Maintenance	Harder to maintain (components at the top)	Easier to maintain (components at ground level)
Efficiency	More efficient, extracts more power from wind	Less efficient, extracts less power from wind
Cost	More expensive	Less costly
Operation in Wind	Works best in moderate wind	Can operate in low wind

Feature	HAWT (Horizontal Axis Wind Turbine)	VAWT (Vertical Axis Wind Turbine)
Speeds	speeds, smooth output	speeds, fluctuating output

6. Describe the construction of a three-bladed horizontal shaft wind turbine generator unit. Explain the terms yaw control and pitch control.



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- **Yaw Control System**: This system helps rotate the nacelle to keep the blades facing into the wind for maximum efficiency.
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7. With the help of a neat sketch, explain the important parts of a horizontal axis wind energy system. What are the aerodynamic forces acting on the blades of the turbine?

Horizontal Axis Wind Energy System

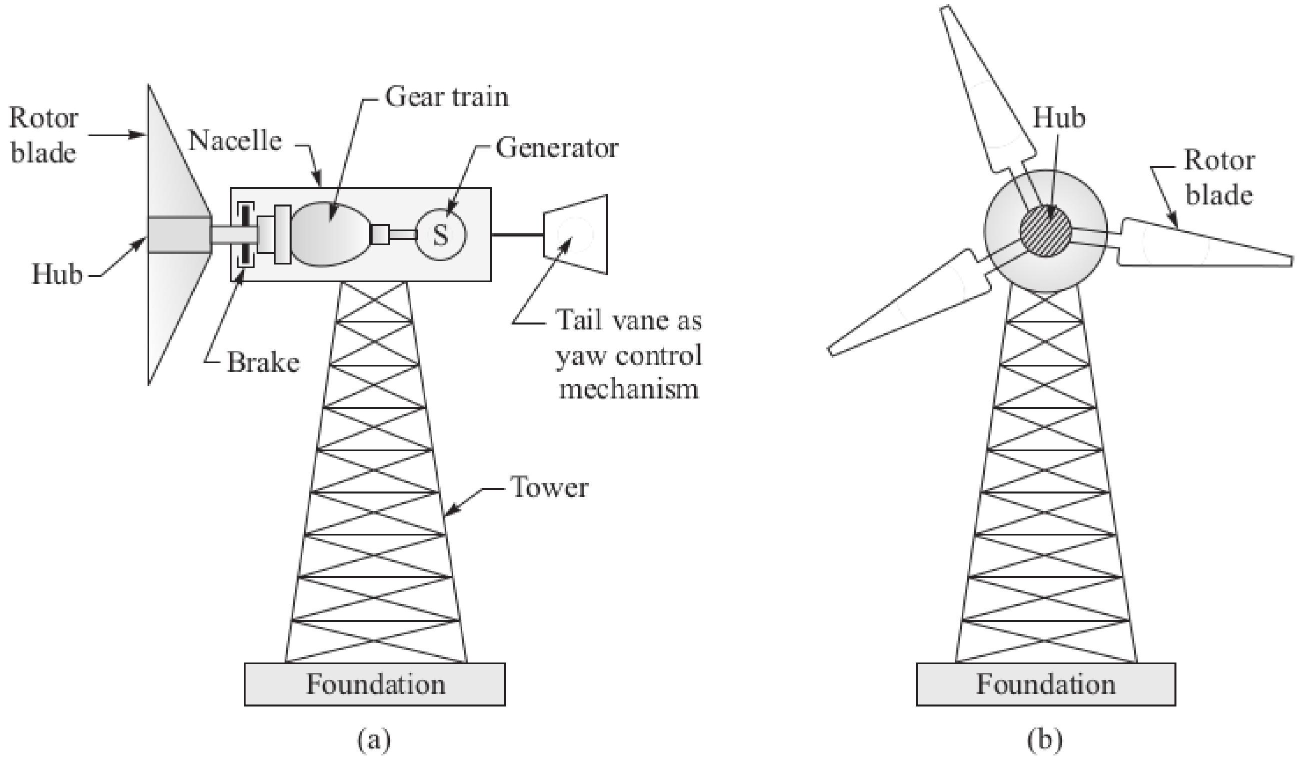


Figure 6.14 Wind turbine (a) Side view of the wind turbine, (b) Front view of the wind turbine.

A **Horizontal Axis Wind Turbine (HAWT)** is one of the most common types of wind turbines. In this system, the blades rotate on a **horizontal axis** (like a propeller on a plane). Let's break down its important parts and how they work together:

Main Parts of a Horizontal Axis Wind Turbine:

1. **Turbine Blades:**
    - The blades are shaped like an **aerofoil** (similar to an airplane wing) to catch the wind and turn it into energy. They are made from strong materials like **fiberglass**.
    - Most wind turbines have **two or three blades**. Three blades are more common because they produce more energy, but two blades are cheaper and simpler to make.
2. **Hub:**
    - The **hub** is the center part of the turbine where all the blades are attached. It also has a mechanism to control the **pitch** (angle) of the blades.
3. **Nacelle:**
    - The **nacelle** is the box that sits on top of the tower. It holds important parts like the **gearbox**, **generator**, and **brakes**. The **gearbox** helps to speed up the rotation of the blades so that the generator can produce electricity.
4. **Yaw Control System:**

- The **yaw control system** makes sure the turbine always faces into the wind. A small **tail vane** on smaller turbines helps automatically turn the nacelle to face the wind.

5. **Tower:**
   - The **tower** holds the nacelle and blades high up in the air. The taller the tower, the better the wind speed the turbine can capture. For larger turbines, the tower is usually higher than the size of the blades.
6. **Generator:**
   - The **generator** turns the mechanical energy from the rotating blades into **electrical energy**, which can be sent to the grid and used by people.

How Does It Work?

1. The **wind blows** and hits the blades of the turbine.
2. The blades start **spinning** because of the wind's energy. This is similar to how a sailboat moves when wind hits the sails.
3. The **rotating blades** turn a shaft connected to the **gearbox**.
4. The gearbox speeds up the rotation and makes it fast enough for the **generator** to produce electricity.
5. The **electricity** is sent from the generator to the electrical grid.

Aerodynamic Forces on the Blades:

When the blades spin, there are a few main forces at work:

1. **Lift Force:**
   - This is the main force that makes the blades spin. Just like how an airplane wing creates lift, the blade shape creates a difference in air pressure, causing the blades to turn.
2. **Drag Force:**
   - This is the air resistance that tries to slow the blades down. While **lift** helps the blades spin, **drag** works against it.
3. **Torque:**
   - The **lift** force causes **torque**, which is a twisting force that helps the turbine rotate and generate power.
4. **Thrust:**
   - This force pushes the turbine forward in the direction of the wind. It's like a windmill pushing against the air.

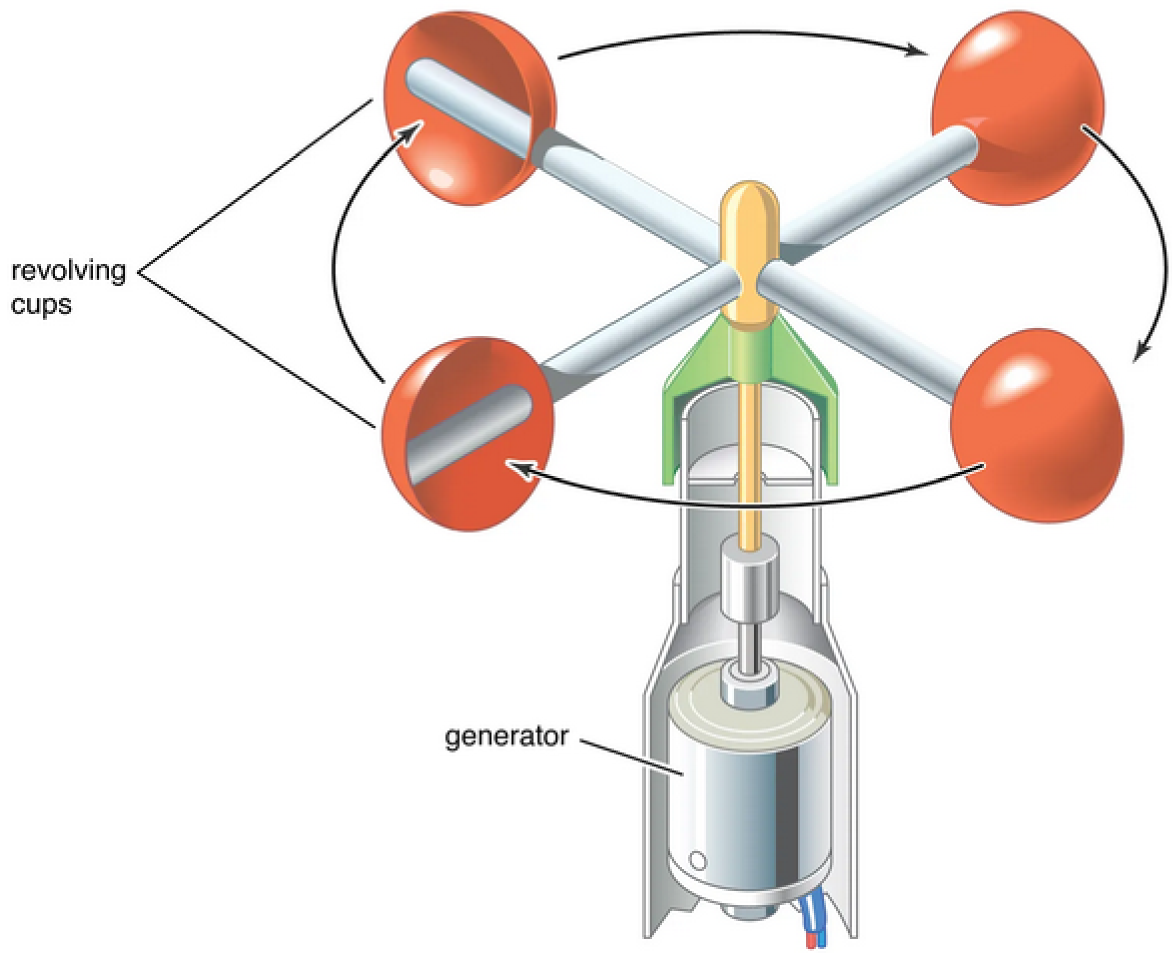
5. **Centripetal Force:**
    - As the blades spin, there’s a force that keeps them moving in a circular path. This helps the turbine stay stable.

8. Explain how wind speed is measured using an anemometer

An anemometer is a tool that measures how fast the wind is blowing.

1. **Swinging Plate**: Imagine a plate that swings from its top edge. When the wind blows, it pushes the plate and makes it tilt. The more it tilts, the faster the wind is blowing.
2. **Cup Rotation**: Some anemometers have cups attached to a vertical pole. When the wind blows, these cups spin. The faster they spin, the stronger the wind.
3. **Wind Pressure**: Another type has a flat plate that faces the wind. When the wind hits the plate, it creates pressure. The more pressure there is, the faster the wind is.
4. **Hot Wire**: In this method, a thin wire is heated up. When wind passes over it, it cools down the wire. By measuring how much the wire cools, we can figure out the wind speed.
5. **Sonic Effects**: Different wind speeds create different sounds (sonic effects). Anemometers can listen to these sounds and use them to estimate how fast the wind is blowing.
6. **Laser Technique**: Some advanced anemometers use lasers and the Doppler effect (which involves changes in sound or light frequency) to measure wind speed accurately.

Example: Cup Anemometer



A **cup anemometer** has three or four cups attached to horizontal arms, which are mounted on a central spindle. Here's how it works:

How It Works:

1. **Wind Blows on Cups:**
    - The anemometer is placed in an open area where the wind can blow across it. The wind hits the cups, causing them to **spin**.
2. **Rotation of Cups:**
    - The faster the wind blows, the **faster the cups rotate**. The force of the wind pushes against the cups, making them turn. The more air resistance (wind speed), the quicker the cups spin.
3. **Speed Measurement:**
    - As the cups spin, the number of rotations is counted. This rotation is directly proportional to the wind speed. Each complete rotation corresponds to a specific wind speed, depending on the design of the anemometer.
4. **Reading the Speed:**

- The anemometer is connected to a **digital or analog display** that shows the wind speed, either in **miles per hour (mph)**, **kilometers per hour (km/h)**, or **meters per second (m/s)**.

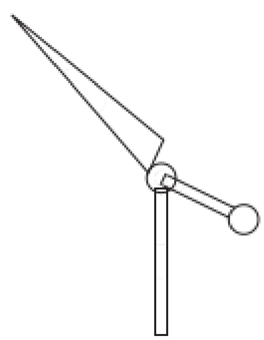
9. Rotor construction of HAWT and VAWT

Rotors are the parts of wind turbines that capture wind energy and convert it into rotational motion. Both Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT) have different rotor designs, each with its unique features, advantages, and disadvantages.

1. HAWT Rotor Designs

HAWTs can have various rotor designs, including:

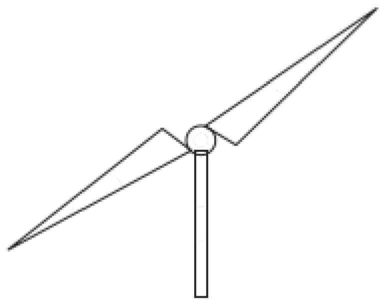
(i) Single-Blade Rotor



(a)

- **Description**: This rotor has one blade and a counterweight to balance it.
- **Merits**: Simple construction, lightweight, and low cost.
- **Demerits**: Makes more noise during operation and is generally less stable. Suitable for low-power applications.

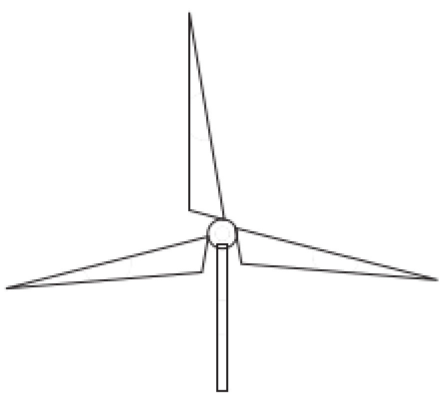
(ii) Two-Bladed Rotor



(b)

- **Description**: Consists of two blades attached to a central hub.
- **Merits**: Smoother power output than single-blade designs and less noise.
- **Demerits**: Less efficient than three-bladed designs and may require a yaw control mechanism.

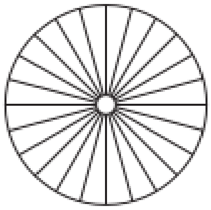
(iii) Three-Bladed Rotor



(c)

- **Description**: The most common type, with three blades.
- **Merits**: Higher efficiency and more power output than two-bladed designs. Good stability and quieter operation.
- **Demerits**: Heavier than two-blade rotors, leading to higher construction and installation costs.

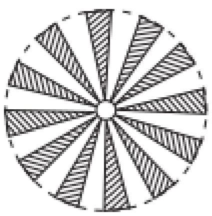
(iv) Chalk Multiblade Rotor



(d)

- **Description**: Features multiple blades designed for low-speed applications.
- **Merits**: High starting torque and can operate in low wind conditions.
- **Demerits**: Generally lower efficiency for power generation.

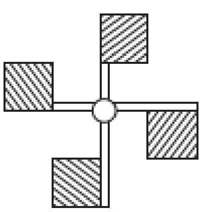
(v) Multiblade Rotor



(e)

- **Description**: Contains several blades, often used in specific applications.
- **Merits**: High solidity, which allows operation at low speeds.
- **Demerits**: Often less efficient for high-speed wind conditions.

(vi) Dutch-Type Rotor

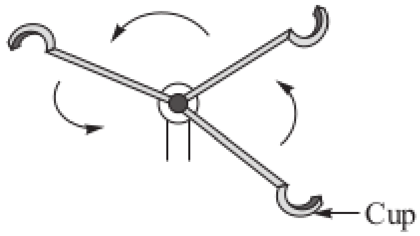


(f)

- **Description**: Similar to multiblade rotors, designed for low-speed applications.
- **Merits**: High starting torque and effective in low wind conditions.
- **Demerits**: Generally less efficient for high power generation.

2. VAWT Rotor Designs

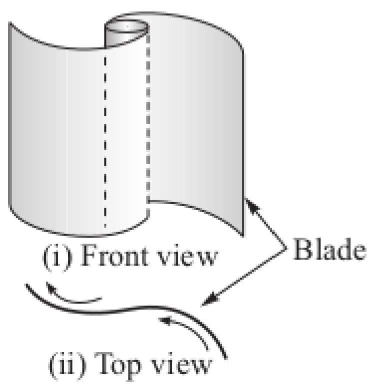
(i) Cup Type Rotor



(a)

- **Description**: Made of three or four cup-shaped structures attached to a vertical shaft.
- **Merits**: Simple design and easy to manufacture.
- **Demerits**: Low efficiency in capturing wind energy, mostly used for measuring wind speeds (e.g., anemometers).

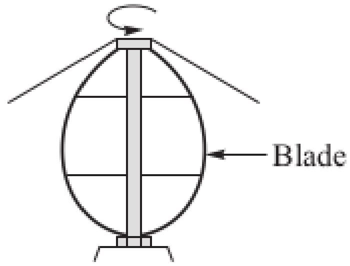
(ii) Savonius Rotor (S-Rotor)



(b)

- **Description**: Composed of two half-cylinders attached to a vertical axis, facing opposite directions.
- **Merits**: High starting torque at low wind speeds, can operate in a wide range of conditions.
- **Demerits**: Low overall efficiency for power conversion. Best for applications like wind pumping.

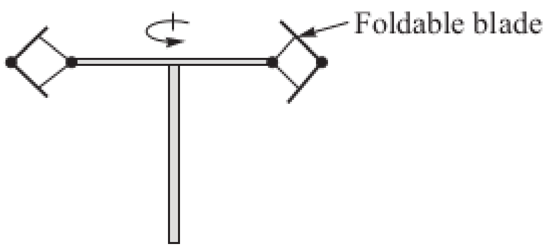
(iii) Darrieus Rotor



(c)

- **Description**: Features two or three curved blades, resembling an eggbeater.
- **Merits**: High power coefficient, suitable for large-scale power generation, and efficient at higher speeds.
- **Demerits**: Not self-starting, often requiring external energy to begin rotation, and has fixed blade pitch, leading to performance issues in high winds.

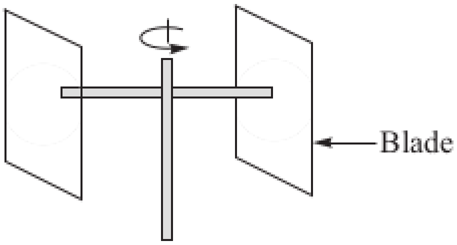
(iv) Musgrove (H-Shaped) Rotor



(d)

- **Description**: Composed of H-shaped blades that can fold to control power.
- **Merits**: Can adapt to changing wind conditions, allowing for better power management.
- **Demerits**: Fixed pitch can limit efficiency in varying wind speeds.

(v) Evans Rotor



(e)

- **Description**: Features hinged blades on a vertical shaft, with the ability to vary pitch during rotation.

- **Merits**: Self-starting design, allowing it to operate in low winds effectively.
- **Demerits**: More complex construction, which may increase maintenance needs.
- **HAWT** rotors are generally more efficient for power generation, especially with three-bladed designs. They are suited for high-speed applications.
- **VAWT** rotors are better for low-speed applications, with designs like the Savonius rotor being great for starting torque but less efficient for energy conversion.

10. Wind energy storage

Wind Energy Storage

Wind energy is an intermittent source of power, meaning that the amount of energy generated by wind turbines can vary significantly based on wind conditions. To ensure a steady supply of electricity even when the wind isn't blowing, it's essential to have effective storage solutions. Here's a simple explanation of how wind energy can be stored for later use:

1. **Chemical Energy Storage (Batteries)**:
    - Wind turbines can charge batteries, storing energy as chemical energy. When needed, this stored energy can be converted back into electricity, making it available for use.
2. **Thermal Energy Storage**:
    - The energy produced by wind turbines can be used to heat water. This can be done by using electric heaters or by using the power to churn the water. The hot water can then be used later for heating or other applications.
3. **Compressed Air Energy Storage**
    - Wind energy can be used to compress air and store it in a tank. When electricity is needed, the compressed air can be released to drive a turbine that generates electricity.
4. **Electrolysis of Water**:
    - Wind-generated electricity can power an electrolysis process that splits water into hydrogen and oxygen. The hydrogen gas can be stored and later converted back to electricity using fuel cells.
5. **Pumped Hydro Storage**:

- Wind energy can be used to pump water from a lower reservoir to a higher one. When electricity is needed, the water can be released back down to generate electricity as it flows through turbines.

6. **Integration with the Electric Grid**:
    - Wind energy can be fed into the existing electric grid. This allows excess energy to be stored in the grid or used to meet peak electricity demands when needed.

11. Environmental impacts of Wind Turbines

1. **Emissions**:
    - Wind turbines produce clean energy with no carbon dioxide emissions during operation.
    - However, some emissions occur during their manufacturing and installation, but these are minimal.
    - The energy used to build and install turbines is usually recovered within a few months of operation.
2. **Impact on Birds**:
    - The rotating blades of wind turbines can pose a risk to birds.
    - Many birds accidentally fly into the blades, leading to injuries or fatalities. This is a concern for wildlife conservation.
3. **Noise**:
    - Wind turbines generate noise due to the movement of the blades and the air around them.
    - This noise can be quite loud and bothersome, which is why turbines are often located far from residential areas.
4. **Interference with Communication**:
    - Tall wind turbines can interfere with microwave signals used for television and communication, affecting the quality of radio and TV reception in nearby areas.
5. **Visual Intrusion**:
    - The large structures of wind turbines can be seen from great distances, which may disturb the natural beauty of landscapes. Some people find them unappealing in scenic areas.
6. **Safety Concerns**:

- There are safety risks associated with wind turbines. For instance, if a blade breaks or gets damaged, it could potentially harm nearby people or property, especially during strong winds.

7. **Impact on Ecosystems**:
    - Wind is a natural part of the Earth's ecosystem, created by differences in temperature and pressure. Large-scale wind energy projects can disrupt local ecosystems and affect the natural balance.