Module-5

Wind power Generator *–Basic components of wind energy conversion system, types of wind generators- Horizontal and vertical axis. Advantages and disadvantages of WECS.*
Solar power generator - *principle of solar cell, Basic Solar Photo voltaic, system for power generation, Advantages and disadvantages.*

Introduction to wind

- Sun is the main source of wind, and hence, wind is a form of solar energy.
- Winds are caused by:

✓ uneven heating of the atmosphere by the sun
✓ the irregularity of the earth's surface
✓ rotation of the earth.

Properties of wind

1. Direction: Wind is described by the direction from which it is blowing.
2. Speed: Wind speed refers to the rate at which the air is moving. miles per hour (mph) or kilometers per hour (km/h).
3. Pressure Gradient: The difference in air pressure between two points is the driving force behind wind.
4. Turbulence: Wind can exhibit turbulence, which refers to irregular and chaotic airflow. Turbulence can cause fluctuations in wind speed and direction, resulting in gusts and eddies.
5. Vertical Profile: Wind can vary with height above the Earth's surface. As you move higher in the atmosphere, away from surface influences, wind speed tends to increase and become more consistent in direction.
6. Seasonal and Local Variations: Wind patterns can vary based on seasonal and local factors.
7. Wind Energy: Wind turbines capture the kinetic energy of the wind and convert it into electricity.

Basic Components of Wind Energy Conversion System (WECS)

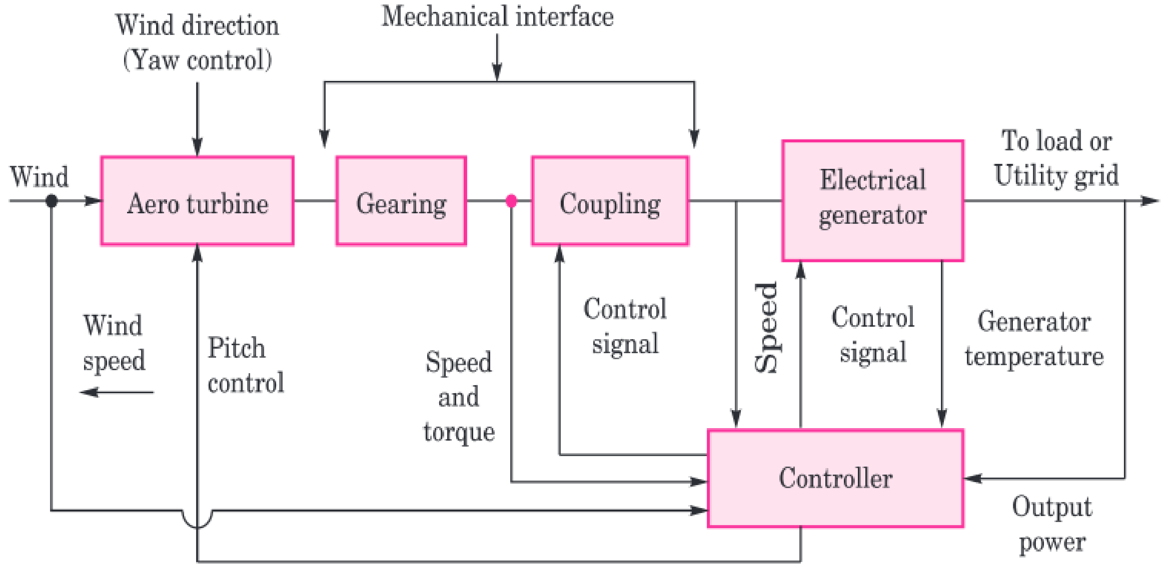


Fig. 6.12. Basic components of a wind electric system.

Mechanical Components	Electrical Components
1. Rotor	1. Generator
2. Main Shaft	2. Power Converter
3. Gearbox	3. Step-up Transformer
4. Mechanical Break	4. Wind Farm Collection Points or Point of Common Coupling
5. Nacelle	
6. Pitch and Yaw Drives	
7. Wind Measuring Equipment	

Mechanical Components

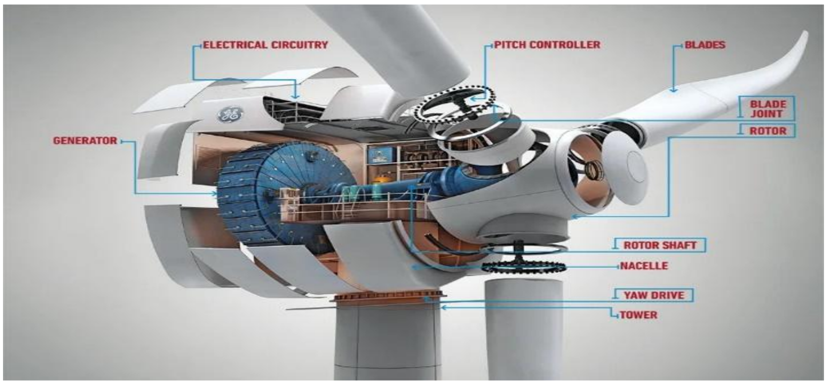


Fig: Mechanical components of WECS (Only for information)

The mechanical components of a WECS include the rotor, the main shaft, gearbox, mechanical breaks, nacelle, pitch and yaw drives, and wind measuring equipment,

1. Rotor: It is the most important component of a WECS. It is a large wheel that has blades attached to it. The rotor is what captures the wind and turns it into mechanical energy.
2. Main Shaft: The main shaft is the shaft attached to the rotor. It is made of steel or aluminum and connected to the gearbox.
3. Gearbox: The gearbox is a device that increases the rotational speed of the rotor. It is made of gears, and it is located in the nacelle.
4. Mechanical Breaks: Mechanical breaks are used to stop the rotor from spinning. They are located in the nacelle and activated when the wind speed is too high.
5. Nacelle: The nacelle is the housing that contains all of the electrical and mechanical components of the WECS. It is located at the top of the turbine, and it is made of steel or aluminum.
6. Pitch and Yaw Drives: Pitch and yaw drives are used to adjust the angle of the blades. They are located in the nacelle, and a computer operates them.
7. Wind Measuring Equipment: Wind measuring equipment is used to measure wind speed and direction. It is located in the nacelle and consists of anemometers and wind vanes.

5.2 Electrical Components

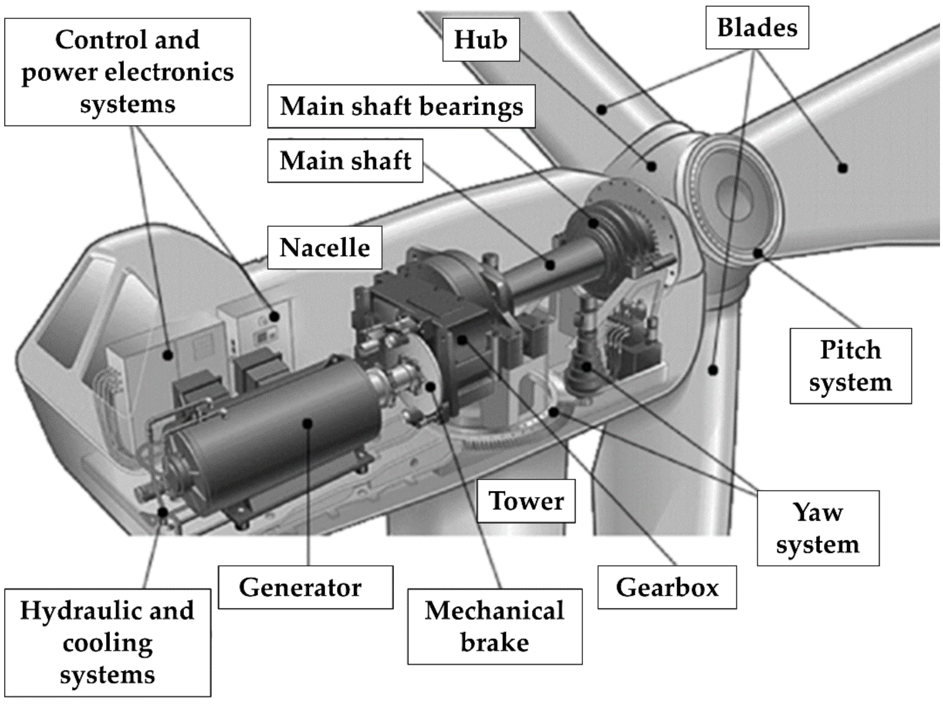
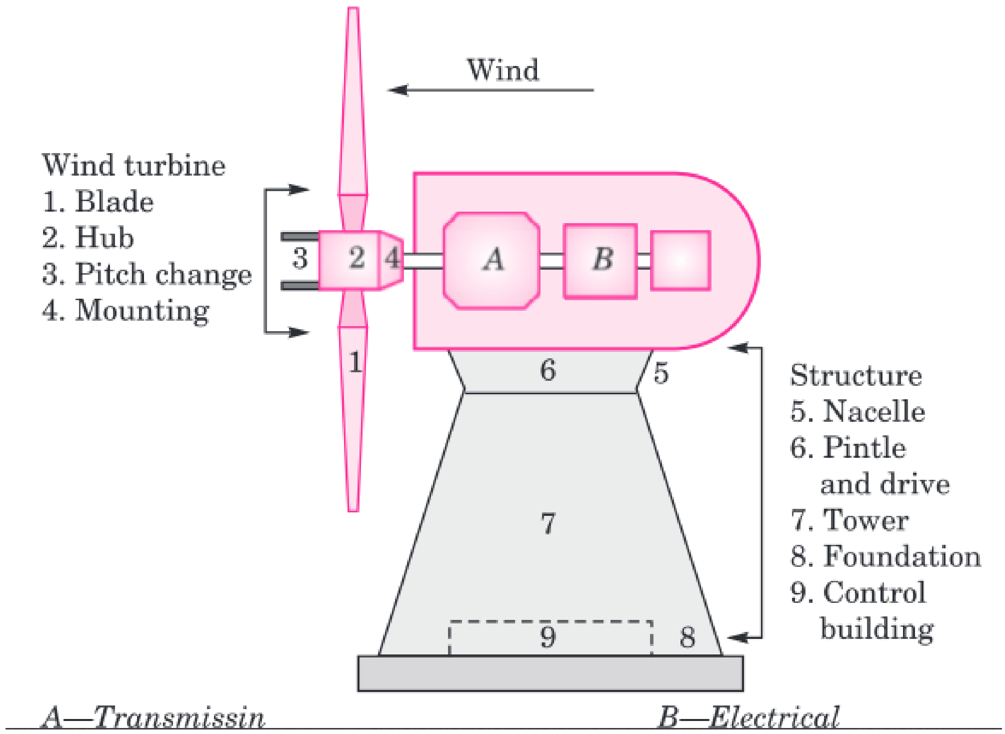


Fig: Electrical components of WECS (Only for information)

The electrical components of a WESC include the generator, power converter, step-up transformer, and wind farm collection points or points of common coupling.

1. Generator: A device that converts mechanical energy into electrical energy. It is located in the nacelle and is connected to the main shaft.
2. Power Converter: The power converter is a device that converts DC into AC. It is located in the nacelle, connected to the generator.
3. Step-up Transformer: The step-up transformer is a device that increases the voltage of the electricity. It is located in the nacelle, connected to the power converter.
4. Wind Farm Collection Points or Point of Common Coupling: Are used to collect the electricity from the turbines. They are located at the turbine's base, and they are connected to the power converter.

5.3 The physical embodiment for such an areo-generator is shown in a generalized form in Fig. below.



The sub components of the windmill are:

1) Rotors are mainly of two types:

- ✓ Horizontal axis rotor
- ✓ Vertical axis rotor

• One advantage of vertical axis machines is that they operate in all wind directions

• The portion of the wind turbine that collects energy from the wind is called the rotor.

2) Windmill head

• Supports the rotor, housing the rotor bearings

• Also incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind

3) Transmissions:

• The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed.

• Generators typically require rpm's of 1,200 to 1,800.

• As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production.

• Some DC-type wind turbines do not use transmissions.

• Instead, they have a direct link between the rotor and generator.

• These are known as direct drive systems.

• Without a transmission, wind turbine complexity and maintenance requirements are reduced.

• But a much larger generator is required to deliver the same power output as the AC-type wind turbines.

4) Control:

• The modern large wind turbine generator requires a versatile and reliable control system to perform the following functions:

• Orientation of the wind in the rotor

• Generator output monitoring — status, data computation and storage

5) Towers:

Four types of supporting towers deserve consideration, these are:

(l) the reinforced concrete tower,

(2) the pole tower,

(3) the built up shell-tube tower, and

(4) the truss tower.

Advantages and Disadvantages of WECS

Advantages:

1. It is a renewable source of
2. non-polluting, so it has no adverse influence on the environment.
3. Wind energy systems avoid fuel provision and transport.
4. On a small scale upto a few kilowatt system is less costly. On a large-scale costs can be with conventional electricity and lower costs could be achieved by mass production.

Disadvantages

1. Wind available in dilute and fluctuating in nature.
2. Unlike water wind energy needs storage capacity because of its irregularity.
3. Wind energy systems are noisy in operation.
4. Wind power systems have a relatively high overall weight. For large systems a weight of 110 kg/kW (rated) has been estimated.
5. Large areas are needed, typically, propellers 1 to 3 m in diameter, deliver in the 30 to 300 W range.
6. Present systems are neither maintenance free not-practically reliable.

Classification of WECS

1. <u>Two broad classifications:</u>

i. **Horizontal Axis Machines:** The axis of rotation is horizontal and the aeroturbine plane is vertical facing the wind.

ii. **Vertical Axis Machines:** The axis of rotation is vertical. The sails or blades may also be vertical.

2<u>. Based on size:</u>

i. **Small Size** –upto 2kW

ii. **Medium Size-** 2 to 100kW

iii. **Large Size** -100kW and above:

2 Sub types: a. Single Generator b. Multiple Generators

3. <u>Based on Output Power:</u>

i. DC output

a.DC generator

b. Alternator rectifier

ii AC output

a. Variable frequency, variable or constant voltage AC.

b. Constant frequency, variable or constant voltage AC.

4<u>. Based on rotational speed of the aeroturbines</u>

i. **Constant Speed with variable pitch blades:** This made implies use of synchronous generator with its constant frequency output.

ii. **Nearly Constant Speed with fixed pitch blades**: This mode implies an induction generator.

iii. **Variable Speed with fixed pitch blades:** This mode could imply, for constant frequency output

(a) Field modulated system

(b) AC-DC-AC link

(c) Double output induction generator

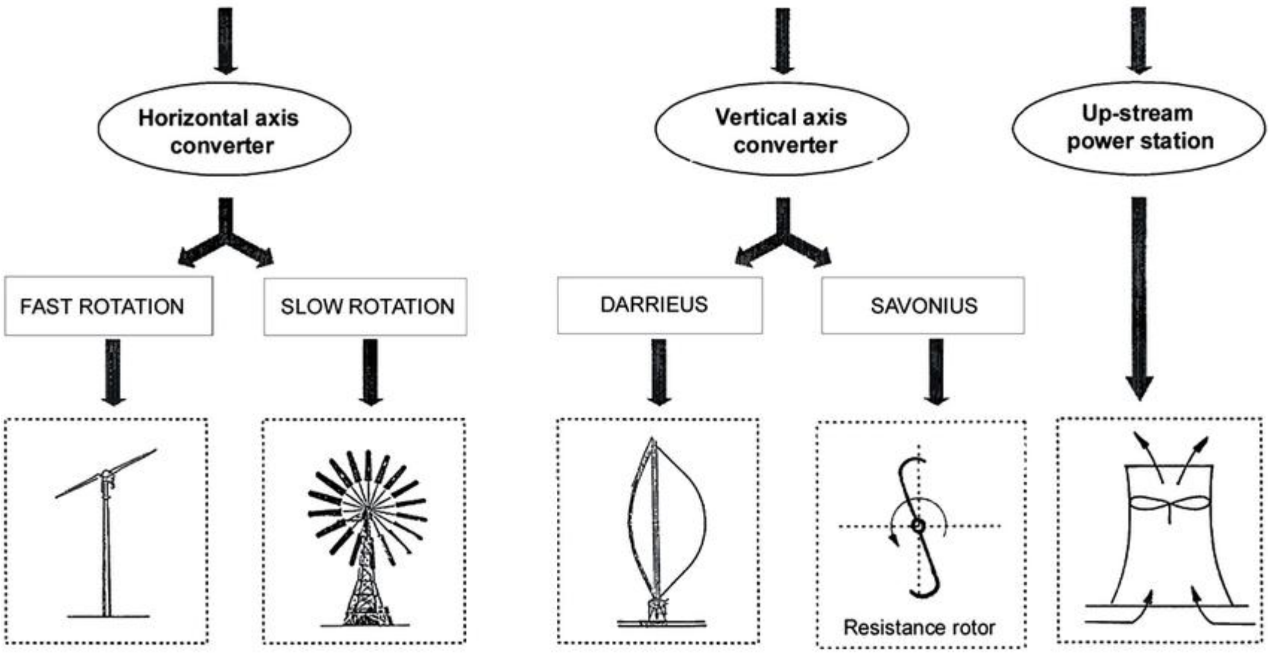
(d) AC commutator generators

(e) Other variable speed constant frequency generating systems.

5. Based on utilization of output :

i. Battery storage.
ii. Direct connection to an electromagnetic energy converter.
iii. Other forms (thermal potential etc.) of storage.
iv. Interconnection with conventional electric utility grids.

Wind Collectors



Rotational Axis

There are two types of rotational axis: horizontal and vertical.

1. A horizontal axis wind turbine (HAWT): is the most commonly used type. The rotor blades are mounted on a horizontal shaft perpendicular to the ground.

<u>2. A vertical axis wind turbine (VAWT):</u> has its rotor blades mounted on a vertical shaft parallel to the ground. VAWT is less common than HAWT because it is more expensive and complicated to build and is not as efficient in converting wind energy into electricity.

Horizontal Axis Wind Turbines (HAWT)

- A HAWT has a similar design to a windmill, it has blades that look like a propeller that spins on the horizontal axis as shown in the figure
- Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and oriented perpendicular to the wind.
- Small turbine are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind.

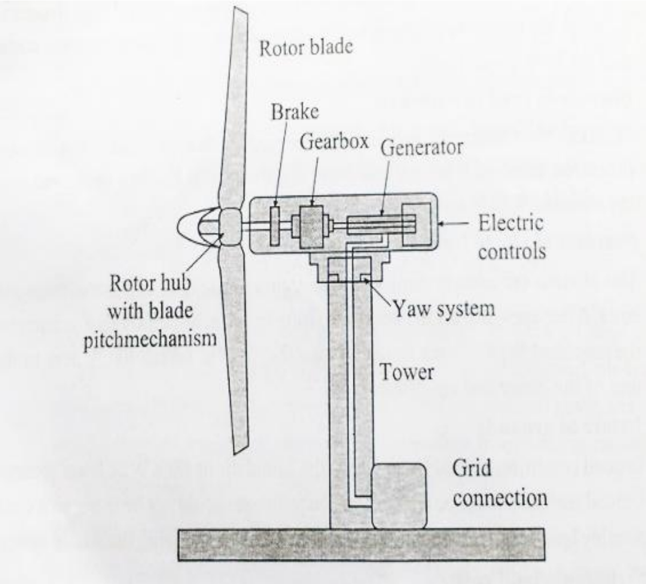


Fig. 5.8 Schematic Structure ofHorizontal Axis Wind Turbines

- Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.
- Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower.
- Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds.

- Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount

HAWT Advantages

1. It includes high output power as compared to the vertical wind turbine.
2. A tall tower gets stronger winds once the wind shear alters.
3. High efficiency.
4. It is not expensive as compared to a vertical-type turbine.
5. It has high reliability.
6. It has a high rate of capacity.
7. Its rotational speed is high.
8. It is more consistent.
9. The blade can also tilt the rotor during a storm to reduce damage.

HAWT Disadvantages

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

HAWT Applications

The applications of horizontal-axis wind turbines include the following.

1. These are the most frequently used wind turbines for commercial and industrial purposes due to their large power output and high efficiency.
2. These are mostly used in wind farms
3. Horizontal axis wind turbines achieve better power output & higher energy efficiency, so used in large-scale wind power plants & also for electricity generation.
4. 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.

7.1 Classification of HAWT: Classified based on no of blades

1. Single-Blade Turbines

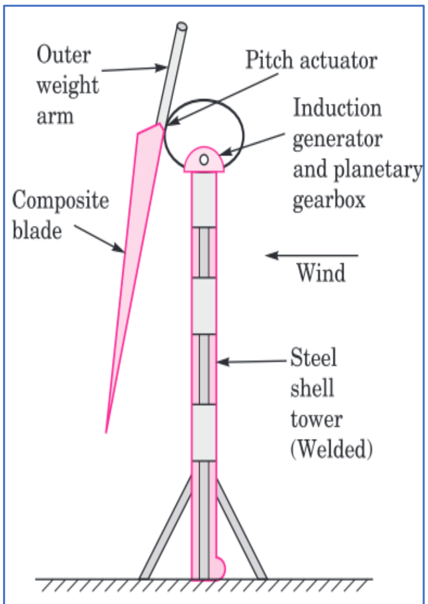
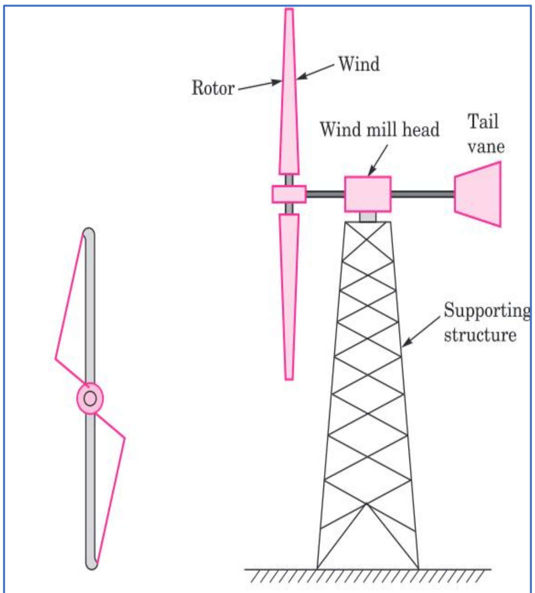


Fig. 6.15. Horizontal axis single blade wind mill.

- Single-blade wind turbines are used in a few limited applications, but they are the least used of all the Horizontal-Axis Wind Turbines.
- To rotate smoothly, single-blade turbines must have one or two counterbalances. The figure shows a single-blade wind turbine with two counterbalances.
- The advantage of this type of wind turbine is the lower cost because of the use of only one turbine blade (and the small weight savings).
- single-blade turbines must run at much higher speeds to convert the same amount of energy from the wind as two-blade or three-blade turbines with the same size blades.

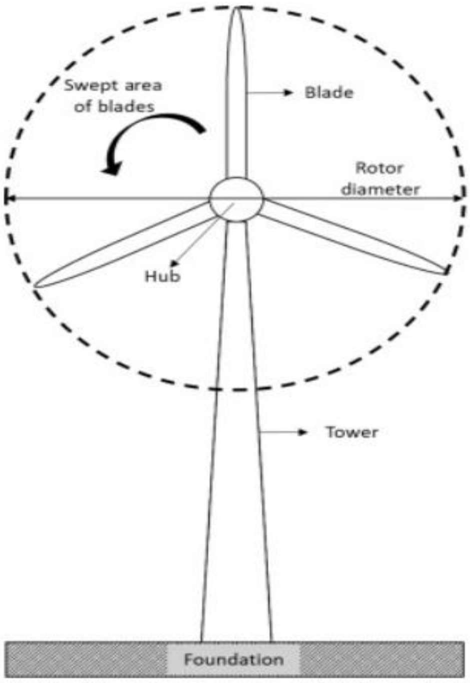
2. Two-Blade Wind Turbines



(a) Two blade prufile (b) Schematic of a horizontal axis type wind mills

- Compared to three-blade turbines, two-blade wind turbines have the advantage of saving on the cost and the weight of the third rotor blade, but they have the disadvantage of requiring higher rotational speed to yield the same energy output.
- This is a disadvantage in terms of both noise and wear of critical bearings, shafts, and gearboxes.

3. Three- blade Wind Turbine



The majority of large horizontal-axis wind turbines use three blades, with the rotor position maintained upwind by the yaw control.

The three blades provide the most energy conversion while limiting noise and vibration. The three blades provide more blade surface for converting wind energy into electrical energy than a two-blade or single-blade wind turbine.

The blades for the larger horizontal-axis wind turbines are so large they must be transported individually by a truck and trailer. This also means that one or more very large cranes are needed to set the tower and turbine in place.

The tower to hold the larger three-blade turbine must also be larger and reinforced to support the weight and to withstand the increased wind power that is harvested to produce its maximum output.

4. Horizontal axis multibladed type:

Here the multiblades are made from sheet metal or aluminium. The rotors have high strength to weight ratios and have been known to service hours of freewheeling operation in 60 km/hr winds. They have good power coefficient, high starting torque and added advantage of simplicity and low cost.

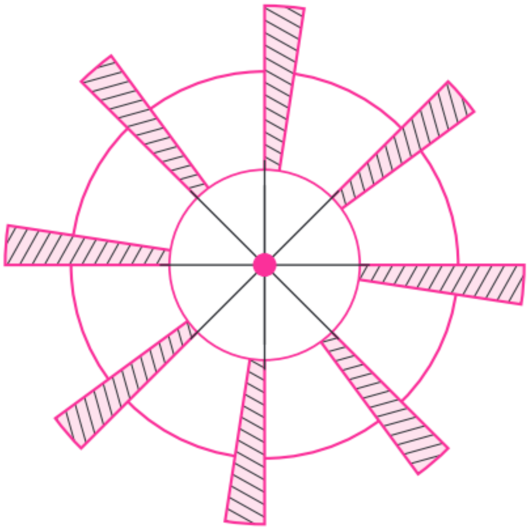


Fig. 6.16. Multiblade propeller.

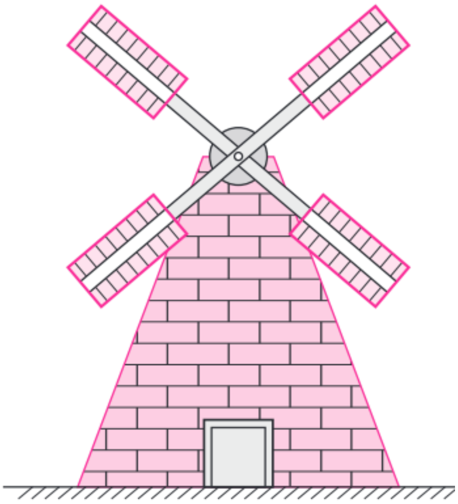


Fig. 6.17. Horizontal axis, Dutch type wind mill.

5. Sail type: The blade surfaces is made from cloth, nylon or plastics arranged as mast and pole or sail wings. There is also variation in the number of sails used. The horizontal axis types generally have better performance. They have been used for various applications, but the two major areas of interest are electric power generation, and pumping water. The latter introduces some complexity into the design as the mechanical energy has to be transmitted over a distance. Also in some cases the rotor motion has to be converted to reciprocating motion.

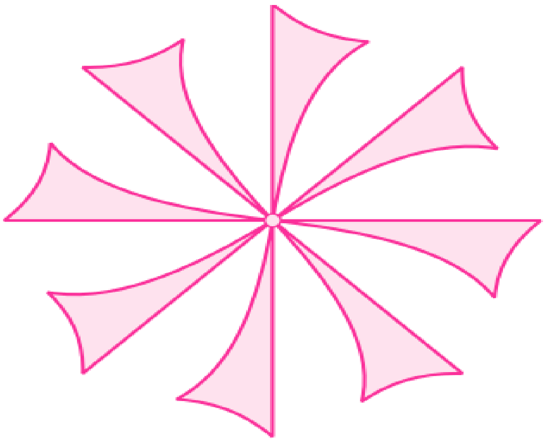


Fig. 6.18. Blades of sail type wind mill.

Vertical Axis Wind Turbines(VAWT)

- Vertical wind turbines(VAWTs), have the main rotor shaft arranged vertically as shown in Fig .
- The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on-site where the wind direction is highly variable or has turbulent winds

- With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT generally creates drag when rotating into the wind.
- VAWTs are a type of wind turbine where the main rotor shaft is set transverse to the wind (but not necessarily vertically) while the main components are located at the base of the turbine
- Vertical axis turbines are powered by wind coming from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom.

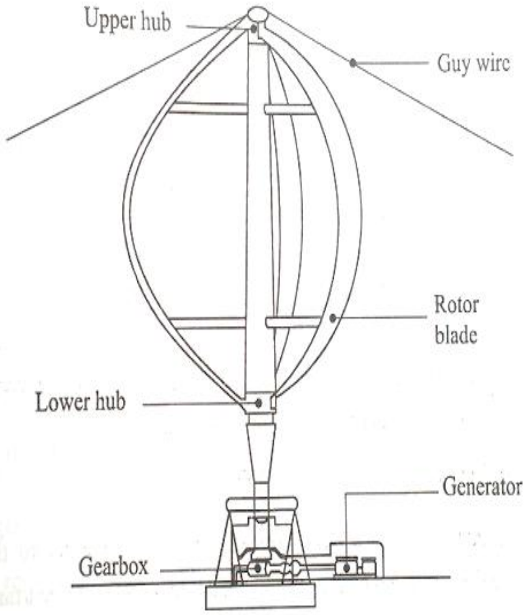


Fig. 5.9 Schematic Structure of Vertical Axis Wind Turbines (Darrieus wind turbine)

VAWT Advantages

1. No yaw mechanisms is needed
2. A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
3. VAWTs have lower wind startup speeds than the typical the HAWTs.
4. VAWTs may be built at locations where taller structures are prohibited.
5. VAWTs situated close to the ground can take advantage of locations where rooftops, means hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

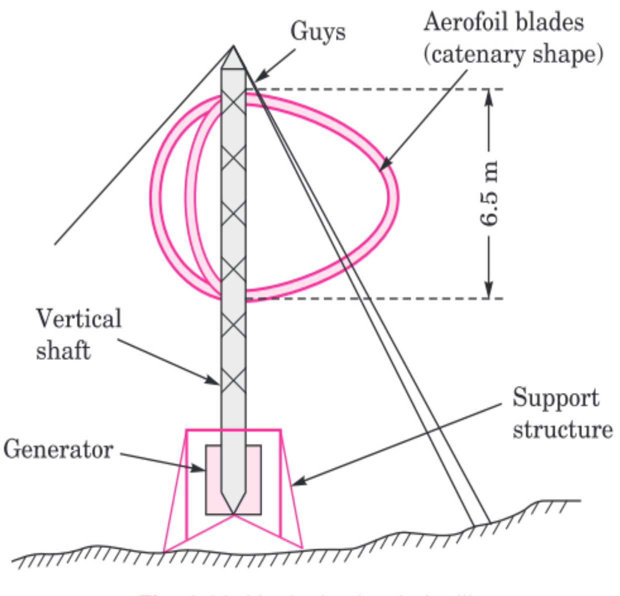
VAWT Disadvantage

1. Most VAWTs have an average decreased efficiency from a common HAWT, mainly because o the additional drag that they have as their blades rotate into the wind.

Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.

2. Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.
3. Because VAWTs are not commonly deployed due mainly to the serious disadvantage mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

Darrieus Wind Turbine



- Darrieus turbine has long, thin blades in the shape of loops connected to the top and bottom of the axle; it is often called an "eggbeater windmill."
- The Darrieus turbine is characterized by its C-shaped rotor blades which give it its eggbeater appearance.
- It is normally built with two or three blades.
- They have good efficiency but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability

Advantages

(1) The rotor shaft is vertical. Therefore it is possible to place the load, like a generator or a centrifugal pump at ground level. As the generator housing is not rotating, the cable to the load is not twisted and no brushes are requires for large twisting angles.

(2) The rotor can take wind from every direction.

(3) The visual acceptation for placing of the windmill on a building might be larger than for an horizontal axis windmill.

(4) Easily integrates into buildings.

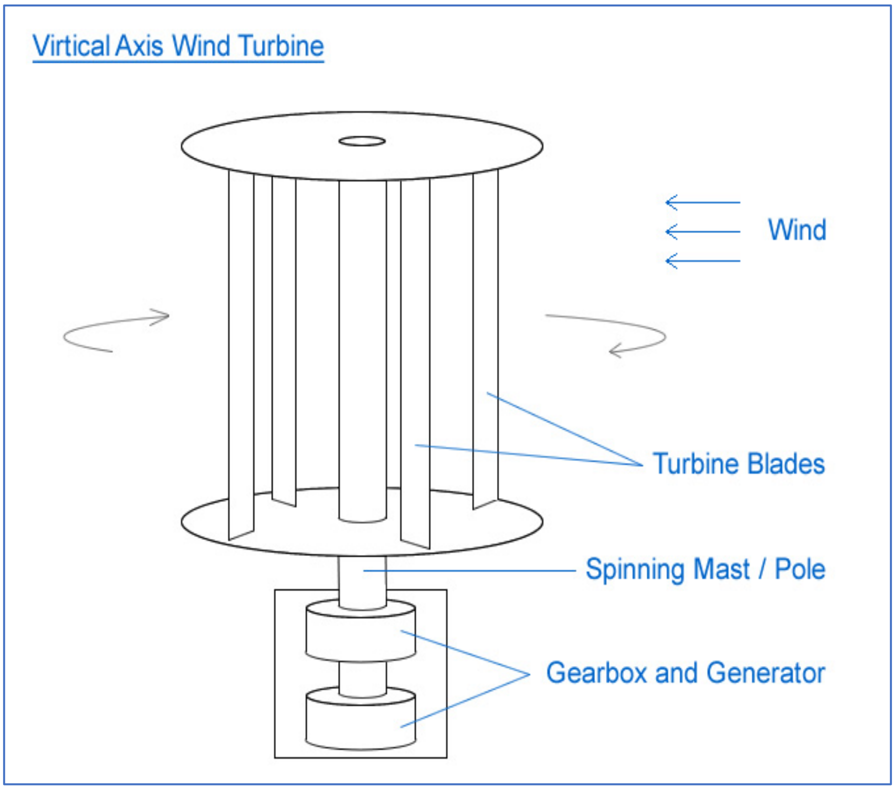
Disadvantages

(1) Difficult start unlike the Savonius wind turbine.

(2) Low efficiency.

Savonius wind turbine

1. The Savonius wind turbine is a type of vertical-axis wind turbine
2. It consists of two to three “scoops” that employ a drag action to convert wind energy into torque to drive a turbine.
3. A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers.
4. They are a drag type turbine they are less efficiency than the common HAWT.
5. Savonius are excellent in areas of turbulent wind and self starting.



Advantages

(1) Having a vertical axis, the Savonius turbine continues to work effectively even if the wind changes direction.

(2) Because the Savonius design works well even at low wind speeds, there’s no need for a tower or other expensive structure to hold it in place, greatly reducing the initial setup cost.

(3) The device is quiet, easy to build, and relatively small.

(4) Because the turbine is close to the ground, maintenance is easy.

Disadvantages

The scoop system used to capture the wind’s energy is half as efficient as a conventional turbine, resulting in less power generation.

Solar Electric Power Generation: Solar Photovoltaics

Introduction.

Energy conversion devices that are used to convert sunlight to electricity by the use of the photovoltaic effect are called solar cells. A single converter cell is called a solar cell that is a photovoltaic cell, and combination of such cells; designed to increase the electric power output is called a solar module or solar array.

Photovoltaic cells are made of semiconductors that generate electricity when they absorb light. These devices have theoretical efficiencies of the order of 25 percent. Actual operating efficiencies are less than half this value.

Solar Cell Principles:

When photons from the sun are absorbed in a semiconductor, they create free electrons with higher energies. Once these electrons are created, there must be an electric field to induce these higher energy electrons to flow out of the semiconductor to do useful work. The electric field in most solar cells is provided by a junction of materials which have different electrical properties.

To obtain a useful power output from photon interaction in a semiconductor three processes are required.

1. The photons have to be absorbed in the active part of the material and result in electrons being excited to a higher energy potential.
2. The electron-hole charge carrier created by the absorption must be physically separated and moved to the edge of the cell.
3. The charge carriers must be removed from the cell and delivered to a useful load before they loose their extra potential.

The flow of electrons through the external conductor constitutes an electric current which will continue as long as more free electrons and holes are being formed by the solar radiation. This is the basis of photovoltaic conversion, that is, the conversion of solar energy into electrical energy. The combination of n-type and p-type semiconductors thus constitutes a photovoltaic (P V) cell or solar cell. All such cell, generate direct current which can be converted into alternating current if desired.

The most normal configuration for a solar cell to make a p-n junction semiconductor is as shown schematically in Fig. The back is completely covered by a metallic contact to remove the charges to the electric load. The collection of charges from the front of the cell is aided by a fine grid of narrow metallic fingers. An anti-reflective coating is applied on the top of the cell.

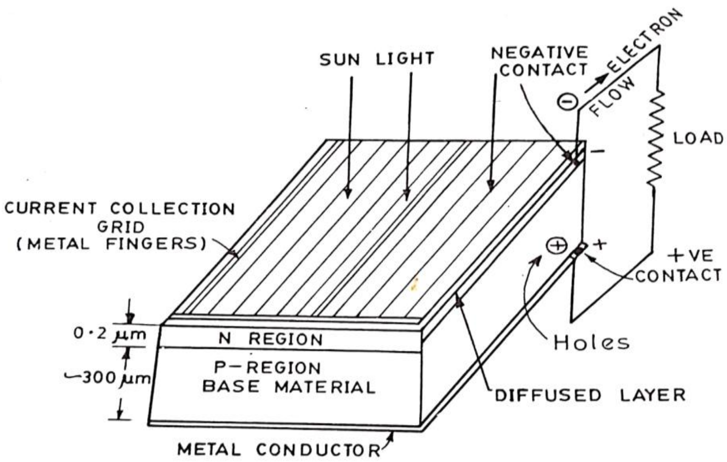


Fig. 5.6.1. Schematic view of a typical solar cell.

The rate at which solar energy reaches the top of the atmosphere (i.e., the solar constant) is 1.353 kilowatts/sq. m (1.353 kW/sq. m). Part of this energy is reflected back to the space, and part is absorbed by the atmosphere. In full sunlight, the solar energy may reach the ground at a rate of roughly 1 kW/sq. m.

A Basic Photovoltaic System for Power Generation

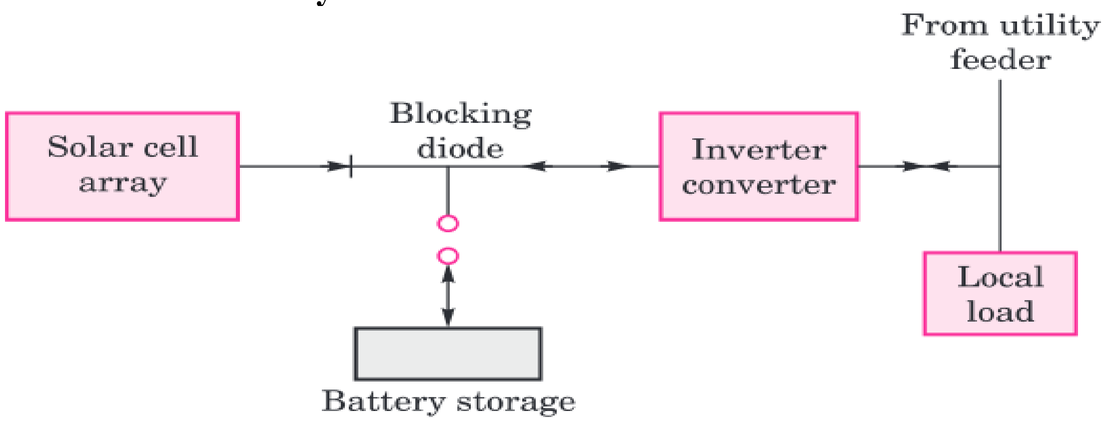


Fig. 5.25. Basic photovoltaic system integrated with power grid.

A basic photovoltaic system integrated with the utility grid is shown in Fig. It permits solarly generated electrical power to be delivered to a local load. It consists of:
(i) Solar Array: converts the insolation to useful DC electrical power.
(ii) A Blocking Diode: which lets the array-generated power flow only toward the battery or grid. Without a blocking diode the battery would discharge back through the solar array during times of no insolation
(iii) Battery Storage: solar generated electric energy may be stored.
(iv) Inverter/converter: converts the battery bus voltage to AC of frequency and phase to match that needed to integrate with the utility grid. Thus it is typically a DC, AC inverter. It may also contain a suitable output step up transformer, filtering and power factor correction circuits, power conditioning, i.e., circuitry to initiate battery charging and to prevent over charging.
(v) Appropriate switches and circuit breakers: to permit isolating parts of the system as the battery and breakers protect PV system and grid

Applications of Solar Photovoltaic System

The terrestrial applications of these include provision of power supply to:
(i) water pumping sets for micro irrigation and drinking water supply,
(ii) radio beacons for ship navigation at ports,
(iii) community radio and television sets,
(iv) cathodic protection of oil pipe lines,
(v) weather monitoring,
(vii) battery charging,
(vi) railway signalling equipment,
(viii) street lighting.
The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of:
(a) a photovoltaic (P V) array,
(c) power control equipment,

(b) storage battery,
(d) motor pump sets, and
(e) water storage tank.

Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages:

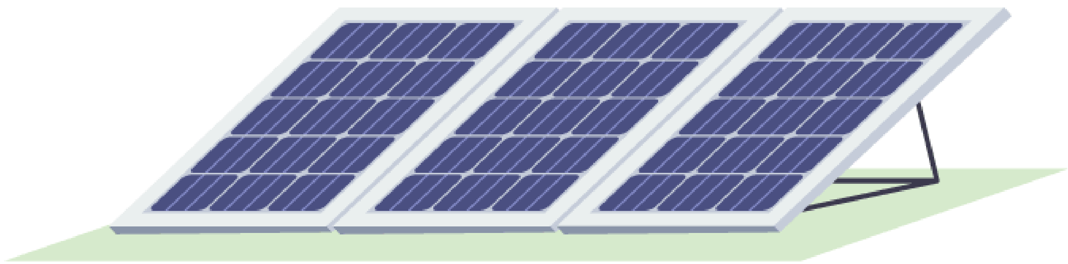
(i) Direct room temperature conversion of light to electricity through a simple solid-state device.
(ii) Absence Of moving parts.
(iii) Ability to function unattended for long periods as evidenced in the space program.
(iv) Modular nature in which desired currents, voltages, and power levels can be achieved by mere integration.
(v) Maintenance cost is low as they are easy to operate.
(vi) They do not create pollution.
(vii) They have a long effective life.
(viii) They are highly reliable.
(ix) They consume no fuel to operate as the sun's energy is free.
(x) They have a rapid response in output to input radiation changes; no long-time constant is involved, as in thermal systems, before a steady state is reached.
(xi) They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuitry to feed power into the utility grid.
(xii) They are easy to fabricate, being one of the simplest of semiconductor devices.
(xiii) They have a high power-to-weight ratio, this characteristic is more important for space applications than terrestrial, may be favourable for some terrestrial applications,
(xiv) Amenable to on-site installation- decentralized power
(xv) They can be used with or without sun tracking for a wide range of applications

Disadvantages:

High cost
Energy storage is required because of no insolation at night.
Efforts are being made world-wide to reduce costs through various technological innovations.

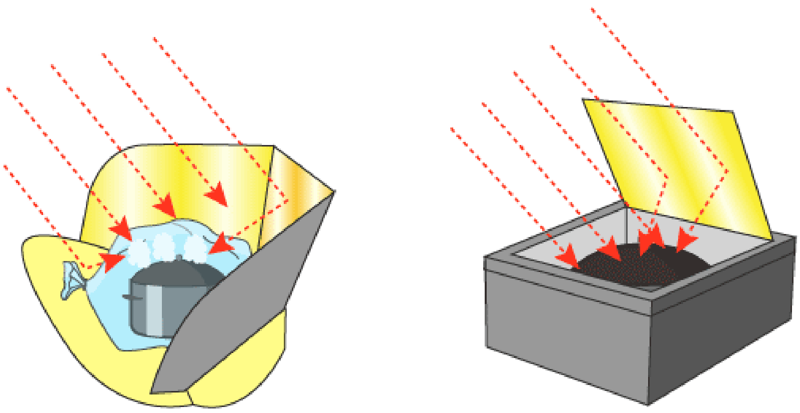
Solar Power:

Solar power is an indefinitely renewable source of energy as the sun has been radiating an estimated 5000 trillion kWh of energy for billions of years and will continue to do so for the next 4 billion years. Solar energy is a form of energy which is used in power cookers, water heaters etc. The primary disadvantage of solar power is that it cannot be produced in the absence of sunlight. This limitation is overcome by the use of solar cells that convert solar energy into electrical energy. In this section, we will learn about the photovoltaic cell, its advantages, and disadvantages.



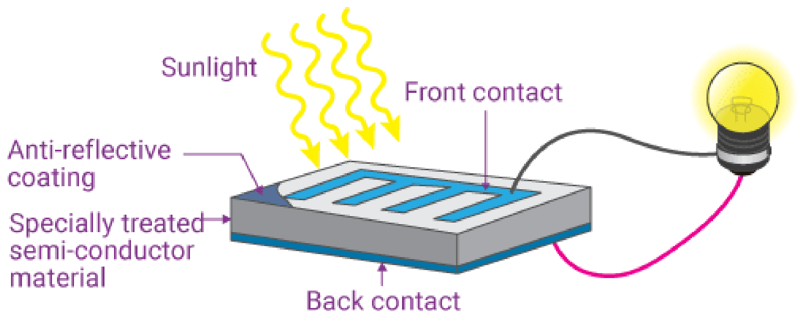
Solar Energy:

It is defined as the radiating light and heat from the sun that is harnessed using devices like heaters, solar cookers, and photovoltaic cells to convert it to other forms of energy such as electrical energy and heat.



Photovoltaic Cell:

- Photovoltaic cells consist of two or more layers of semiconductors with one layer containing positive charge and the other negative charge lined adjacent to each other.
- Sunlight, consisting of small packets of energy termed as photons, strikes the cell, where it is either reflected, transmitted or absorbed.
- When the photons are absorbed by the negative layer of the photovoltaic cell, the energy of the photon gets transferred to an electron in an atom of the cell.
- With the increase in energy, the electron escapes the outer shell of the atom. The freed electron naturally migrates to the positive layer creating a potential difference between the positive and the negative layer. When the two layers are connected to an external circuit, the electron flows through the circuit, creating a current.



Advantages of Photovoltaic Cells:

- **Environmental Sustainability:** Photovoltaic cells generate clean and green energy as no harmful gases such as CO_x, NO_x etc are emitted. Also, they produce no noise pollution which makes them ideal for application in residential areas.
- **Economically Viable:**The operation and maintenance costs of cells are very low. The cost of solar panels incurred is only the initial cost i.e., purchase and installation.
- **Accessible:** Solar panels are easy to set up and can be made accessible in remote locations or sparsely inhabited areas at a lesser cost as compared to conventional transmission lines. They are easy to install without any interference with the residential lifestyle.
- **Renewable:** Energy is free and abundant in nature.
- **Cost:** Solar panels have no mechanically moving parts except in some highly advanced sunlight tracking mechanical bases. Consequently, the solar panel price for maintenance and repair is negligible.

Disadvantages of Photovoltaic Cells:

- The efficiency of solar panels is low compared to other renewable sources of energy.
- Energy from the sun is intermittent and unpredictable and can only be harnessed in the presence of sunlight. Also, the power generated gets reduced during cloudy weather.
- Long-range transmission of solar energy is inefficient and difficult to carry. The current produced is DC in nature and the conversion of DC current to AC current involves the use of additional equipment such as inverters.
- Photovoltaic panels are fragile and can be damaged relatively easily. Additional insurance costs are required to ensure a safeguard of the investments.