PART-B ESSAY QUESTIONS WITH SOLUTIONS

2.1 Solar Energy Storage

2.1.1 Different Methods – Sensible, Latent Heat and Stratified Storage

Q38. Why there is a need in solar thermal energy storage?

Answer :

Need of Solar Thermal Energy Storage

The need of solar thermal energy storage is explained by considering the following cases,

1. In some cases, the energy supplied from the source may be constant. It may consist of a sharp peak load of a very short duration. Hence, in such cases very less amount of energy has to be stored. However, the amount of energy required to be stored is minimum and the energy transfer rate involved must be very high. If there is no provision of thermal energy storage, then a source which provides energy with larger rate is required, in order to meet the sharp demand which increases the total system cost.

2. The energy supplied by a source may vary i.e., the source may have a constant load similar to that of solar energy. For such cases, the amount of energy needed for storage must be stored in day time, rather than in the night time, because of lack of energy supplied at night. However, the energy source required for such storage must be high, in order to meet the load at day time and also to supply energy at night time.

3. The amount of energy supplied by source and the amount of energy in demand may vary. For example, consider a case where there is occurrence of solar space heating load at night time. In such case, the entire energy is collected during day time and stored to meet the demand at night. However, the amount of energy needed for such storage must be large.

4. In some cases, solar energy available in summer might be required in winter. For such situation, the energy collected during summer goes to storage and is later obtained from storage for winter. This is called as seasonal or long term storage.

Q39. Classify different solar energy storage systems and explain them in brief.

[April-18, (ME), (R13), Q5(b) | Model Paper, Q4(a)]

OR

Explain different methods of storing solar energy.

Answer :

Solar energy storage systems may be classified as below,

1. **Thermal Storage**

   Thermal storage can be achieved in two ways, sensible heat storage and latent heat storage.

   (i) **Sensible Heat Storage**

   For answer refer Unit-II, Q40, Topic: Sensible Heat Storage (without figure).

   (ii) **Latent Heat Storage**

   For answer refer Unit-II, Q41, Topic: Latent Heat Storage.

2. **Electrical Storage**

   Electrical storage can be achieved by capacitors, inductors and batteries.

   (i) **Capacitors Storage :** Large amount of electrical energy can be stored in capacitors. Capacitors store electrical energy at high voltage and low current. The expression for the total energy storage is given as,

$$H_{cap} = \frac{1}{2} V \varepsilon E^2$$

Where,

V – Volume of the dielectric

ε – Constant

E – Electric field strength.

(ii) **Inductors Storage** : Inductors store electrical energy at low voltage and high current. The expression for energy stored in an inductor is given as,

$$H_{ind} = \frac{1}{2} V \mu H_m^2$$

Where,

μ – Permeability of the material

H_m – Magnetic flux density

(iii) **Battery Storage :** Secondary batteries are used for this purpose because they are rechargeable. Some of such batteries are Pb – acid, Ni – Cd, iron air batteries, etc.

3. **Chemical Storage**

It is achieved by two methods. They are,

(i) **Storage in the Form of Fuel**

In this, the reactant in the battery is generated by a photochemical reaction promoted by solar radiation. This photochemically charged battery discharges electrical energy whenever needed. The photochemical reaction is shown below.

$$2NOCl + \text{Photons} \rightarrow 2NO + Cl_2$$

$$AgCl\,(s) + \text{Photons} \rightarrow Ag(s) + \frac{1}{2} Cl_2$$

$$NO_2 + \text{Photons} \rightarrow NO + \frac{1}{2} O_2$$

$$H_2C + \frac{1}{2} O_2 \xrightarrow{ZnO} H_2O_2$$

(ii) **Thermo-chemical Energy Storage**

In this type of storage, some reversible chemical reactions are used for storage of high temperatures. In forward reaction heat is absorbed and stored in the form of products and heat is liberated in the reversible reaction.

$$A + B \rightleftharpoons AB$$

4. **Mechanical Energy Storage**

This is achieved by three methods.

(i) **Pumped Hydroelectric Storage**

In this, surplus power during off-peak hours is used to pump water from a lower reservoir to a higher reservoir. During peak hours, this pumped water at higher heads is then allowed to flow through a hydraulic turbine, which drives an electric generator.

(ii) **Compressed Air Storage**

In this, air is pumped into a suitable pressurized storage tank and used, when the wind is unavailable. This air drives an air turbine, which in turn drives a generator.

(iii) **Flywheel Storage**

In this, surplus power during off-peak hours is stored in the form of mechanical energy in a flywheel. During peak hours, energy stored in the flywheel can be used to operate a generator to produce electricity.

5. **Electromagnetic Energy Storage**

For answer refer Unit-III, Q4.

Q40. Explain about any two methods of solar energy storage.

July-19, (R15), Q5(b)

OR

Discuss in detail any two of the solar energy storage methods.

Answer :

1. **Sensible Heat Storage**

It is a type of thermal energy storage. The material involved in the process undergoes no change in phase, over the temperature zone to which it is subjected in the storage unit. The equation for energy storage with respect to a fixed temperature difference is given as,

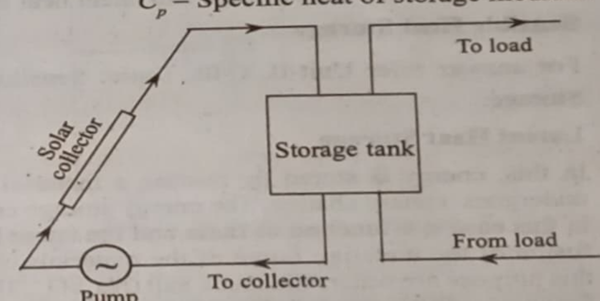
Where,

$$Q_S = (mC_p)_S (T_1 - T_2)$$

T_1, T_2 – Temperature limits of cycle

m – Mass of storage medium

C_p – Specific heat of storage medium



Figure

The system operates between the minimum requirements of the process and the vapour pressure of the liquid.

The capacity of heat storage depends upon the product of C_p and m. Most commonly used materials for storage are,

(i) Water

(ii) Rock, gravel or crushed store

(iii) Iron shot

(iv) Iron, red-oxide and iron-ore

(v) Refractory materials like silicon oxide, magnesium oxide and aluminium oxide.

2. **Capacitor Storage**

It is one of the methods of electrical storage. Capacitors are employed for the storage of large amount of electrical energy for long periods. The energy stored is given by,

$H = 1/2\ \varepsilon\ VE^2$

Where, ε – Constant

V – Dielectric volume

E – Electric field strength.

Electric field strength is dependent on the material and is limited by the breakdown strength (E_{br}) for the dielectric. The electrical energy, thus stored becomes limited for a material. Mica is the best available dielectric material.

Leakage losses are difficult to avoid with a usage of dielectric, as the conductivity of material is not zero. Also, capacitive storage for long durations of more than 12 hours is uneconomical.

The capacitor accumulates electrical energy at high voltage and low current.

Q41. How solar energy can be stored in the form of thermal energy? Explain.

Answer :

Thermal Energy Storage

By heating, melting or vaporization of a material, the solar energy can be stored and this energy can be made available as heat by reversing the process. Thermal energy storage is used for domestic water and space heating applications, and for the high temperature storage system required for thermal power generation. Thermal storage can be activated by two methods, sensible heat storage and latent heat storage.

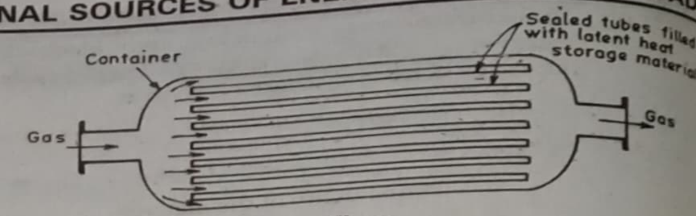
1. **Sensible Heat Storage**

For answer refer Unit-II, Q40, Topic: Sensible Heat Storage.

2. **Latent Heat Storage**

In this, energy is stored by heating a material which undergoes a phase change. The energy storage capacity in this case is a function of mass and the latent heat of fusion of the material. Some of the materials used for this purpose are water, Glauber's Salt ($Na_2SO_4 . 10H_2O$), $Fe(NO_3)_2 . 6H_2O$ and Salt Eutectics.

The major advantage of latent heat storage system is that, it is compact in size, compared to a sensible heat storage system. However, the principle of working is complex, as it involves heat transfer between a fluid and storage medium. During the heat extraction process, the storage material first solidifies at the heat transfer surface. Hence, the thermal resistance to the flow of heat keeps on increasing as heat is extracted from the storage. In order to prevent the excess thermal resistance the storage material is placed in long thin containers and the gas is passed through narrow spaces between the tubes. Alternatively, the storage material is placed in the spaces between the tubes and the gas is passed through the tubes.



Figure

Q42. Explain different methods of latent heat storage techniques with line diagrams.

April-18, (EEE), (R13), Q5(a)

Answer :

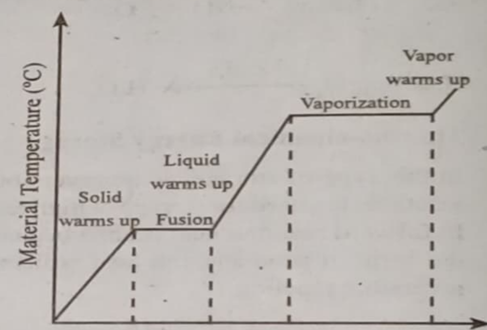
Latent Heat Storage Techniques

In this, energy is stored by heating a material which undergoes a phase change. The energy storage capacity in this case is a function of mass and the latent heat of fusion of the material.

The heat is stored in a material, which undergoes phase transformation during addition and extraction of heat and hence, such materials are called phase change materials.

Various techniques based on the phase changes are,

1. Solid to gas (vapour)
2. Liquid to gas (vapour)
3. Solid to liquid
4. Solid to solid.



Figure

1. **Solid to Gas (vapour) (lathine change)**

The solid to gas (vapour) technique is most difficult and complicated process which cannot be used for storage as there is large volume changes.

2. **Liquid to Gas (vapour)**

The liquid to gas (vapour) technique is also not suitable for energy storage. This is because,

(i) If the system is closed type with constant volume, the vapour pressure increases to a large extent during evaporation, which also leads to the increase in temperature which is required for phase change. Thus, storage is not practicable in constant volume.

(ii) If the system is closed with constant pressure, then there is a large change in the volume during evaporation which makes the system not suitable for storage application.

(iii) If the system is open type with constant pressure (ambient pressure), then the storage material gets evaporated on heat storage. Hence, it cannot be employed for storage application.

3. **Solid to Liquid**

In solid to liquid technique, the storage of heat uses salt hydrates, as storage material. The amount of heat or cold to be stored depends on the storage material selected. In this, storage involves phase change by melting and solidification. When the container used is large enough to fit the phase with larger volume, there will be no significant change in pressure. Thus, both melting and solidification takes place at constant temperature.

4. **Solid to Solid**

The solid to solid technique involves transformation of one crystalline form to other. This includes small changes in volumes which possess small latent heats.

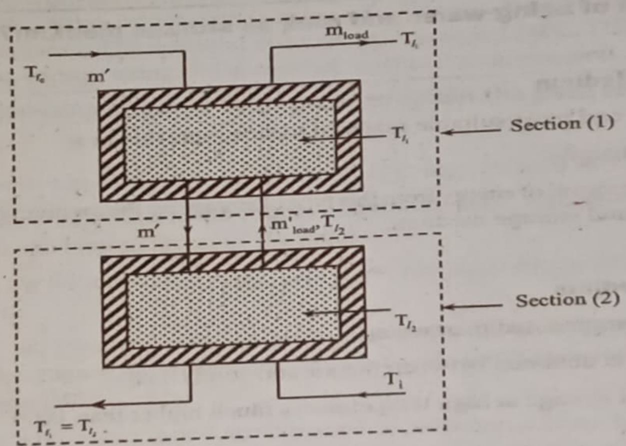
Q43. Draw and elaborate the analysis of a thermally stratified sensible heat liquid storage system.

Answer :

Analysis of Thermally Stratified Sensible Heat Liquid Storage System

It is quite difficult to analyse the thermally stratified tank, as it considers the temperature profile to be solved, as a function of time. Moreover, this issue is not considered practically in one dimensional, since the heat is also conducted through the walls of storage tank.

The analysis of thermally stratified sensible heat liquid storage tank is shown in figure below,



Figure

Thermally stratified heat can be analysed by considering a storage tank with various well-mixed sections at different temperatures and by writing energy balance equation for each section. For example, assume that the storage tank with two well mixed sections having a temperature T_{l_1} and T_{l_2} respectively. The energy balance on these sections is given by,

For section (1),

$$(\rho v c_p)e_1 \frac{dTl_1}{dt} = \dot{m}c_p\,(T_{f0} - T_{l1}) - \dot{m}_{\text{load}}\,C_p\,(T_{l1} - T_{l2}) - (UA)t_1\,(T_{l1} - T_a) \quad \text{... (1)}$$

For section (2),

$$(\rho v c_p)e_1 \frac{dTl_2}{dt} = \dot{m}c_p\,(T_{l1} - T_{l2}) - \dot{m}_{\text{load}}\,C_p\,(T_{l2} - T_{l1}) - (UA)t_2\,(T_{l2} - T_a) \quad \text{... (2)}$$

The above equations are written based on the assumption that the flow enters the tank at section (1) only. This can be possible only when $T_{f0} > T_{l1}$. If $T_{f0} < T_{l1}$ then there is no existence of flow.

Then, by combining the differential equations (1) and (2), the value of T_{l1} and T_{l2} can be determined. The above equation can be solved by expressing them in finite difference form and selecting a specific time period. Subsequently, T_{l1} and T_{l2} can be obtained from one time period to the other.

Q44. Differentiate between sensible and latent heat storage systems with diagrams.

June-18, (R13), Q4(a)

Answer :

	Sensible Storage System		Latent Storage Systems
1.	Energy stored by heating the material that does not undergo phase change during collection and discharge of energy.	1.	Energy stored by heating the material that undergoes phase change during collection and discharge of energy.
2.	Some of the heat carrying media are water, oils, rocks, pebbles, refractory materials etc.	2.	Some of the heat carrying media are Water, Glauber's salt; $Na_2SO_4 \cdot 10H_2O$, $FeNO_3 \cdot 6H_2O$, Salt Eutectics, etc.
3.	The size of storage tank is bigger.	3.	The size of tank and other components is compact.
4.	Energy storage and delivery will be at variable temperature.	4.	Energy storage and delivery are at constant temperature.
5.	Since there is no phase change process, thermal resistance of media will not vary.	5.	Due to phase change process, the thermal resistance of the media may increase.
6.	Sensible heat energy is given as, $\dot{Q}_s = \dot{m}c_p\Delta T$ Where, $\dot{m}$ – Mass flow rate of material C_p – Specific heat ΔT – Change in temperature.	6.	Latent heat energy is given as, $\dot{Q}_s = \dot{m}L$ Where, $\dot{m}$ – Mass flow rate of media L– Latent heat of fusion of fluid.

Q45. What are the advantages of using water and rock as storage medium?

Answer :

Advantages of Water as Storage Medium

1. It is a cheap, easily available and most suitable material to store sensible heat.
2. It has high thermal storage capacity.
3. There is a direct addition and removal of energy from this type of storage by the medium itself, which eliminates the temperature drop between transport fluid and storage medium.
4. Cost of pumping is less.

Advantages of Rock as Storage Medium

1. Rock can be more easily accommodated than water.
2. High heat transfer coefficient is obtained between the air and solid (rock).
3. It can be employed for thermal storage at high temperatures much higher than 100°C where water cannot be used in liquid form.
4. Rock itself acts as a heat exchanger, decreasing the total cost of the system.
5. Rock as storage medium is comparatively cheaper.

2.1.2 Solar Ponds

Q46. Describe the working of a concentration gradient solar pond.

May-19, (R15), Q5(b)

OR

Describe briefly a basic type of solar pond.

May-15, (R09), Q3(a)

OR

Discuss in detail about the mechanism of salt-gradient solar pond with the aid of neat sketches.

Answer :

Solar Pond

It is a natural or an artificial water body used for the collection and absorption of solar radiation from the sun and its storage as heat. Therefore, solar pond is a combination of solar radiation energy collection and sensible heat storage. Solar pond is either a shallow or a deep lake, surrounded by the insulating, absorbing and storing materials.

Working

A solar pond contains dissolved salts for generating a stable density gradient. It is basically divided into three layers. They are surface convection zone, non-convection zone and the storage zone as shown in figure.

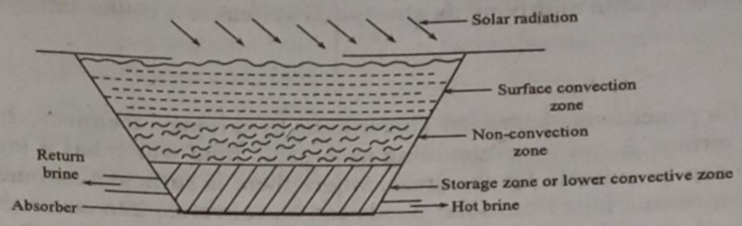


Figure: Solar Pond

The solar radiation from the sun is absorbed by the absorber situated at the depth of the solar pond. This results in rising the temperature of the water at the beneath portion of the pond. The temperature rise is very small. So, for increasing the temperature rise in pond, the water is mixed with salt. The salt concentration will get removed over a period of time because the water at beneath remains hot due to the upward diffusion of salt. The amount of salt required is large. So, it is normally recycled by evaporating the saline water through the surface. The solar energy is extracted by removing the hot water continuously from the bottom of pond and then passing it through a heat exchanger. The fresh water is also added from the top portion of the pond. The mixing and removing of water is carried on three zones of the pond.

The surface convective zone is a low uniform concentration zone. It possesses usually a small thickness and ambient temperature. The central zone is a non-convective zone. This zone usually reduces the heat losses in upward direction and serves as thermal storage zone. The last zone or beneath portion of zone is a storage zone. It is the main thermal storage zone and possesses low convection property. The material used for this zone is LDPE, HDPE, hypalon, etc. Therefore, solar pond can be used for storing the solar energy using the natural or artificial arrangements.

Q47. What are the special arrangements made in solar pond to retain the heat energy content in Solar pond?

Answer : May-17, (EEE), (R13), Q5(b)

The various arrangements made in a solar pond to retain the heat energy content in solar pond are,

1. By maintaining the higher density of salt water at the bottom of the solar pond. Because, this prevents the natural convection of heat transfer between the top and bottom layers of the pond.
2. If dark surface is maintained at the bottom of the pond, then more radiation can be absorbed and that in turn increases the temperature of the bottom layer.
3. The top layer should have low salt concentration and bottom layer should be of high salt concentration. Because, if the same level of concentration is maintained, then the temperature of pond will be equivalent to the atmospheric temperature. Hence extraction of heat is impossible.
4. In a convecting solar pond, the whole solar pond arrangement is placed in a large bag that allows convection, but does not allow evaporation. In order to preserve the heat, bag is coated with black colour at the bottom and a foam insulation is also arranged
5. The selection of site for a solar pond also effects the heat loss to the ground. If the ground water table for the pond is situated at a minimum depth of 5 m from the surface level, then the heat lost to the ground can be reduced.

Q48. What are the applications of a solar pond?

Answer :

Applications of Solar Pond

The various applications of solar pond are as follows,

1. Heating and cooling of buildings
2. Production of power
3. Industrial process heat
4. Desalination
5. Heating the animal housing, drying crops on farms
6. Heat for biomass conversion.

1. **Heating and Cooling of Buildings**

Solar ponds are used for heating even at large latitude stations and also for heating during cloudy days. This is because of having large storage capacity in the lower storage zone of the solar pond. Generally, a solar pond with 100 m in diameter and 1 m deep storage zone is capable of driving an absorption system or a chiller satisfying a required cooling load of 50 houses in a community.

2. **Production of Power**

Solar ponds can be used for generating electricity. This is done by driving a thermoelectric device or an organic Rankine cycle engine in which a turbine is run by evaporating an organic fluid which has a low boiling point. The solar pond for generating electricity can be suitable for the areas, where there is sufficient amount of solar radiation and suitable topography. Even low temperature heat from solar ponds can be converted into electricity. The efficiency of conversion of electricity is limited due to low operating temperatures which are usually of the order 70°C-100°C. Thus, Solar Pond Power Plant (SPPP) requires organic fluids with low boiling points like halo-carbons (such as freons) or hydrocarbons (such as propane).

3. **Industrial Process Heat**

Thermal energy is required in the industries for manufacturing and treatment of materials and goods. Scientists have found the applications of solar pond for supplying process heat in industries as an alternate to oil, natural gas, electricity and coal. Industrial process heat is used in crop drying and in paper industries which is highly economical as compared to oils and natural gases.

4. **Desalination**

The cheap thermal energy can be used to desalinate or purify water for drinking or irrigation. The multi-flash desalination plant below 100°C can be used for producing distilled water. This system is widely used in areas, where there is shortage of pure water and availability of only saline water. It has been found that a solar pond of 0.31 km^2 area can be used to produce about 4700 m^3/day of distilled water. Also, multi-flash desalination plant can be used to produce five times more of distilled water as that of conventional basin type solar still.

5. **Drying Crops on Farms**

In farmland, where there is enough space, low grade heat can be used for drying crops and to heat animal houses.

6. **Heat for Biomass Conversion**

Solar ponds can be used for converting biomass to alcohol or methane.

Q49. With the help of schematic diagram, explain the working of solar pond electric power plant.

Answer : Sept.-20, (R16), Q4(b)

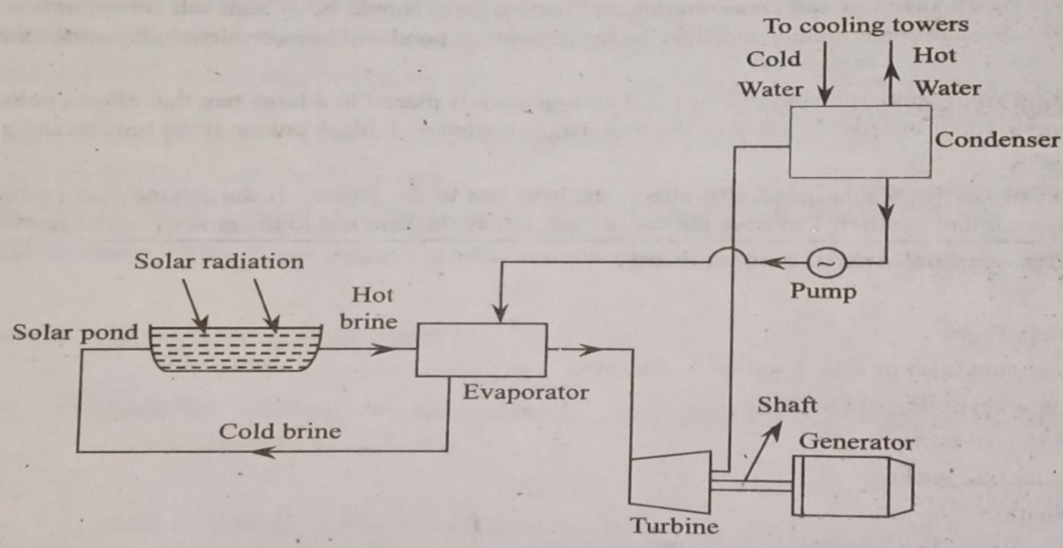


Figure: Solar Pond Electrical Power Plant

The solar pond is used for lower thermal electrical power production. The solar pond receives and absorbs the direct radiation from sun, thereby collects the heat. It can absorb about 50% of radiation, which drops to 20% due to heat losses. It can collect heat even on cloudy day. When, the temperature of the lower layer of pond reaches above 60°C, then, the generated heat is utilized to run the Rankine cycle heat engine. The organic fluid is vapourized by using the heat from the pond through heat exchanger. This vapour under high pressure is passed through the turbine, where it expands and rotates the blades of the turbine. The vapour then passes through the condenser where it gets condensed by using cold water from cooling tower and the liquid is then pumped back to the evaporator, and the cycle is repeated. The generator set is connected to the turbine through shaft, thus producing electrical energy.

2.2 Solar Applications

2.2.1 Solar Heating/Cooling Technique

Q50. With a neat sketch explain the principle of conversion of solar energy into heat.

Answer : July-21 (EEE), (R16), Q3(b)

The principle involved in the conversion of solar radiation into heat is "Green-house effect".

The gases in the atmosphere that absorb the solar radiation are referred as greenhouse gases (GHG). These include carbondioxide (CO_2), water vapour (H_2O), nitrous oxide (N_2O), methane (CH_4) and chlorofluoro carbons (CFCs).

When the solar radiation strikes the surface of the earth in the form of visible light, ultraviolet light, infrared and other types of radiation, the gases trap the sun's heat and help to sustain life on earth. There is a progressive increase in the greenhouse gases with the industrialization of the planet. These gases trap more amount of solar energy and reflect back less amount towards the outer space, thus making the planet warmer than it used to be. Solar energy generation requires minimum temperature as 30°C-40°C.

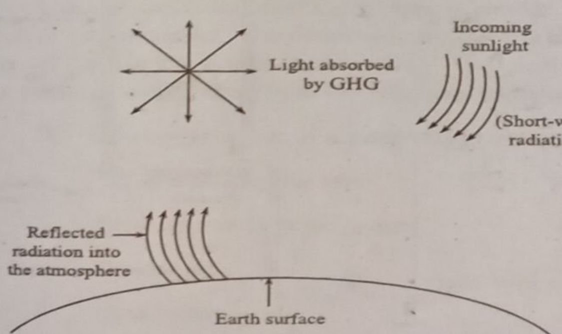


Figure: Green House Effect

Q51. List out the various solar applications.

Answer :

The various solar applications are,

1. Solar thermal applications :
   - (i) Water heating
   - (ii) Space heating
   - (iii) Space cooling
   - (iv) Solar distillation
   - (v) Solar drying.
2. Photovoltaic applications:
   - (a) Industrial applications
     - (i) Telecommunication
     - (ii) Cathodic protection
     - (iii) Aircraft applications
     - (iv) Alarm system
     - (v) Defence equipment
     - (vi) Emergency equipment.
   - (b) Electrical power generation
   - (c) Consumer applications such as pocket calculators, watches, clocks, radio, electric fence, toys, etc.

Q52. Explain any two solar heating applications.

Answer : May-13, (R09), Q3(a)

Applications of solar energy are,

1. Solar water heating
2. Solar space heating
3. Solar drying
4. Solar distillation, etc.

1. **Solar Water Heating by Natural Circulation**

   For answer refer Unit-II, Q53, Topic: Natural Circulation Solar Water Heating System.

2. **Solar Space Heating by Active Method**

   A space heating using solar radiation by active method is carried by using equipment like flat-plate collectors, pump, storage tank, heat exchanger, auxiliary heaters, etc as shown in figure.

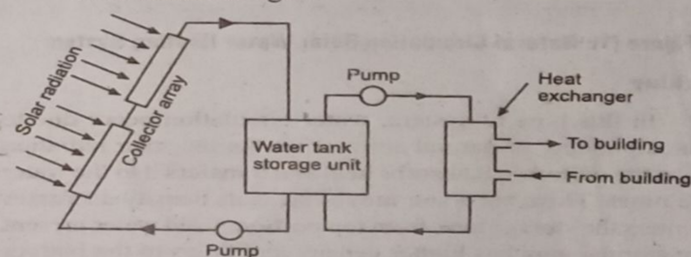


Figure: Space Heating

As the solar radiation falls on the collector, the collector heats the water flowing across it. The hot water is then pumped towards the storage tank. In the storage tank, the hot water is stored. This hot water is pumped to the heat exchanger to transfer the heat to the air circulating in the room. Two pumps are used for pumping the water between the collector and the tank, and between the tank and heat exchanger.

Q5. With a neat sketch explain working of solar water heating systems. April-18, (ME), (R13), Q4(a)

OR

Explain solar water heating system at natural circulation and forced circulation type.

Answer :

Natural Circulation Solar Water Heating System

Construction

It comprises of solar collector insulated storage tank, water circulation tubes, auxiliary heater etc. Usually single glazed flat plate collector is employed. Collector is a welded fabrication of copper sheet and copper tubes. Both sheet and tubes are coated with black coating which has high absorption capacity. Collector is positioned such that it faces the such and its inlet and outlet are connected to top and bottom portion of storage tank respectively. Storage tank is positioned such that its bottom surface is 0.3 m above top of collector. In addition to connections from collector, it also provided with other connections at bottom and top portions in order to allow cold water from mains and hot water for distribution respectively. Auxiliary heater is also installed in storage tank as shown in figure.

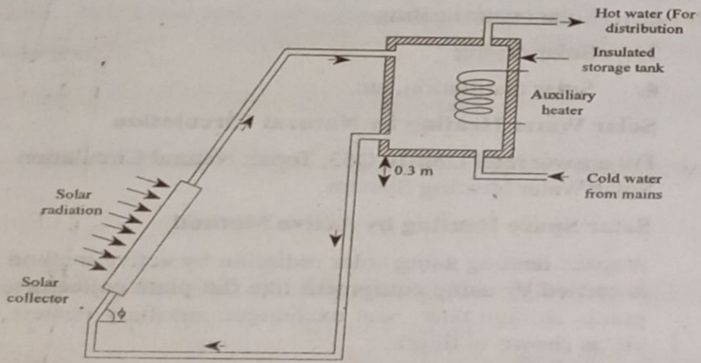


Figure (1): Natural Circulation Solar Water Heating System

Working

In this type of system, water circulation occur due to thermosiphoning or natural convection. As the solar radiation falls on the collector, it absorbs heat and transfers it to the water in the tubes. Then, hot water moves up as its density decreases and enters the storage tank from top portion. Cold water present in the storage tank has higher density and flows to the bottom portion of collector to obtain heating. Difference in densities of hot and cold water is the cause for circulation of water through the storage tank and collector. Whenever it is required, hot water is taken out from top of the tank for distribution and drawn amount of water is replaced by supplying cold water from mains. During day i.e., when sun shines, water circulation continues, but during nights flow direction may reversed and loss of heat to ambient air occurs. In order to avoid this, a level difference of 0.3 m between top of collector and bottom of storage tank is required to be maintained. During cloudy and rainy days, heating is obtained by auxiliary heater which works with electrical input. This type of heater is mostly employed for domestic applications.

Forced Circulation Solar Water Heating System

Construction

Its construction is similar to that of natural circulation water heating system. Only changes in this are in position of storage tank and inclusion of pump in the system. Pump is located in return circuit i.e., on the pipe line connecting lower part of storage tank and bottom header of the collector. As pump enables water circulation, tank can be positioned at more convenient level. This system is also provided with control unit to activate the pump.

Working

When temperature at outlet of collector is 7°C greater than that at storage tank, pump gets activated and pumps the water into collector from storage tank. Whenever it is required hot water is drawn off from top of the tank for distribution. Then, cold water from mains is supplied into storage tank in order to replace the drawn off hot water. Again when collector outlet temperature increases, pump enables water circulation and cycle continues. A non-return valve is required to be positioned below the collector inlet in order to avoid reverse water flow, thereby reducing thermal losses. On cloudy and rainy days, heating system works with help of auxiliary heater which is a back-up for solar heating system. This type of system is mostly suitable for hot water supply in large quantities for hospitals, hostels, offices and industries.

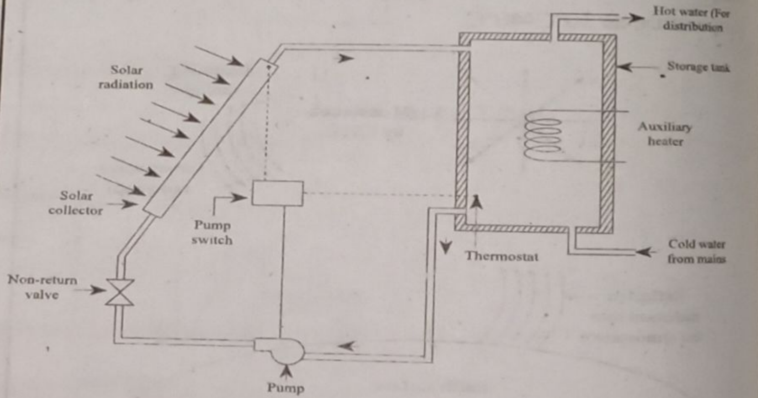


Figure (2) : Forced Circulation Water Heater

Q54. What are the limitations of using solar water heating systems?

Answer : May-15, (R09), Q3(b)

Limitations of Solar Water Heating Systems

1. It becomes inefficient in cloudy conditions, as the energy obtained from the sun is very less or negligible.
2. Continuous supply of cold water is required for operating the system.
3. Proper insulation should be provided and maintained for the tank, in order to use the water during nights.
4. Scale formation in the collector results in the decrease of system's efficiency.
5. Due to vapour locking phenomenon in pipelines, the supply of hot water ceases.
6. During winter, the system may require additional backup energy for heating water, such as electrical, gas, fuel, etc.
7. These systems are larger is size and hence, difficult to transport.
8. Cost of these systems is high and they are not suitable for indoor installation.

Q55. Compare the performance of solar air heaters with water heating systems.

Answer : May-19, (R15), Q5(a)

Difference between Solar Air Heating and Water Heating Systems

Parameter	Solar Air Heater	Solar Water Heater
Working fluid	Air	Water
Principle process	In this, solar energy is converted to heat energy to increase the air temperature.	In this, solar energy is converted to heat energy to increase the water temperature.
Any usage of chemical for anti-freezing	No	Yes
Heat loss from collector	High	Low
Value of heat transfer coefficient	Low (Between absorber plate and air)	High (Between absorber plate and water)
Heat output	Less	Relatively more
Thermal efficiency	Low	High

Q56. Explain the working of solar cooling system with the help of a diagram. July-19, (R15), Q5(a)

OR

Describe the layout and working of a continuous solar cooling system.

Answer : May-17, (ME), (R13), Q5(a)

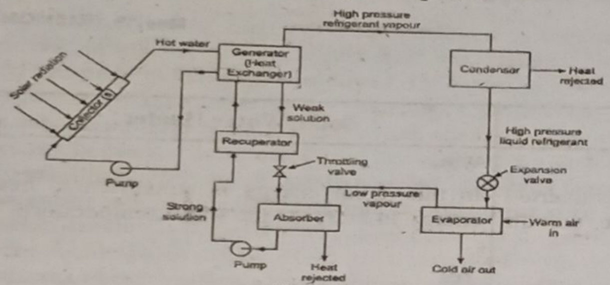
A continuous solar cooling system is similar to a conventional vapour absorption refrigeration system, in construction as well as the operation. The commonly used refrigerant – absorbent solutions in absorption cycle are Lithium bromide - water ($LiBr - H_2O$) and Ammonia – water ($NH_3 - H_2O$). $LiBr - H_2O$ system is used in solar cooling system because of its simplicity and requirement of comparatively lower generator temperature of around 85°C to 95°C which can be achieved by a flat-plate collector.

The main components of a solar vapour absorption cooling system are,

1. Flat-plate collector array
2. Generator or heat exchanger
3. Condenser
4. Evaporator
5. Absorber

Working

In evaporator, heat from the warm air or surroundings is absorbed by the low pressure liquid refrigerant and gets evaporated. This evaporated low pressure vapour then enters the absorber where it readily gets absorbed by the low temperature hot solution releasing the latent heat of condensation due to cooling by the circulating water. Now, this strong solution of $LiBr - H_2O$ from absorber is pumped to the generator by using a pump which increases its pressure. In the generator, heat from the solar collector array is supplied to this high pressure strong solution due to which refrigerant vapour gets evaporated leaving behind a weak solution. This high pressure weak solution is returned to the absorber by passing it through a throttle or pressure reducing valve. And the high pressure refrigerant vapour from absorber is condensed in the condenser to a high pressure liquid refrigerant which is then returned back to evaporator by passing it through a throttle or expansion or pressure reducing valve and the cycle repeats.



Figure

Q57. With the help of a schematic diagram, explain solar passive cooling system.

Answer : April-18, (ME), (R13), Q4(b)

Passive space cooling is one in which no mechanical devices are used and heat transportation occurs by natural processes of convection, radiation and conduction. This can be achieved in several ways such as,

1. Shading
2. Ventilation
3. Evaporation
4. Radiation
5. Ground coupling
6. Dehumidification

1. **Solar Passive Space Cooling by Ventilation**

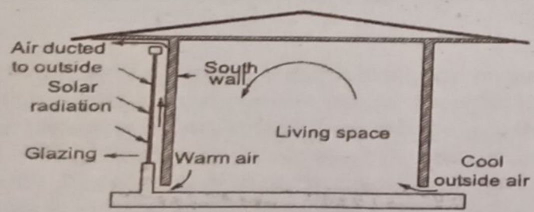


Figure (1) : Solar Passive Space Cooling by Ventilation

This method is effective in places where the outside temperature is moderate and it utilizes the solar 'chimney effect' for air circulation. In this, a glazing is provided on the external side of the south wall with some ducts as shown in figure (1). Solar radiation falling on the glazing heats up the air between the glazing and the interior south wall due to which this heated air rises up and escapes to the outside, drawing the warm air from the room into this space because of natural draught. Now, the cool and fresh outside air enters the room through the bottom air vent provided on the other side of the room and the cycle continues.

2. **Solar Passive Space Cooling by Dehumidification**

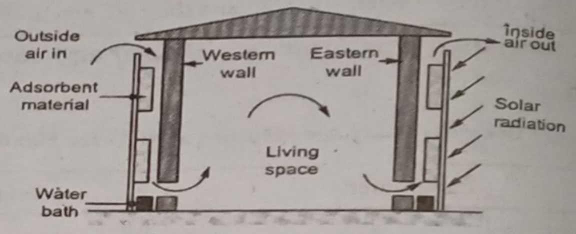


Figure (2) : Solar Passive Space Cooling by Dehumidification

In this method, dehumidification and cooling in the room is carried out by adsorption and evaporation. The walls of a specially designed house in the east and the west are installed with solid adsorbent materials and water baths as shown in figure (2). This method utilizes the concept of chimney effect for air circulation. During morning times, the sun rays fall on the east-wall, which absorbs solar radiation and passes this heat to the air, which rises up as a result, and escapes out. The cool and fresh air is drawn in from the west wall through ducts because of natural draught. This drawn air is dehumidified by a solid adsorbent material and then is cooled evaporatively by water baths. This dehumidified and cooled air then enters the room and the cycle is repeated. During evening times, the sun rays fall on the west wall due to which the flow of air and the functions of east and west walls are reversed to achieve the same cooling effect.

Q58. List the various applications of solar energy. Also explain anyone application, which is economically viable in the present contest.

Answer : May-17, (EEE), (R13), Q4(b)

Applications of Solar Energy

For answer refer Unit-II, Q51.

Solar Water Heating

For answer refer Unit-II, Q53.

2.2.2 Solar Distillation and Drying

Q59. Explain the working of solar distillation process with a neat sketch.

June-18, (R13), Q4(b)

OR

Explain the construction and operation of solar still.

May-13, (R09), Q3(b)

OR

With a neat sketch, explain about solar distillation process. Mention its advantages.

Answer :

Model Paper, Q4(b)

Solar Distillation

Solar distillation is the process of converting the saline water into distilled or pure water, by the use of solar radiation.

For this purpose, a device called solar still is used. The basin type solar still is shown in the figure below.

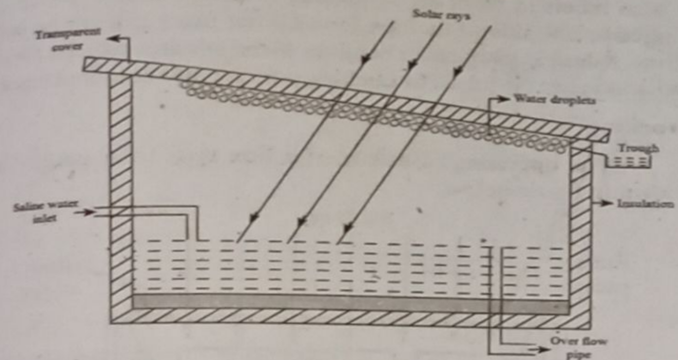


Figure: Basin Type Solar Still

It consists of a basin, which is made shallow and is coated with a black lining called basin liner, an overflow pipe, transparent glass cover, inlet for saline water and trough for collecting distilled water.

In this process, the solar rays are made to pass into the basin through a transparent cover. The saline water flows into the basin through an inlet. The black surface absorbs the heat from solar rays and heats the water. The evaporated water vapour is condensed into water by the inner surface of the glass cover, which is at lower temperature. Then, the distilled water is collected in the trough, as it is directed down by the slope of the cover. The distilled water is then supplied to the storage tank. The excess water is discharged from the basin, through an overflow pipe.

Advantages

1. The operation is simple, as no chemicals are used.
2. The amount of energy consumed is less.
3. Highly skilled labour is not required, as the operation is easy.
4. Maintenance cost is low.

Q60. Explain about solar drying.

Answer :

July-19, (R15), Q4(b)

Solar Drying

It is the process of removing the moisture and preserving the products, by utilising the solar energy. The most basic method of solar drying is that, the crops laid in the form of layers are exposed to direct sunlight. However, in this method, the crops may get contaminated, as they are placed in an open environment. To overcome this, solar dryers are used.

Solar dryers are classified into two types. They are,

1. Natural convection type dryers
2. Forced convection type dryers.

1. Natural Convection Type Dryers

These type of dryers does not use any blower and they are simple in operation. Also, the cost of operation is less. A cabinet dryer is an example of natural convection type dryer and is explained as follows.

It consists of a cabinet, which is provided with a transparent cover, perforated trays, and inlet and outlet path for air flow.

The products being dried are kept on the perforated trays. When the solar energy is incident on the cabinet, the rays pass through the transparent cover and get absorbed by the products and cabinet walls. Air flows into the cabinet from the bottom and gets heated, due to the solar heat. Thus, the material is dried and the air passes out from the outlet. The circulation of air takes place naturally.

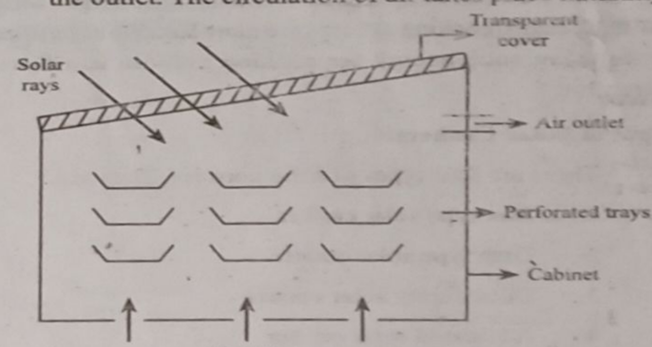


Figure (1) : Cabinet Dryer

2. Forced Convection Type Dryers

In this type, a blower or fan, driven by electrical or mechanical energy, is employed for air circulation. An example of this type of dryer is convective dryer, which is used for large scale drying.

It consists of an air heater, blower and a chamber. The blower circulates the air through the air heater. During circulation, the air gets heated due to the incident solar rays. Then, this hot air is supplied into the chamber, where the material to be dried is placed. Thus, the material is dried. These type of driers have very high efficiency.

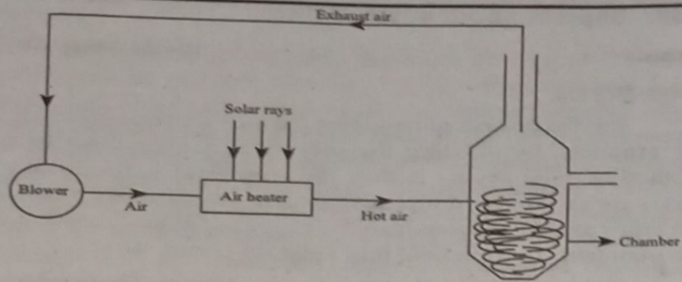


Figure (2) : Convective Dryer

Q61. What is a solar cooker? What are the types of solar cookers? Explain any one in detail.

Answer :

Solar Cooker

Solar cooker is a device which uses solar energy to cook or heat food or drink. The operation cost of these devices is nothing and they do not use any fuels. Thus, these benefits promotes solar cooker in world wide applications.

Thermal energy utilized for cooking consumes a large fraction of the total energy consumption, particularly in rural areas. Different types of fuels such as firewood, coal, cooking gas, dung cakes, kerosene and agricultural wastes are used for cooking purposes. But all these are fossil fuels and are depleting very fast. Firewood causes deforestation. Agricultural wastes, cow dung cakes, cooking gas etc., are more suitable as fertilizers. Hence using solar energy for cooking purpose is a feasible alternative.

Types of Solar Cookers

There are four types of solar cookers. They are,

1. Box type solar cooker
2. Dish type solar cooker
3. Community solar cooker
4. Advanced solar cooker

Box Type Solar Cooker

Construction

The box type solar cooker contains the following elements,

1. Outer box
2. Blackened aluminium tray
3. Double glass cover
4. Reflector mirror
5. Insulation
6. Cooking pots.

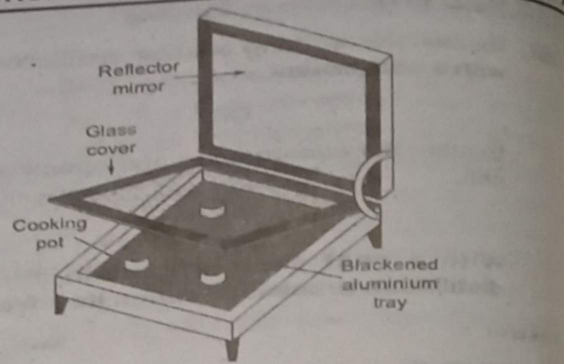


Figure (1): Box type Solar Cooker

The outer box is made of fibre glass or aluminium sheet. The insulating material is placed in between the outer cover of the box and the blackened aluminium tray in order to prevent heat loss Along with direct solar radiation, reflected radiation is also received from an adjustable reflected mirror which is hinged to one side of the box towards the inner side of the box cover. A double glass cover behaves as the window which allows radiation onto the tray. The cooking pots are also coloured black.

Working

The operating principle of a box type solar cooker is shown in figure below,

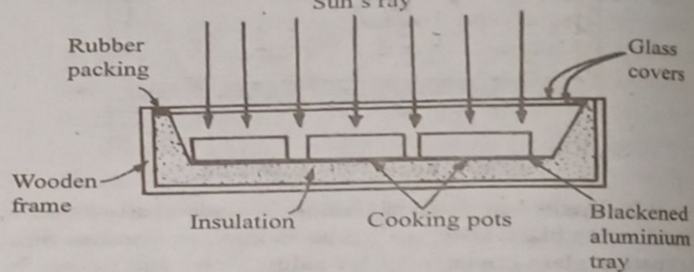


Figure (2) : Principle of Box Type Cooker

The sun rays enter into the solar box through the glass covers (transparent covers) and get absorbed by the blackened aluminium tray. The radiation which is of only shorter wavelength enters into the box as higher radiation wavelength is unable to penetrate through the glass cover. The glass covers provided in the box are two in order to reduce the heat loss. The heat is trapped inside the glass cover because of green house effect. The convective heat loss is reduced by installing a rubber packing in between the upper lid and the box over its whole perimeter.

The box is kept under sun and the rays are absorbed by the blackened metal tray, and the reflecting mirror is adjusted so as to reflect the maximum solar radiation into the box, thereby increasing the temperature of solar box. The cooking pots with the food material inside the solar box get heated up and the food is cooked in certain amount of time depending upon the temperature inside the box. This temperature depends upon the strength of the sun's radiation and the insulation material.

Q62. What are different approaches of thermal electric conversion system from solar energy?

April-18, (EEE), (R13), Q5(b)

Answer :

Different Approaches of Thermal Electric Conversion System from Solar Energy

1. Parabolic troughs
2. Solar tower (use of heliostats)
3. Solar dishes.

Parabolic Troughs

In this system, many (small) concentrating collectors, each individually track the sun. The collectors are 2-D parabolic troughs (or) 3-D parabolic bowls. Each collector transfers solar heat to a fluid and hot fluid is then gathered from all the collectors at a particular part (i.e., power station). The transfer fluid can be streamed and used directly as working substance in thermal power plant (steam turbine) and this system occupies very large area. The collectors may be parabolic trough type (or) paraboloidal dish type. Several fluids can be used directly (or) indirectly by heat transport i.e., water, air, sodium etc. This system operating at higher temperatures and at higher efficiency, leads to higher material costs and lower life time. Flat plate collectors are not suited due to low operating capacity and less efficiency. Tracking requirement is essential orient towards the sun rays by rotating focal line. The operating temperature is 200°C to 300°C. The plant ranges upto 50 MW.

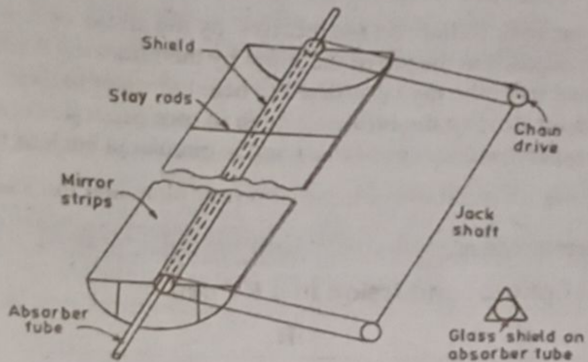


Figure (1)

Solar Tower (Use of Heliostats)

For answer refer Unit-II, Q63.

Solar Dishes

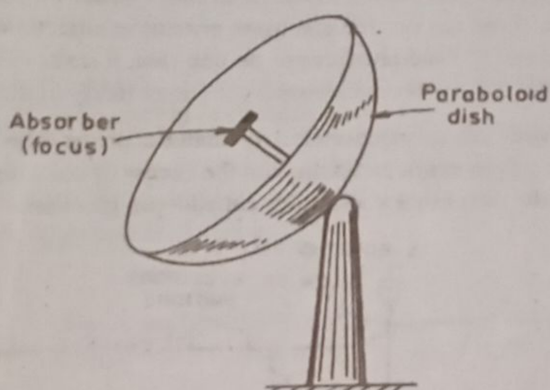


Figure (2) : Solar Dish

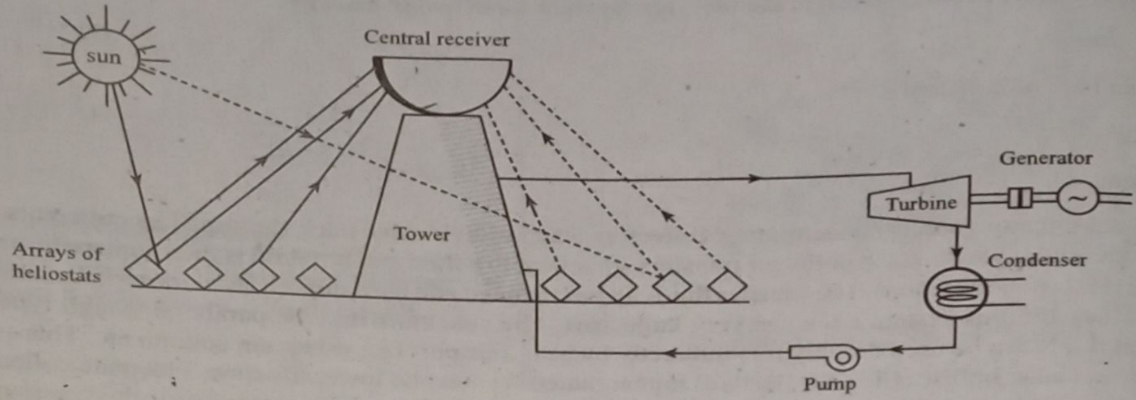
It can be observed from figure that a dish is a single unit with a parabolic reflector. It consists of a heat engine which is mounted on a framework. This entire single unit tracks the sun across the sky. Most of the solar dishes operate at 25 kW power.

Solar dishes are widely used because of their simplicity and efficiency. These dishes have the capability to achieve 30% energy conversion efficiency.

Q63. Give a neat diagram of central tower receiver power plant and explain its operation.

Answer :

Central Tower Receiver Power Plant



Figure

It consists of a central tower with receiver, arrays of mirrors or heliostats, turbine, generator, condenser and a pump.

During the operation, the incident solar radiations are received by the arrays of heliostats, placed around the tower. They reflect the rays on to the central receiver situated at the top of the tower by their tracking control system and these rays are absorbed by the central receiver. The heat obtained from the rays is utilised to heat the water present in the tower and convert it into steam in the receiver. This steam is then used for driving the turbine, which in turn generates electric power, by means of a generator. The exhaust steam from the turbine is condensed in a condenser and is circulated back to the tower, using a pump.

Thus, the power is generated using a central tower receiver power plant and the Rankine cycle is followed.

2.2.3 Photovoltaic Energy Conversion

Q64. Explain the mechanism of photoconduction in a PV cell. Dec.-20, (R16), Q1

OR

Explain the principle of solar photovoltaic power generation. May-17, (ME), (R13), Q5(b)

OR

Describe the principle of solar photovoltaic energy conversion.

Answer : April-14, (R09), Q4(a)

Consider an intrinsic semi-conductor such as silicon, in which all four valence electrons of the atom participate in chemical bond. Thus, at zero absolute temperature, there are no free electrons present in silicon. When a piece of this material is doped by five valence electron materials such as arsenic and phosphorus on one side, it leads to an excess electron on that side and the material becomes an n-type semiconductor. [illegible] excess electrons can move freely in the semiconductor lattice.

When this same material is doped with a three valence electron material on the other side, it leads to deficiency of electrons on that side. Thus, the material becomes a p-type semiconductor, and the excess of holes are free to move in the lattice. This piece of material whose one side is p-type and the other side is n-type is called a p-n junction.

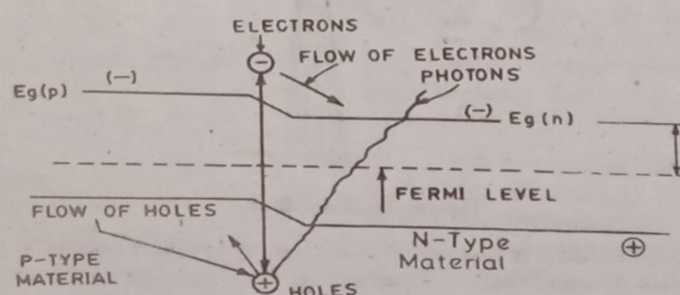


Figure (1)

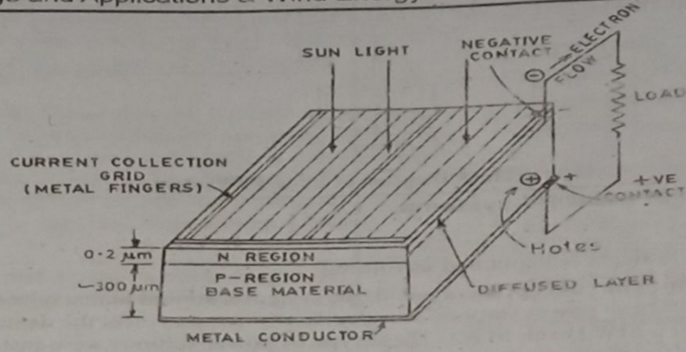


Figure (2)

When this piece of semiconductor material is exposed to sunlight, the p-n junction absorbs some photons. As a result the free electrons from the n-side will tend to flow to the p-side, and the holes from the p-side will tend to flow to the n-side to compensate their deficiencies on both sides. Due to this diffusion of electrons and holes, an electric field (E_F) will be produced from the n-region to the p-region as shown in figure (1). This electric field will increase until it reaches an equilibrium with the sum of the diffusion potentials for holes and electrons.

If the two semiconductor materials are connected with electrical contacts, and are also connected through an external conductor, the free electrons from the n-type material will flow through the conductor to the p-type material. Here, the free electrons will combine with the holes and become electrons. Thus, both eh electrons and holes will be removed. The flow of electrons through the external conductor produces an electrical energy, and this will continue as long as more free electrons and holes are being formed by the solar radiation. This is the principles of conversion of solar energy into electrical energy (i.e., photovoltaic conversion). Thus, the combination of both n-type and p-type semiconductors constitutes a photovoltaic (PV) cell or solar cell. These cells produce direct current which can be converted into a.c current. The schematic diagram of the typical solar cell is shown in figure (2).

Q65. Explain the component parts of a solar PV system along with their functions.

July-21 (EEE), (R16), Q3(a)

Answer :

The solar PV system consists of following components.

1. PV module
2. Balance of system (BOS)

1. **PV Module**

The PV module in PV system generates the d.c. power. The inverters are used to convert this d.c. power into 220V, 50 Hz a.c. power to run the electrical appliances used in households.

2. **Balance of System (BOS)**

The components of PV system other than PV module are collectively known as 'Balance of systems'. It includes the storage batteries, an electronic charge controller and an inverter.

Storage Batteries

The storage batteries with charge regulators are used in PV systems for back-up power supply during nights and cloudy days. Usually, batteries are charged during the day time and supply power to the loads.

Electronic Charge Regulator

The storage batteries are equipped with microprocessor based charge regulators, which monitor the voltage and temperature in order to regulate the input and the output currents to prevent overcharging and excessive discharge.

Inverter

The inverter is used for converting the d.c. power from battery or PV array to a.c. power. It is provided with automatic switch-off feature to prevent overloading and short circuit problems.

The block diagram of solar PV system is shown in below figure.

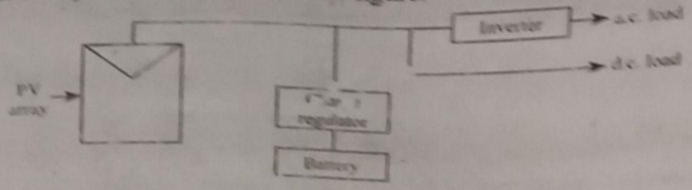


Figure: Block Diagram of Solar PV System

Q66. Explain the classification of solar PV systems.

Answer :

The classification of solar PV systems is explained as follows,

1. **Central Power Station System:** The concept involved in this system is similar to that of conventional type power stations, where power is fed to the grid. These power stations are specifically setup to meet the demand of daytime peak loads. The capacity of these plants is upto 6 MW (Peak MW). These type of power stations were installed in USA and Europe.

2. **Distributed System:** The use of distributed form of energy is effective, when solar energy or other renewable energy sources are used.

   (i) **Stand- alone PV System:** It comprises of a MPPT controller, which helps in sensing the output (current or voltage) of PV cell array. Also, it is possible to obtain maximum power under any given conditions, by controlling the operating point, through this controller. Then, the output power is fed to the load centres, in the form of ac. When the output obtained exceeds the requirement, it is used for charging the batteries or supplied to the dump heaters.

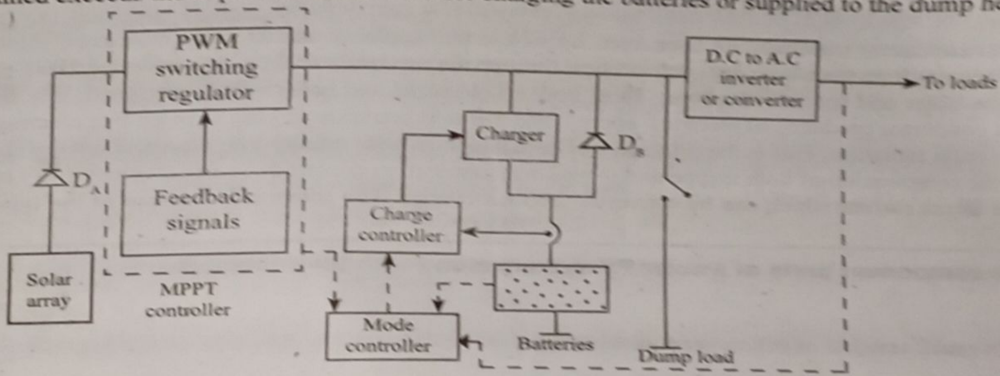


Figure (1): Stand-alone Solar PV System

The battery supplies the load when there is no sufficient availability of sun rays. The discharge diode 'D_B' is used to prevent the problem of overcharging of batteries. The array diode 'D_A' isolates the PV cell array from battery, in order to prevent discharge of battery through array during night. A mode controller controls the working of system, within specified parameters.

   (ii) **Grid-Interactive Solar PV System:** In this system, dump heaters are replaced with grids and excess output power is fed to these grids. The use of battery is eliminated and the continuous supply of power in absence of sunshine is maintained by means of grids. The synchronized operation is achieved by suitable mechanism and D.C power is converted into A.C. by means of an inverter. Then, harmonics are filtered, voltage is adjusted and filtered output power is supplied to the grid.

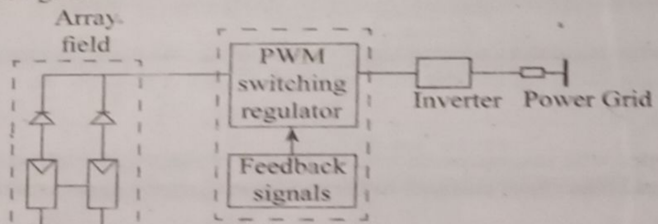


Figure (2): Grid-interactive Solar PV System

Also, PV modules are being provided with an integral inverter, hence, they are called as A.C PV modules. Thus, the design of PV system is greatly and effectively simplified.

(iii) **Hybrid Solar PV System:** These type of systems are adopted to provide energy from other sources, apart from the PV system. When it is economical to fulfill a part of energy requirement of the system, by other sources like diesel or gasoline generator or non-conventional sources like wind energy or fuel cell, these systems are employed.

Q67. What are the advantages and disadvantages of photovoltaic solar energy conversion?

Answer :

Advantages of Photovoltaic Solar Energy Conversion

1. No moving parts and low maintenance cost.
2. Direct conversion of light to electricity at room temperature.
3. No environmental pollution.
4. Very long life and easy to fabricate.
5. Solar energy is free and no fuel required.
6. Can be started easily as no starting time is involved.
7. These have high power-to-weight ratio, therefore very useful for space application.
8. These can be used with or without sun tracking.

Disadvantages of Photovoltaic Solar Energy Conversion

1. Photovoltaic energy conversion is expensive.
2. Due to the non-availability of solar radiation at nights, the energy received during day has to be stored in suitable storage devices. Reliable batteries for energy storage are not available.
3. For setting up a solar power plant a very large land has to be acquired.
4. Cost of electrical power generated is relatively high.
5. Fabrication of silicon crystals consume more work force and energy.
6. The initial capital required for setting up a solar plant is very high.

Q68. State applications of solar PV System.

Answer :

The first application of solar photovoltaic system was in 1958 to power the space satellite, Vanguard-1. Since then solar cells are chosen as power source in space applications due to their low weight, reliability and durability. Solar cells have survived the harsh physical conditions of space-high vacuum, high radiation and large temperature variations. Success of solar cells in space led to their terrestrial applications. There are three broad categories for PV applications i.e., industrial, social and consumer applications.

1. **Industrial Applications**

   (i) **Telecommunications:** PV systems are both economical and reliable power source for telecommunication and several such systems are installed throughout the world.

   (ii) **Cathodic Protection:** In this technique, small PV panels may be used to provide a small direct current very efficiently and this current is impressed on the structure at regular intervals to prevent electrochemical corrosion.

   (iii) **Navigational Purpose:** Marine beacon and navigational lights on buoys around the world are now-a-days being powered reliably and cost effectively by simple PV generators, which were earlier powered by kerosene or batteries with several maintenance problems.

   (iv) **Remote Aircraft Beacons:** Remote radio and light beacons near the airports may be powered economically by solar PV.

   (v) **Alarm Systems:** PV systems are being used to power railway signals, alarm systems, fog, fire and flood hazard warnings, traffic lights and highway telephones.

   (vi) **Defence Equipment:** Many defence equipment like mobile telephones, remote instrumentation, remote radar, water purifier, etc., may be effectively powered by PV.

   (vii) **Emergency Equipment:** Battery charging on life boats and rafts and for providing essential service after earthquakes, floods and other natural disasters may be done efficiently by PV system.

2. **Social Applications:** These include providing electric power to remote villages and islands specially in developing countries by PV system where large number of villages remain unconnected to main grid. PV is best suited for rural applications and is environmental friendly.

3. **Consumer Applications:** A very large number of consumer items are now being powered by solar PV. Some of these solar powered products are pocket calculators, watches, clocks, torches, lantern, garden lights, radios, electric fences, toys, etc.

2.3 Wind Energy

2.3.1 Wind Energy

Q69. Give the classification of wind.

OR

What are the sources of wind? Explain.

Answer :

Wind is classified into two types,

1. Planetary or global winds
2. Local winds.

1. Planetary or Global Winds

Planetary winds are those winds which usually blow under the influence of permanent or planetary belts (i.e., higher pressure to lower pressure belts). Planetary winds are categorized into three types. They are,

(i) Trade winds

(ii) Westerlies

(iii) Polar winds.

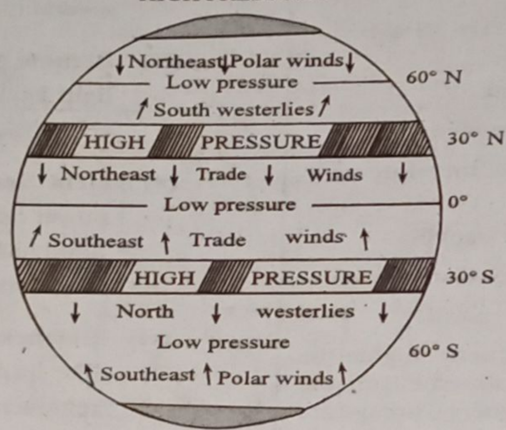


Figure: Planetary Winds

(i) Trade Winds

The word trade is derived from trado (Latin word) which means constant direction. The Northeast trade winds are the winds which blow from northeast to southwest in northern hemisphere. The southeast trade winds are the winds which blow from southeast to northwest in southern hemisphere. Trade winds blow with high speed.

(ii) Westerlies

The South-westerlies winds blow from southwest to northeast in northern hemisphere. The North-westerlies winds blow from northwest to southeast in southern hemisphere. The north-westerlies between 40°s and 60°s latitudes blow with great force because of the absence of land barriers.

(iii) Polar Winds

The Northeast polar winds blow from northeast to southwest in northern hemisphere. The Southeast polar winds blow from southeast to northwest.

2. Local Winds

Local winds are the winds which blow in accordance to local pressure gradient conditions. These are originated from local weather conditions and blow for shorter period of time.

The best example for local winds are the land and sea breezes. Land and sea breezes are produced due to the heating of land and sea. These are characterized by the daily changes in the pressure gradient called diurnal winds. Some of the local winds are characterized due to the change in temperature also.

Q70. Explain about primary, secondary and tertiary winds and how to make use of them for power generation.

[July-21, (EEE), (R16), Q5(b) | Model Paper, Q5(a)]

Answer :

Primary Winds

The primary winds are also known as planetary winds.

For answer refer Unit-II, Q69, Topic : Planetary or Global Winds.

Secondary Winds

The secondary winds are also known as 'seasonal winds' or 'periodic waves'. These winds change their direction periodically with different seasons. The monsoon winds in India are the example of secondary winds.

Tertiary Winds

The tertiary winds are also known as 'local winds'.

For answer refer Unit-II, Q69, Topic : Tertiary Winds.

Generation of Energy from the Wind

For answer refer Unit-II, Q78.

Q71. Distinguish between local winds and planetary winds.

Answer :

Differences between Local Winds and Planetary Winds

	Local Winds		Planetary Winds
1.	The wind circulation within a smaller area are called as local winds.	1.	The wind circulation on global basis are called as planetary or global winds.
2.	These winds are caused by (i) Differential heating of land surface and water bodies due to solar radiation. (ii) Differential heating of slopes on hillside and of low lands.	2.	The speed and direction of these winds are determined by (i) Differential heating of the earth at equatorial and polar regions. (ii) Rotation of earth about its axis (coriolis force).
3.	Land, mountain and sea breezes are the examples of local winds.	3.	Trade winds, westerlies and polar winds are the three types of planetary winds.
4.	These are characterized by either pressure gradient or by temperature differences.	4.	These are characterised by differences in pressure.
5.	These winds blow over a shorter distances.	5.	These winds blow over longer distances than local winds
6.	These winds blow near to the earth's surface.	6.	These winds blow away from the earth's surface.
7.	These are unpredictable as they change with the weather.	7.	They can be predictable as they do not change with weather.

Q72. Explain how to locate the potential sites for establishing a wind farm.

July-21, (ME), (R16), Q4(b)

OR

Briefly discuss the criteria involved in the selection of site for wind turbine installation.

Sept.-20, (R16), Q6(a)

OR

What are the main considerations in selecting a site for wind generator?

Answer :

Selection of site for wind generators is a most important aspect, when considered with respect to the generation of power and feeding of power into a conventional electric grid. The wind power increases with the speed so these machines should be located in areas, where winds are strong and persistent.

Some of the main considerations in selecting a site for wind generators are discussed below.

1. **High Annual Average Speed**

The power in the wind mainly depends on the velocity of the wind and is given by,

$$P_\omega = kV^3$$

Where,

P_ω – Power in the wind

V – Wind velocity

k – Constant.

2. **Availability of Anemometry Data**

The another factor is to measure the speed of wind without any errors, in order to ensure efficient operation. The anemometry data over a certain time period at the precise spot, where WECS is to be built, is necessary.

3. **Availability of Wind at the Proposed Site**

Maximum energy in the wind is known with the help of $V_{(t)}$ curve, which predicts the electrical output and hence, revenue return of the WECS machine.

4. **Wind Structure at the Proposed Site**

It is necessary to know the structure of the wind and is defined by $V_{(t)}$ curve.

5. **Altitude of the Proposed Site**

The winds velocity changes according to the altitudes i.e., the winds have higher velocities at higher altitudes, which in turn produces more power.

6. **Terrain and its Aerodynamic**

It is important to know about terrain of the site to be chosen, as it is preferable that, the wind must flow in horizontal direction.

7. **Local Ecology**

Local ecology should also be considered while choosing the site. If the surface of the ground is bare rock, then the lower hub height is sufficient, but if it contains grass, the hub height should be high, as the grass destructure the wind.

8. **Distance to Roads or Railways**

Transportation of machinery to the site should also be considered.

9. **Nearness of Site to Local Centre or Users**

Distance between the users and the site, where electricity is generated, should also considered. If the distance between them is short, then transmission length, losses and costs are minimized.

10. **Nature of Ground**

The wind machines are erected from ground. So WECS are secured, if ground surface is rigid or stable.

11. **Favourable Land Cost**

Land cost should be low, as it contributes to the total WECS cost.

12. **Other Conditions**

Other conditions such as icing, blowing dust, etc. should not be present at the site, which may affect the performance of aeroturbine blades.

Q73. Write short notes on applications of wind energy.

May-16, (R09), Q4(b)

OR

Discuss the applications of wind turbines.

Answer :

Applications of Wind Energy

The energy extracted from the wind is mechanical mo[illegible] and this can be directly used for some applications or can be converted to electricity, heat or fuel. Applications of powerful turbines up to about 50 kW are for operating irrigation pumps, navigational signals and remote communication, relay and weather stations and for offshore oil drilling platforms.

(i) **Pumping Applications**

The typical application is pumping of irrigation water and the other applications include the pumping of water for aqueducts or for pumped-hydro storage of energy.

(ii) **Direct Heat Applications**

Mechanical motion derived from wind power can be used to drive heat pumps or to produce heat from the friction of solid materials or by the churning of water or other fluids and in other cases, by the use of centrifugal and other types of pumps in combination with restrictive orifices, that produce heat from friction and turbulence, when the working fluid flows through them.

(iii) **Electric Generation Applications**

Wind turbines are used in centralized power transmission to drive A.C. type synchronous generators. In such applications wind electricity from generator is directly supplied to main power lines by using voltage step-up transformers.

(iv) **Sea Transport Applications**

In ferries which travels for short distances, wind turbines are positioned onboard to serve as propeller. Wind turbines are also used to drive large sized cargo ships.

Q74. Describe wind energy potential and its measurement.

Answer :

Observations of speed, temperature and pressure of wind are carried out at National Weather Stations (NWS). Thus, comprehensive data regarding long term information of wind speed, temperature and pressure is provided by NWS. In previous years, data on wind speed is prepared manually

Observer used to predict the speed of wind every hour for one to two minutes and noted it on a strip chart. In recent yea observation systems in NWS are provided with automated surface. Samples of speed and direction of wind are done at frequency of 1 Hz, averages for time period over 5 seconds, then rounded. By considering 24 such 5 sec samples, calculation for 2 minutes running average is made. Obtained data is summarised as monthly data sheets and, they are kept available for purchase.

Wind energy potential is the power available in the wind per unit area, therefore it is also known as wind power density. By using data sheets (wind speed data), it is possible to calculate, power available per unit area for year, months or seasons. If wind speed data is available for more than a year, then month data or year data are averaged so as to calculate annual values by month or year.

Wind energy potential, $\dfrac{P}{A} = \dfrac{\sum_{i=1}^{n} \dfrac{P_i}{A}}{n}$

But,

$$P = \text{K.E}$$
$$= \frac{1}{2} m V^2$$
$$= \frac{1}{2} (\rho A V) V^2$$
$$P = \frac{1}{2} \rho A V^3$$

Then,

$$\frac{P}{A} = \frac{\sum_{i=1}^{n}\left(\frac{1}{2}\rho_i A V_i^3\right)\frac{1}{A}}{n}$$

$$\frac{P}{A} = \frac{\sum_{i=1}^{n}\frac{1}{2}\rho_i V_i^3}{n}$$

Where,

ρ_i - Wind density of i^{th} observation

V_i - Wind velocity of i^{th} observation

n - Number of observations.

Q75. Discuss the prospects and status of wind energy in india.

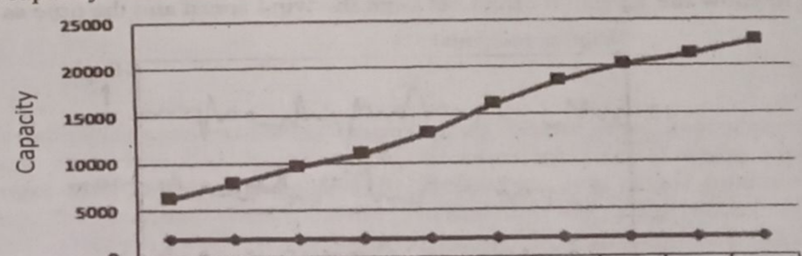
April-18, (ME), (R13), Q6(a)

Answer :

Prospects of Wind Energy in India

The Ministry of New and Renewable Energy (MNRE) has set a goal in 2015, i.e., the capacity of generating wind power must reach 60,000 MW by the end of the year 2022. By January 2014, in India, the capacity of wind energy for installed units is 20.23 GW among the total electricity generated of 234.6 GW. The wind energy constitutes for about 8.7% of all the renewable energy sources combinedly accounts for 12.6%. More additional capacity includes Maharashtra with 847 MW in the financial year 2013-14. According to the report of India 2010, the employees working directly or indirectly for wind energy industries are 42,000 people. By the year 2020, it reaches to about 60,000 jobs as per the estimation of growth by MNRE. The jobs may be categorized to construction, development, commissioning and project planning.

The wind power generating capacity from 2006 to 2015 in India is shown in the figure below,



	1	2	3	4	5	6	7	8	9	10
YEAR	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CAPACITY(megawatt)	6270	7850	9587	10925	13064	16084	18421	20149	21264	22644

Figure: Wind Power Installed Generating Capacity from 2006 to 2015

Status of Wind Energy in India

India was the fifth largest market in the world by 2013. In India, the gross wind power potential is of about 48,561 MW as per estimation. Major wind energy stations located in India at Tamil Nadu, Maharashtra and Gujarat. The various wind energy capacity (state wise) in India (as of 31 March, 2015) are tabulated below. Of which, Tamil Nadu stands first.

SL.No.	State	Wind Energy Capacity (MW)
1.	Tamil Nadu	7455.2
2.	Maharashtra	4450.6
3.	Gujarat	3645.4
4.	Rajasthan	3307.2
5.	Karnataka	2638.4
6.	Andhra pradesh	1031.4
7.	Madhya pradesh	879.7
8.	Kerala	35.1
9.	Others	4.30
	Total	23447.3

Q76. Compile and elaborate the meteorological data of wind speeds in India and classify the sites into fair, good and excellent wind energy potential sites.

Answer :

Each country will adopt certain services to record and display weather related data which includes wind speed and wind direction.

Wind speed measurements are carried out by using anemometers. The rotating cup anemometer is widely used anemometer for wind speed measurement. Wind direction measurements are done with the help of a wind vane with a direction indicator. Generally, the wind speed data is measured. The anemometer for measuring wind speed works on any one of the mentioned principles below,

1. A simple anemometer is used in which a plate is pivoted to a movable joint along its top edge vertically. The deflected angle of the plate gives the measure of the wind speed with respect to the vertical.
2. The speed of the wind can also be measured by the wind pressure exerts on the flat plate.
3. The rotating cup anemometer contains 3 or 4 cups which are placed uniformly about a vertical axis. The speed of the rotating cups indicates the wind speed.
4. An anemometer based on the effect of sound can also be used for measuring wind speed. The speed of the wind is inversely proportional to the sound travels in the wind. Sound travels in stationary wind at a defined speed. The speed either increases or decreases accordingly if there is a movement of air.
5. The hot-wire anemometer calibrates the speed by sensing the cooling effect of the wind on the hot-wire. The current is passed in the anemometer through hot-wire and thus heat is produced.
6. The different types of anemometers for the measurement of wind speed are ultrasonic anemometer laser anemometer and SODAR Doppler anemometer.

A graph is plotted to show the variation effect between the wind speed and the time as shown in figure below,

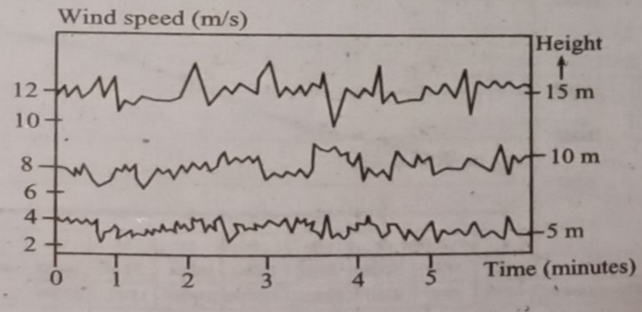


Figure: Variation of Wind Speed and Time

From the graph, the following points are concluded as,

1. There is an increase in the speed of the wind as the height increases.
2. There is a fluctuations in the wind speed with respect to time. This means, there is a presence of unsteady air movements at the recorded area.
3. At a wider range of frequencies the turbulences are extended.

Classification of Wind Energy Potential Sites

The classification of wind energy potential resources are as follows,

Wind Energy Potential Sites	Density of Wind Power (W/m^2)	Wind Speed (m/s)
Fair	100 – 150	4.3 – 5.0
Good	150 – 200	5.0 – 5.5
	200 – 300	5.5 – 6.3
Excellent	300 – 400	6.3 – 7.0
	400 – 600	7.0 – 8.2
	600 – 1000	8.2 – 10.1

Q77. Discuss the energy potential from wind in the context of India. Where can wind turbines be installed?

Answer : May-19, (R15), Q6(a)

Energy Potential From Wind in the Context of India

For answer refer Unit-II, Q75.

Suitable Places for Installation of Wind Turbines

For answer refer Unit-II, Q24.

2.3.2 Horizontal And Vertical Axis Wind Mills

Q78. Explain with a neat sketch the construction and working of wind electric generating plant

May-15, (R09), Q4(b)

OR

Describe with a neat sketch the working of a wind energy conversion system.

OR

Describe with a neat sketch the working of wind energy conversion system with main components.

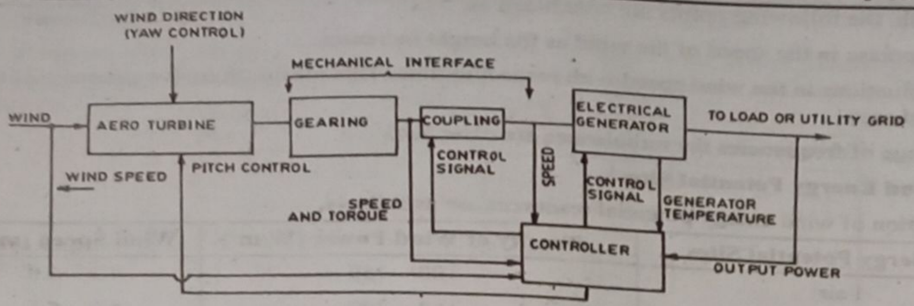
Answer : July-21 (ME), (R16), Q4(a)

Wind Energy Conversion System

The main components of a wind energy system are,

1. Aeroturbine
2. Gearing
3. Coupling
4. Electrical generator
5. Controller.

The main function of aeroturbine is to convert energy in moving air to rotary mechanical energy. In the case of horizontal wind axis turbine, they may require pitch control and yaw control. The rotary mechanical energy generated by the aeroturbine is transmitted to an electrical generator with the help of gears and coupling. The output of this generator is connected to the load or power grid as per the requirements. The locations where the wind is in one direction of the turbine, is designed in such a way that the orientation of the rotor is fixed so that the swept area is perpendicular to the predominant wind direction. Such a machine is said to be yaw fixed. The function of controller is to sense the wind speed, wind direction, shaft speeds and torques at one or more points. It detects the output power and temperature of generator. It also senses the proper control signals which helps in equating the electrical output and wind energy input. Due to the occurrence of strong winds, electrical faults etc., the wind energy system can be protected by the controller.



1.Aeroturbine 2. Gearing 3. Coupling
4.Mechanical interface 5. Electrical Generator 6. Controller

Figure: Basic Components of a Wind Energy System

Q79. Give an overview of control techniques for wind turbine systems along with their significance.

Answer :

July-21 (EEE), (R16), Q5(a)

The various control for wind turbine systems are as follows.

1. Generator control
2. Transmission control
3. Load control

1. **Generator Control**

Generator control schemes are decided by the generator being used. Generators that are most commonly used for production of electrical power from wind power are, Permanent magnet generator, D.C generator and induction generator.

2. **Transmission Control**

Wind energy generator is connected to load by means of transmission link. Silicon controlled type rectifier is used to vary, power supplied to load through transmission link. Such equipment consists of thyristors (power electronic devices). When gate of an individual thyristor is supplied with delayed trigger pulses control in conduction span that is on time and off time of thyristors is obtained.

3. **Load Control**

For wind turbine, stepwise load approximation to speed or power characteristic is obtained by employing load resistors. For a specific speed of wind, discrete resistance is selected so that turbine operates closely at its maximum value of C_P (coefficient of performance) while generator is set to operate within permissible current loading. The method of generation control is of low cost and simple, and preferred for small wind turbines of stand alone type.

Q80. Distinguish between onshore and offshore wind energy systems.

Answer :

July-21, (EEE), (R16), Q6(a)

	Onshore Wind Energy System		Offshore Wind Energy System
1.	These are large installations of wind turbines located on land.	1.	These are installations located in water bodies.
2.	The wind speeds on onshore is less than the offshore and not steadier.	2.	These systems have the potential to generate more electricity at a constant rate due to higher and more consistent wind speeds.
3.	The onshore farms create noise pollution and effect humans and environment negatively and also change the patterns of the surface air.	3.	Generally, offshore wind farms are far away from the human residences and have minimum impact on environment.
4.	These are easily accessible.	4.	Difficult to access these systems.
5.	Cheaper to build and maintain.	5.	Expensive to build and difficult to maintain.

Q81. How are WEC systems are classified? Discuss in detail.

April-18, (EEE), (R13), Q6(b)

OR

Give a brief description on types of wind turbines.

[April-18, (ME), (R13), Q7(a) | June-18, (R13), Q7(a)]

OR

Explain various configuration of wind turbines in detail with neat diagram.

Answer :

May-13, (R09), Q4(a)

Wind Mill

It is a device which converts the kinetic energy of the wind into the mechanical energy of the turbine shaft. It is also called wind turbine.

Classifications of Wind Mills

There are two broad classifications of wind mills,

(i) **Horizontal Axis Machines**

The axis of rotation of wind mill 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, as on the ancient persian wind mills or so, as on the modern Darrius rotor machine.

Wind mills can also be classified based on the following parameters.

1. **Electrical Power Output**

(i) **Small Scale (upto 2 kW)**

These might be used on farms, remote applications and other places requiring relatively low power.

(ii) **Medium Size Machines (2-100 kW)**

These wind turbines may be used to supply less than 100 kW rated capacity, to several residences or local use.

(iii) **Large Scale or Large Size Machines (100 kW or up)**

These are used to generate power for distribution in central power grids.

2. **Type of Output Power**

(i) D.C output

(ii) A.C output

3. **Rotational Speed of Wind Mill**

(i) Constant speed

(ii) Nearly constant speed

(iii) Variable speed with fixed pitch blades.

4. **Utilization of Output Mode**

(i) Battery storage

(ii) Direct connection to an electromagnetic energy converter

(iii) Other forms of storage

(iv) Interconnection with conventional electric utility grids.

Q82. Explain the advantages and limitations of wind energy conversion systems.

Answer :

May-17, (ME), (R13), Q6(a)

Advantages of Wind Energy Conversion System

1. There is no requirement of fuel supply.
2. Wind power plant consumes less time for its construction.
3. It is a non-polluting power system, thereby no adverse effect is produced on the environment.
4. Wind turbine occupies very small floor area.

Disadvantages of Wind Energy Conversion System

1. This system is noisy in operation.
2. Only limited amount of power is produced, i.e., ranging from 30 kW to 300 kW.
3. It involves very high initial cost.
4. The overall weight of the wind power system is relatively high.

Q83. What are the various components of a horizontal axis wind turbine explain?

Answer :

May-19, (R15), Q7(b)

The main components of horizontal axis wind turbine are,

1. Turbine blades
2. Generators
3. Yaw system
4. Hub
5. Nacelle
6. Towers.

1. **Turbine Blades**

Epoxy composites and glass fibre are used in the manufacture of turbine blades. To reduce the air friction, the blades are slightly twisted from outer tip. Modern turbines have two or three blades having aerofoil type cross section.

2. **Generator**

The type of generators used are either constant speed or variable speed generators. Variable speed generators are expensive and inaccurate and are not used in common practice. There are different types of constant speed generators, among which synchronous induction and permanent magnet types are used.

3. **Yaw System**

Yaw system controls the position of the nacelle around the vertical axis. Hence, by using yaw system, the position of nacelle is adjusted such that it faces the wind. The yaw system is provided at the base of the nacelle.

4. **Hub**

The central part of a rotor, where all the blades are connected is called hub. The mechanism for pitch angle control is provided in the hub.

5. **Nacelle**

It houses the rotor brakes, gearbox, generator, electrical switch gear and control. The switch gear and control block enables to control the system, according to the requirement. It is placed on the top of a tower.

6. **Towers**

Four types of towers generally used are as follows,

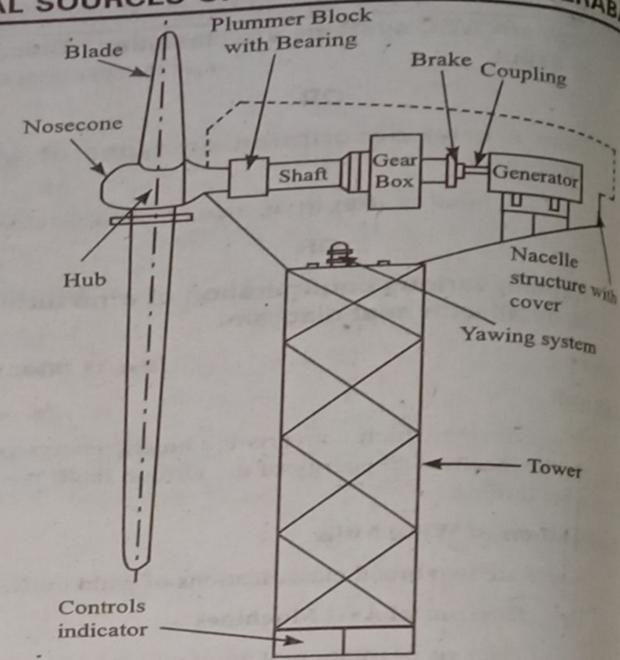
(i) Truss tower

(ii) Pole tower

(iii) Reinforced concrete tower

(iv) Built up shell-tube tower.

The most common and preferred tower is truss tower, because it is widely applicable. The parts of truss tower are stiff, inexpensive, readily available and can be transported easily. Truss tower is designed to withstand the wind load, even if they occur frequently over a short period.



Figure

Q84. Describe horizontal axis type aero generators.

April-18, (EEE), (R13), Q6(a)

OR

Write the working principle of horizontal axis turbine.

Answer :

In a horizontal axis wind turbine the axis of the rotor's rotation is parallel to the wind stream and the ground. It is built with a propeller type rotor on a horizontal axis i.e., a horizontal main shaft. It may be two (or) three bladed (or) more blades. The rotor converts linear motion of the wind into rotational energy that is used to drive a generator.

In this type of design, rotor drives a generator through a step up gear box. The blade rotor is usually designed to be oriented downwind of the tower. The components are mounted on a bed plate which is attached on a pintle at the top of the tower. The rotor blades are continuously bent by unsteady aerodynamic, gravitational and inertia loads, when the machine is in operation. If the blades are made of metal, flexing reduces their fatigue life with rotor, the tower is also subjected to above loads, which may cause serious damage. If the vibrational modes of the rotor happen to coincide with one of the natural mode of the vibration of the tower, the system may shake itself to pieces. Because of the high cost of the blade rotors with more than two blades are not recommended. Rotors with more than two, say 3 or 4 blades would have slightly higher power coefficient.

Working: The basic principle is that the flow of air is parall to the rotational axis of the turbine blades. The wind passes ov both surfaces of the blade creating a lower pressure area abov the air foil. The pressure differential between top and botto surface results in aerodynamic lift. The blades of the turbine a constrained to move in a plane with the hub as its centre, the li force causes rotation about the hub. In addition to lift force, drag force perpendicular to lift force impedes rotor rotation. I has high lift-to-drag ratio.

Q85. Explain various horizontal axis wind turbines.

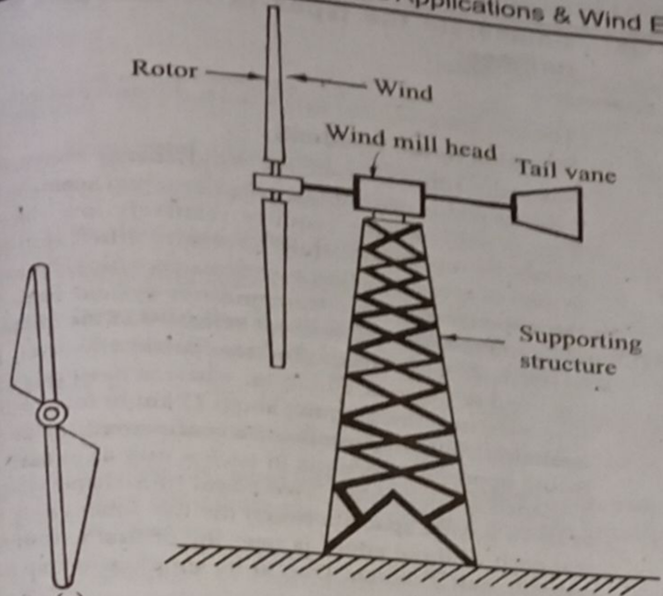
Answer :

Horizontal Axis Wind Mills

The important horizontal axis wind turbines are a follows,

1. **Horizontal axis using two aerodynamic blades**

In this design, the parts of the windmill are placed on the bed plate which is fastened to a pintle on the top of th tower. A step up gearbox is used to drive the generato The aerodynamic blades are generally positione downwind of the tower. During the working of th windmill, the rotor blades are always bent due to the aerodynamic structure, inertia and gravitational load The bending (flexing) is more if the blades are made o metal. This decreases the fatigue life and causes dama to the windmill. The cost of the blades is so high.



(a)
Two blade profile

(b)
Schematic of a horizontal axis type wind mills

Figure (1) : Horizontal Axis Two Aerodynamic (Blades Wind)

2. **Horizontal Axis Propeller Type using Single Blades**

It consists of a single blade of long length which is mostly below 60m. This blade is placed on a rigid hub. The tower shadow, gravity and the changes in the wind directions might be factors causing the bending moments if the length of the blade is above 60m. In order to balance the long length blade centrifugally, counter weight is used. Using the counter weight of less cost will decrease the overall cost of the windmill.

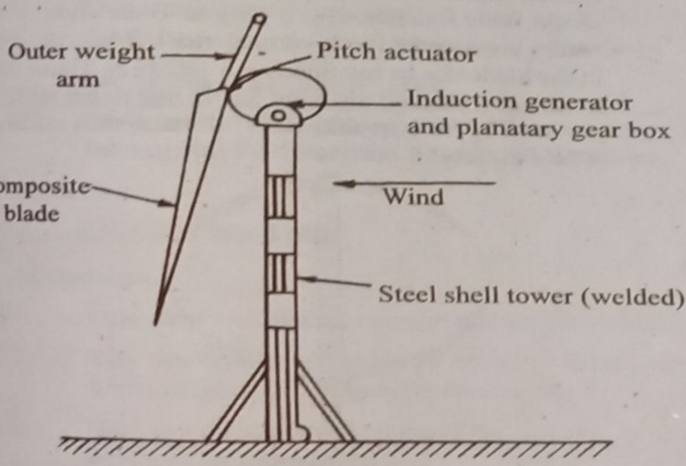


Figure (2): Horizontal Axis Single Blade Wind Mill

3. **Horizontal Axis Multi-Bladed Type**

These windmills have more number of blades which are made of aluminium or sheet metal. The following are the advantages of this wind mill.

(i) High strength to weight rotors

(ii) Simple in design and construction

(iii) Less cost

(iv) High starting torque

(v) Good power coefficient.

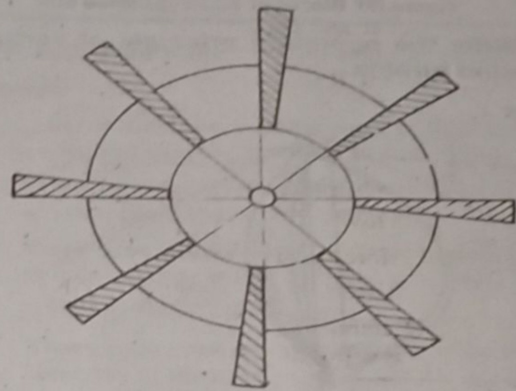


Figure (3): Horizontal Axis Multibladed Type

4. **Horizontal Axis Dutch-Type Wind Mill**

In this windmill, the blades were made of wooden slats. These are the oldest models of windmills and were used for a long time mostly in Europe. Generally, the windmill consists of 4 blades.

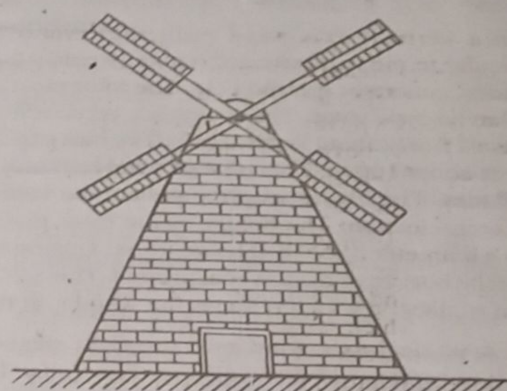


Figure (4): Horizontal Axis Dutch-Type Wind Mill

5. **Sail-Type**

This windmill was invented recently. Cloth, plastic and nylon are the materials used for the blade surfaces of the windmill. The arrangement of the blades resembles mast and pole or the sail wings.

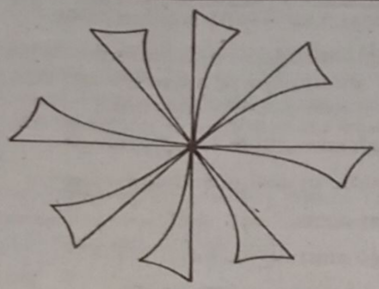


Figure (5): Blades of Sail-Type Wind Mill

Q86. Write the operating principle of vertical axis wind turbine.

Answer :

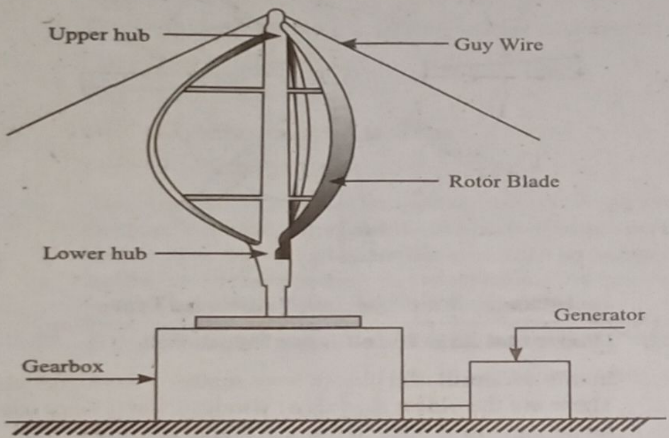


Figure: Vertical Axis Windmill

In a vertical axis wind mill, the rotor's rotation is perpendicular to the wind stream, It mainly consists of a tower, rotor, blades, generator, gearbox etc. The rotor most commonly used is Darrius type rotor. The tower is a vertical hollow shaft which rotates freely about vertical axis. The maximum height of the tower is about 100 m. This type of wind mill may have two or three blades. The blades are thin and curved in shape, with an airfoil cross-section. The height of the rotor may be about 94 m with a diameter of 65 m. The gearbox, generator etc., are mounted at the bottom of the tower at ground. This facilitates the elimination of nacelle which reduces the weight on the tower.

Working: A vertical axis wind mill does not require a yaw control as it accepts wind from all the directions. The wind passing through the blades rotates the blades,. This rotation of the blades causes the rotor rotation which is mounted on a rotating tower. The tower rotation runs the generator which is in connection with it. Thus power is generated by the generator. The major advantage of vertical axis windmill is, it is independent of wind direction. When the direction of wind changes, it do not turn into the stream. These machines are called panemones.

Q87. Enumerate the types of vertical axis wind turbines.

Answer :

The two main vertical axis wind turbines are as follows,

1. **Savonius Rotor Windmill**

Savonius rotor is used for wind-energy conversion systems and is of simplest type like a cup anemometer. This is self-starting, requires relatively low velocity winds for operation, thus have low efficiency. This system of conversion has a vertical axis which eliminates the expensive power transmission system from the rotor to the axis, and it is not sensitive to the direction of wind. Savonius rotor produces power effectively for the wind as slow as 10 km/hr, whereas most-propeller type wind machines require about 15 km/hr for effective operation. Savonius rotor consists of two half-cylinders facing opposite directions in such a way as to have an S-shaped cross-section. Two edges of S-shape overlap to leave a wide space between the two inner edges, so that each of these edges is near the central axis of the opposite half cylinder. Due to its simple structure it is easy to manufacture.

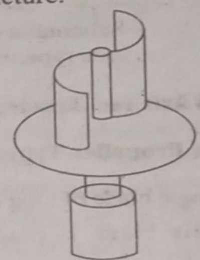


Figure (1) : Savonius Rotor

2. **Darrius Rotor Wind Mills**

This rotor has been invented by a french engineer G.J.M Darrius in 1925. In this arrangements, the blades are supported in a way that minimizes the bending stresses in the normal operations. It consists of two or three thin curved blades. The cross-section of the blades is airfoil shape with constant chord length. Both ends of the blades are attached to a vertical shaft. Thus, the force in the blade due to rotation is pure tension. These wind mills can withstand the wind forces due to the stiffness provided by the pure tension. The blades thus made are lighter in weight.

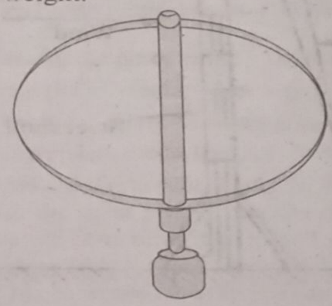


Figure (2) : Darrius Rotor

Q88. With a neat sketch explain the types of wind turbines.

Answer : July-21 (ME), (R16), Q5(a)

The wind turbines are mainly classified into two categories. They are,

1. **Horizontal Axis Wind Turbines**

   For answer refer Unit-II, Q85.

2. **Vertical Axis Wind Turbines**

   For answer refer Unit-II, Q86.

Q89. Describe the salient features of a vertical-axis wind turbine with the help of a diagram.

Answer : July-19, (R15), Q6(a)

Salient Features of a Vertical Axis Wind Turbine

1. Vertical axis wind turbines consists of less components. Thus, comparatively less parts will undergo breakdown and wearing.
2. Operation of these turbines is independent of wind direction. As axis about which these turbines rotate, lies at almost right angle to the direction of the wind, they are capable of receiving wind from all directions. Therefore, design of yaw devices becomes simple.
3. Components such as gear box and generator are positioned at ground level. Therefore, maintenance becomes easier and complexity of tower design is reduced.
4. Can be employed for synchronous applications without using pitch control devices.
5. It is possible to design vertical axis wind mills of smaller sizes by scaling down to a considerably lower valve, so that they fit on rooftops for urban applications.
6. Transportation and installation of these turbines is easy.
7. These turbines possess aerofoil pitch angle, thus drag reduction at low and high pressures is possible.

For figures refer Unit-IV, Q37.

Q90. Discuss the advantages and disadvantages of horizontal and vertical axis wind turbines.

Answer :

Horizontal-axis Wind Mills

Advantages

1. Orientation of blades, helps in maintaining stability.
2. Tall tower allows access to stronger wind, thereby increasing the power generation capacity.
3. Tall tower allows placement on uneven land or in offshore locations.
4. It can be installed in forests, above tree line.
5. These wind mills are self-starting.
6. It is cheaper per unit of output, because of higher production volume and larger size.

Disadvantages

1. It is difficult to operate at low heights and in case of turbulent winds.
2. The tall towers and long blades are difficult to transport on the sea and on land.
3. Supply of these wind mills is less than the demand, as per previous observations.
4. It has more environmental impacts.

Vertical-axis Wind Mills

Advantages

1. Easier to maintain, because most of their moving parts are located near the ground.
2. As the rotor blades are vertical, yaw control is not needed, which reduces the cost.
3. These have a higher aerofoil pitch angle, thus, leading to reduced drag at low and high pressures.
4. It can operate at low heights.
5. There is no need of orientation of wind mill with the direction of the wind.

Disadvantages

1. They possess low efficiency comparatively.
2. Height and sweep area of the wind mill are limited.
3. These wind mills need to be installed on a relatively flat surface of land.

Q91. What are the advantages and disadvantages of horizontal axis windmill over vertical axis windmill.

Answer :

Advantages

1. A horizontal axis windmill or wind turbine (HAWT) has a variable blade pitch which helps the blades in collecting maximum amount of wind energy during the day.
2. The base of the tower in a HAWT is tall. This makes the blades to access stronger wind at sites with wind shear. In VAWT, tower base is short and thus it cannot use wind speed at higher elevations. Thus generates less power.
3. The efficiency in a HAWT is higher when compared to VAWT. This is primarily because the blades in a HAWT always move perpendicular to the wind and thus receives maximum power through the whole rotation.

   In a VAWT, the blades have reciprocating actions which require the airfoil surfaces to backtrack against the wind for part of the cycle. In the process of backtracking against the wind, the efficiency reduces in VAWT.

4. In a HAWT, the wind strikes the face of the blades at a consistent angle regardless of the position of its rotation. This causes the lateral wind loading to be consistent over the course of rotation. Due to this consistency in wind loading the vibrations and hence noise is reduced.

In a vertical axis windmill, the blades being vertical, the wind does not strike the face of the blade at consistent angle. The inconsistency in wind loading causes stress in each blade and thus changes the sign twice during each revolution. Thus with this the probability of blade failure is increased due to the reversal of the stress.

Disadvantages

1. As the horizontal axis wind turbines consists of tall towers and long blades (upto 45 meters), the transportation of the auxiliary equipment to the site is very difficult. In case of VAWT, the tower is short and hence easy to transport.
2. The cost of installing the towers in a HAWT is very expensive as it requires very tall and cost effective cranes as well as highly skilled personal. On the other hand installation of VAWT is less expensive.
3. To support the heavy blades, gear box and generator in a HAWT, massive tower is to be constructed. In case of VAWT, the generators can be located nearer to the ground and hence requires small tower.
4. The design of HAWT is complex when compared to a VAWT.
5. The HAWT is not omnidirectional like VAWT.
6. HAWT requires additional yaw control mechanism to turn the blades and needle towards the wind. But, a VAWT requires no steering mechanism to head the rotor into the wind.

Q92. Explain the procedure of wind generation and control for electrical energy.

Answer: Dec.-20, (R16), Q5

Wind Generation

For answer refer Unit-II, Q78.

Procedure of Control for Electrical Energy

Out of Syllabus.

Q93. Compare horizontal and vertical axis windmills and briefly list of various types of rotar systems.

Answer: Sept.-20, (R16), Q5(a)

Difference between Horizontal and Vertical Axis Wind Mills

For answer refer Unit-II, Q30.

Types of Rotar Systems

For answer refer Unit-II, Q26.

Q94. Comment on the relative features of HAWT and VAWT.

April-14, (R09), Q5(a)

Answer :

Features of HAWT

For answer refer Unit-II, Q90, Topic: Advantages.

Features of VAWT

For answer refer Unit-II, Q89.

Q95. A HAWT having the rotor diameter as 80 m is rotating at 40 rpm. The wind speed is 20 m/s at 1 atm and 27°C. Calculate the torque produced at the shaft for maximum output the of the turbine.

Answer : June-18, (R13), Q7(b)

Given that,

Diameter of rotor, $D = 80$ m

Radius of rotor, $R = \frac{80}{2} = 40$ m

Speed of wind, $u_0 = 20$ m/s

Pressure of wind, $P = 1$ atm $= 1.01325 \times 10^5$ Pa.

Temperature of wind, $T = 27°C = 300$ K

Speed of the rotor, $\omega = 40$ rpm

$$= 2\pi \times \frac{40}{60}$$

$$= 4.188 \text{ rad/s}$$

Area of motor, $A = \pi R^2$

$$= \pi \times (40)^2$$

$$= 5026.548 \text{ m}^2$$

Density of air, $\rho = \frac{P}{RT}$

$$= \frac{1.01325 \times 10^5}{287 \times 300}$$

$(\because \overline{R} = 287$ J/kg K)

$$= 1.177 \text{ kg/m}^3$$

For maximum output of the turbine,

Interference factor, $a = \frac{1}{3}$

Maximum power coefficient, $C_{p_{max}} = 0.593$

T_{1P} – Speed ratio is given as,

$$\lambda = \frac{R\omega}{u_0}$$

$$= \frac{40 \times 4.188}{20}$$

$$= 8.376$$

Power available in wind is given as,

$$P_0 = \frac{1}{2}(\rho A)u_0^3$$

$$= \frac{1}{2} \times (1.77 \times 5026.548) \times (20)^3$$

$$= 23664987.98 \text{ W}$$

$$= 23.665 \text{ MW}$$

∴ The maximum torque acting on the ideal turbine rotor is given as,

$$T_M = \frac{P_0}{u_0} R$$

$$= \frac{23.665}{20} \times 40$$

$$= 47.33 \text{ N}$$

Maximum torque coefficient is given as,

$$C_{T_{max}} = \frac{C_{P_{max}}}{\lambda}$$

$$= \frac{0.593}{8.376}$$

$$= 0.07079$$

∴ Torque produced at the shaft for maximum output of the turbine is,

$$T_{sh\,max} = T_M \times C_{T_{max}}$$

$$= 47.33 \times 0.07079$$

$$= 3.348 \simeq 3.35 \text{ N}$$

2.3.3 Performance Characteristics – Betz Criteria

Q96. Write a short note on the performance of wind mills.

Answer :

The performance of a wind mill is defined as 'coefficient of performance' (C_p)

$$C_p = \frac{\text{Power delivered by the rotor}}{\text{Maximum power available in the wind}}$$

$$C_p = \frac{P}{P_{max}} = \frac{P}{\frac{1}{2}\rho A V^3} \quad ...(1)$$

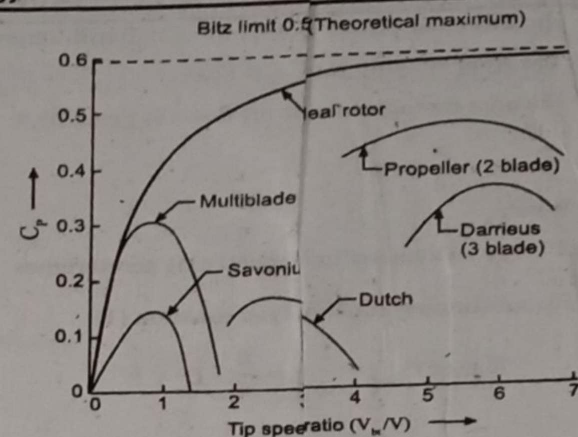
Where,

ρ – Density of air

A – Swept area,

V – Velocity of wind

The plot between C_p and tip speed ratio ($TSR = V_{bt}/V$) is shown in below figure.



Fure

Where, V_{bt} – Speed oflade tip.

C_p is lowest for Savonis and Dutch types, wherea the propeller types have the highst value of C_p.

In the designing of wid mills, it is important to keep the power to weight ratio at te lowest possible level.

Q97. Derive the expressn for power devebped due to wind energy.

[May-17, (ME), (R13), Q6(b) |May-17, (EE) (R13), Q5]

OR

Derive the expresson for energy available in the wind.

Answer :

Expression for Energy Avilable in the Wind(or) Power Available in the Wind

The energy available in the wind can be alculated by applying the concept of kinetcs. The principle of wind machines is to convert kinetic energy of wind into mechaical energy.

Let,

V – Velocity of wind in km/h

ρ – Density of air (at sea level, = 1.225 kg/m³)

A – Area through which the air ows.

The quantity of air passing in unit tir through the area 'A' with velocity 'V' is given by,

∴ Mass = Volume of air × Densi of air

$$m = (V \times A) \times \rho$$

The kinetic energy of the wind is ven by,

$$\text{K.E} = \frac{1}{2} m V^2$$

$$\text{K.E} = \frac{1}{2} \times (\rho \times A \times V) \times \text{ watts}$$

$$\text{K.E or total power, } P_{total}\ \frac{1}{2} \times \rho \times A \times V^3 \text{ watts}$$

Therefore, the power out of the wind will varies as cube of the wind velocity (i.e., $_{tal} \alpha V^3$).

The area through which air flows is given by,

$$A = \frac{\pi}{4} \times D^2 \quad \text{... (2)}$$

Where,

D – Diameter in horizontal axis aeroturbines

By substituting equation (2) in equation (1),

$$\text{K.E or } P_{Total} = \frac{1}{2} \rho \times \frac{\pi}{4} \times D^2 \times V^3$$

$$P = \frac{1}{8} \pi D^2 V^3$$

∴ The above equation represents the energy available in the wind or power available in the wind.

Q91. What is Betz limit and show that a wind turbine cannot extract more than 59.3% wind energy?

Sept.-20, (R16), Q5(b)

OR

Show that a wind turbine cannot extract more than 59.3% of wind energy.

April-18, (ME), (R13), Q6(b)

OR

Derive an expression for maximum power coefficient for a horizontal axis wind turbine.

April-18, (ME), (R13), Q7(b)

OR

Prove that the maximum power coefficient C_p for a windmill is 0.593.

OR

Show that for horizontal wind mill the maximum power can be obtained when exit velocity = (wind velocity)/3 and the maximum power is $\frac{8}{27} \rho AV^3$.

OR

What is the Betz limit and how is it applied to wind turbines.

Answer : **[July-21 (ME), (R16), Q5(b) | Model Paper, Q5(b)]**

Energy from the wind stream is extracted by a wind turbine, by converting the kinetic energy (K.E.) of the wind into mechanical energy (i.e., rotational motion) required to operate an electric generator.

The following assumptions are made to derive the energy equation.

1. The flow of wind is 'incompressible'. Thus, the air stream diverges as it passes through the turbines.

2. The mass flow rate of the wind is 'constant' at far up-stream, at the rotor and at far down stream.

Let,

p – Atmospheric wind pressure

p_{us} – Pressure on upstream of wind turbine

p_{ds} – Pressure on downstream of wind turbine

V – Atmospheric wind velocity

V_{us} – Velocity of wind upstream of wind turbine

V_{bl} – Velocity of wind at blades

V_{ds} – Velocity of wind downstream of wind turbine before the wind front reforms and regains the atmosperic level.

A_{bl} – Area of blades

$\dot{m}$ – Mass flow rate of wind

ρ – Density of air.

The kinetic energy of wind stream passing through the turbine rotor is given by.

$$K.E. = \frac{1}{2} \dot{m} V_{bl}^2$$

Mass flow rate of the wind,

$$m = \rho A_{bl} V_{bl}$$

$$\therefore \quad K.E. = \frac{1}{2} \rho A_{bl} V_{bl} \times V_{bl}^2 = \frac{1}{2} \rho A_{bl} V_{bl}^3 \quad \text{...(1)}$$

The force on the rotor disc, F is given by,

$$F = (p_{us} - p_{ds}) A_{bl} \quad \text{...(2)}$$

The force on the rotor disc is also given by,

$$F = \dot{m}[V_{us} - V_{ds}] \quad \text{...(3)}$$

[i.e., Momentum per unit time form upstream to downstream winds]

By applying Bernoulli's equation to upstream and down-stream sides,

$$p + \frac{1}{2} \rho V_{us}^2 = p_{us} + \frac{1}{2} V_{bl}^2 \quad \text{...(4)}$$

$$\text{And, } p_{ds} + \frac{1}{2} \rho V_{bl}^2 = \rho + \frac{1}{2} \rho V_{ds}^2 \quad \text{...(5)}$$

By solving the equations (4) and (5),

$$p_{us} - p_{ds} = \frac{1}{2} \rho [V_{us}^2 - V_{ds}^2] \quad \text{...(6)}$$

By equating the equations (2) and (3),

$$p_{us} - p_{ds} A_{bl} = \dot{m}[V_{us} - V_{ds}] = \rho A_{bl} V_{bl} [V_{us} - V_{ds}] \quad \text{...(7)}$$

By solving equations (6) and (7),

$$\frac{1}{2} \rho [V_{us}^2 - V_{ds}^2] = \rho V_{bl} [V_{us} - V_{ds}]$$

$$V_{bl} = \frac{[V_{us} + V_{ds}]}{2} \quad \text{...(8)}$$

Then,

In a wind turbine system "speed flow work", W, is equal to the difference in kinetic energy between upstream and downstream of turbine for unit mass flow $(\dot{m} = 1)$

Therefore,

$$W = (K.E)_{us} - (K.E)_{ds}$$

$$W = \frac{1}{2}[V_{us}^2 - V_{ds}^2]$$

The power output 'P' of wind turbine (rate of workdone) is given as,

$$P = \frac{1}{2}\dot{m}[V_{us}^2 - V_{ds}^2] = \dot{m}\left[\frac{V_{us}^2 - V_{ds}^2}{2}\right]$$

$$= \rho A_{bl}\left[\frac{V_{us} + V_{ds}}{2}\right]\left[\frac{V_{us}^1 - V_{ds}^2}{2}\right]$$

$$\left[\because \dot{m} = \rho A_{bl} V_{bl} = \rho A_{bl}\left\{\frac{V_{us} + V_{ds}}{2}\right\}, \text{ from eequation (8)}\right]$$

$$\therefore \quad P = \frac{1}{4}\rho A_{bl}[V_{us} + V_{ds}][V_{us}^2 - V_{ds}^2] \qquad \text{...(10)}$$

The P_{max} (maximum turbine output) is obtained by differentiating the equation (10) with respect to V_{ds} and equating to zero.

i.e., $\frac{dP}{dV_{ds}} = 3V_{ds}^2 + 2V_{us}V_{ds} - V_{us}^2 = 0$

The above quadratic equation has two solutions. They are,

$V_{ds} = \frac{1}{3}V_{us}$ and $V_{ds} = V_{us}$

For power generation, $V_{ds} < V_{us}$,

Therefore,

$$V_{ds} = \frac{1}{3}V_{us} \qquad \text{...(11)}$$

By substituting the equation (11) in equation (10),

$$P_{max} = \frac{1}{2}\rho A_{bl}\left[V_{us} + \frac{1}{3}V_{us}\right]\left[V_{us}^2 - \left\{\frac{1}{3}V_{us}\right\}^2\right]$$

$$= \frac{1}{3}PA_{bl}\left[\frac{4}{3}V_{us}\right]\left[\frac{8}{9}V_{us}^2\right]$$

$$\therefore \quad P_{max} = \frac{8}{27}\rho A_{bl}V_{us}^3 \qquad \text{... (12)}$$

$$= \frac{16}{27}\left[\frac{1}{2}\rho A_{bl}V_{us}^3\right]$$

$$= 0.593\left[\frac{1}{2}\rho A_{bl}V_{us}^3\right]$$

Total power in the wind stream, $P_{total} = \frac{1}{2}\rho A_{bl}V_{us}^3$ ...(13)

$$P_{max} = 0.593\, P_{total}$$

Then, the coefficient of power is given by, $C_P = \frac{P_{\max}}{P} = 0.593$ ...(14)

The factor 0.593 is known as Betz limit.