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SEC2T (Renewable Energy and Energy Harvesting), Topic:- Solar Energy

❖ Introduction :

Solar energy is an important, clean, cheap and abundantly available renewable energy. It is received on Earth in cyclic, intermittent and dilute form with very low power density 0 to 1 kW/m2.Solar energy received on the ground level is affected by atmospheric clarity, degree of latitude, etc. For design purpose, the variation of available solar power, the optimum tilt angle of solar flat plate collectors, the location and orientation of the heliostats should be calculated.

Units of solar power and solar energy:

In SI units, energy is expressed in Joule. Other units are angley and Calorie where

1 angley = 1 Cal/cm2.day

1 Cal = 4.186 J

For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of kJ/m2/day or kJ/m2/hour. Solar power is expressed in terms of W/m2 or kW/m2.

Essential subsystems in a solar energy plant:

1. **Solar collector or concentrator**: It receives solar rays and collects the energy. It May be of following types:

a) Flat plate type without focusing

b) Parabolic trough type with line focusing

c) Paraboloid dish with central focusing

d) Fresnel lens with centre focusing

e) Heliostats with centre receiver focusing

2. **Energy transport medium:** Substances such as water/ steam, liquid metal or gas are used to transport the thermal energy from the collector to the heat exchanger or thermal storage. In solar PV systems energy transport occurs in electrical form.

3. **Energy storage:** Solar energy is not available continuously. So, we need an energy storage medium for maintaining power supply during nights or cloudy periods. There are three major types of energy storage: a) Thermal energy storage; b) Battery storage; c) Pumped storage hydro-electric plant.

4. **Energy conversion plant**: Thermal energy collected by solar collectors is used for producing steam, hot water, etc. Solar energy converted to thermal energy is fed to steam thermal or gas-thermal power plant.

5. **Power conditioning, control and protection system**: Load requirements of electrical energy vary with time. The energy supply has certain specifications like voltage, current, frequency, power etc. The power conditioning unit performs several functions such as control, regulation, conditioning, protection, automation, etc.

6. **Alternative or standby power supply**: The backup may be obtained as power from Electrical network or standby diesel generator.

Energy from the sun:

The sun radiates about 3.8 x 1026 W of power in all the directions. Out of this about 1.7 x 1017 W is received by earth. The average solar radiation outside the earth's atmosphere is 1.35 kW/m2 varying from 1.43 kW/m2 (in January) to 1.33 kW/m2(in July).

Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors. The first installation of solar thermal energy equipment occurred in the Sahara desert approximately in 1910 when a steam engine was run on steam produced by sunlight. Because liquid fuel engines were developed and found more convenient, the Sahara project was abandoned, only to be revisited several decades late.

Solar thermal collectors are classified by the United States Energy Information Administration as low-, medium-, or high-temperature collectors. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for fulfilling heat requirements up to 300 deg C / 20 bar pressure in industries, and for electric power production. However, there is a term that used for both the applications. Concentrated Solar Thermal (CST) for fulfilling heat requirements in industries and Concentrated Solar Power (CSP) when the heat collected is used for power generation. CST and CSP are not replaceable in terms of application.

A solar thermal collector system gathers the heat from the solar radiation and gives it to the heat transport fluid. The heat-transport fluid receives the heat from the collector and delivers it to the thermal storage tank, boiler steam generator, heat exchanger etc. Thermal storage system stores heat for a few hours. The heat is released during cloudy hours and at night. Thermal-electric conversion system receives thermal energy and drives steam turbine generator or gas turbine generator. The electrical energy is supplied to the electrical load or to the AC grid. Applications of solar thermal energy systems range from simple solar cooker of 1 kW rating to complex solar central receiver thermal power plant of 200 MW rating.

SOLAR COLLECTORS :-

Introduction:

Solar thermal energy is the most readily available source of energy. The Solar energy is most important kind of non-conventional source of energy which has been used since ancient times, but in a most primitive manner. The abundant solar energy available is suitable for harnessing for a number of applications. The application of solar thermal energy system ranges from solar cooker of 1 kw to power plant of 200MW. These systems are grouped into low temperature (<150oC), medium temperature (150-300oC) applications.

Solar Collectors-

Solar collectors are used to collect the solar energy and convert the incident radiations into thermal energy by absorbing them. This heat is extracted by flowing fluid (air or water or mixture with antifreeze) in the tube of the collector for further utilization in different applications. The collectors are classified as;

- Non concentrating collectors
- Concentrating (focusing) collectors

Non concentrating collectors-

In these collectors the area of collector to intercept the solar radiation is equal to the absorber plate and has concentration ratio of 1. Flat Plate Collectors (Glaze Type) Flat plate collector is most important part of any solar thermal energy system. It is simplest in design and both direct and diffuse radiations are absorbed by collector and converted into useful heat. These collectors are suitable for heating to temperature below 100oC.

The main advantages of flat plate collectors are:

- It utilizes the both the beam as well as diffuse radiation for heating.
- Requires less maintenance.

Disadvantages-

- Large heat losses by conduction and radiation because of large area.
- No tracking of sun.
- Low water temperature is achieved.

The constructional details of flat plate collector are given below

(a) Insulated Box: The rectangular box is made of thin G.I sheet and is insulated from sides and bottom using glass or mineral wool of thickness 5 to 8 cm to reduce losses from conduction to back and side wall. The box is tilted at due south and a tilt angle depends on the latitude of location. The face area of the collector box is kept between 1 to 2 m2.

(b) Transparent Cover: This allows solar energy to pass through and reduces the convective heat losses from the absorber plate through air space. The transparent tampered glass cover is placed on top of rectangular box to trap the solar energy and sealed by rubber gaskets to prevent the leakage of hot air. It is made of plastic/glass but glass is most favourable because of its transmittance and low surface degradation. However with development of improved quality of plastics, the degradation quality has been improved. The plastics are available at low cost, light in weight and can be used to make tubes, plates and cover but are suitable for low temperature application 70-120oC with single cover plate or up to 150oC using double cover plate. The thickness of glass cover 3 to 4 mm is commonly used and 1 to 2 covers with spacing 1.5 to 3 cm are generally used between plates. The temperature of glass cover is lower than the absorber plate and is a good absorber of thermal energy and reduces convective and radiative losses of sky.

(c) Absorber Plate: It intercepts and absorbs the solar energy. The absorber plate is made of copper, aluminum or steel and is in the thickness of1 to 2 mm. It is the most important part of collector along with the tube products passing the liquid or air to be heated. The plate absorbs the maximum solar radiation incident on it through glazing (cover plate) and transfers the heat to the tubes in contact with minimum heat losses to atmosphere. The plate is black painted and provided with selective material coating to increase its absorption and reduce the emission. The absorber plate has high absorption (80-95%) and low transmission/reflection.

(d) Tubes: The plate is attached to a series of parallel tubes or one serpentine tube through which water or other liquid passes. The tubes are made of copper, aluminum or steel in the diameter 1 to 1.5 cm and are brazed, soldered on top/bottom of the absorber water equally in all the tubes and collect it back from the other end. The header pipe is made of same material as tube and of larger diameter. Now-a-days the tubes are made of plastic but they have low

thermal conductivity and higher coefficient of expansion than metals. Copper and aluminum are likely to get corroded with saline liquids and steel tubes within hibitors are used at such places.

Removal of Heat: These systems are best suited to applications that require low temperatures. Once the heat is absorbed on the absorber plate it must be removed fast and delivered to the place of storage for further use. As the liquid circulates through the tubes, it absorbs the heat from absorber plate of the collectors. The heated liquid moves slowly and the losses from collector will increase because of rise of high temperature of collector and will lower the efficiency. Flat-plate solar collectors are less efficient in cold weather than in warm weather. Factors affecting the Performance of Flat Plate Collector.

The different factors affecting the performance of system are:

(a) Incident Solar Radiation: The efficiency of collector is directly related with solar radiation falling on it and increases with rise in temperature.

(b) Number of Cover Plate: The increase in number of cover plate reduces the internal convective heat losses but also prevents the transmission of radiation inside the collector. More than two cover plate should not be used to optimize the system.

(c) Spacing: The more space between the absorber and cover plate the less internal heat losses. The collector efficiency will be increased. However on the other hand, increase in space between them provides the shading by side wall in the morning and evening and reduces the absorbed solar flux by 2-3% of system. The spacing between absorber and cover plate is kept 2-3 cm to balance the problem.

(d) Collector Tilt: The flat plate collectors do not track the sun and should be tilted at angle of latitude of the location for an average better performance. However with changingdeclination angle with seasons the optimum tilt angle is kept $\Phi + 15o$. The collector is placed with south facing at northern hemisphere to receive maximum radiation throughout the day.

(e) Selective Surface: Some materials like nickel black ($\alpha = 0.89$, $\varepsilon = 0.15$) and black chrome ($\alpha = 0.87$, $\varepsilon = 0.088$), copper oxide ($\alpha = 0.89$, $\varepsilon = 0.17$) etc. are applied chemically on the surface of absorber in a thin layer of thickness 0.1 μm. These chemicals have high degree of absorption (α) to short wave radiation (<4 μm) and low emission (ε) of long wave radiations (>4 μm). The higher absorption of solar energy increase the temperature of absorber plate and working fluid. The top losses reduce and the efficiency of the collector increases. The selective surface should be able to withstand high temperature of 300-400oC, cost less, should not oxidize and be corrosive resistant. The property of material should not change with time.

(f) Inlet Temperature: With increase in inlet temperature of working fluid the losses increase to ambient. The high temperature fluid absorbed the less heat from absorber plate because of low temperature difference and increases the top loss coefficient. Therefore the efficiency of collector get reduced with rise in inlet temperature.

(g) Dust on cover Plate: The efficiency of collector decreases with dust particles on the cover plate because the transmission radiation decreases by 1%. Frequent cleaning is required to get the maximum efficiency of collector.

Concentrating Collectors

Concentrating collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors use optical system in the form of reflectors or refractors.

These collectors are used for medium (100-300o C) and high-temperature (above 300oC) applications such as steam production for the generation of electricity. The high temperature is achieved at absorber because of reflecting arrangement provided for concentrating the radiation at required location using mirrors and lenses.

These collectors are best suited to places having more number of clear days in a year. The area of the absorber is kept less than the aperture through which the radiation passes, to concentrate the solar flux. These collectors require tracking to follow the sun because of optical system. The tracking rate depends on the degree of concentration ratio and needs frequent adjustment for system having high concentration ratio. The efficiency of these collectors lies between 50-70%. The collectors need more maintenance than FPC because of its optical system. The concentrating collectors are classified on the basis of reflector used; concentration ratio and tracking method adopted.

FPC with Reflectors

The mirrors are placed as reflecting surface to concentrate more radiations on FPC absorber. The fluid temperature is higher by 30oC than achieved in FPC. These collections utilize direct and diffuse radiation.

Lens Focusing Type

The fresnel lenses are used to concentrate the radiation at its focus. The lower side of lenses is grooved so that radiation concentrates on a focus line.

Compound Parabolic Collectors

These collectors are line focusing type. The compound parabolic collectors have two parabolic surfaces to concentrate the solar radiation to the absorber placed at bottom. These collectors have high concentration ratio and concentrator is moving to track the sun.

Cylindrical Parabolic Collectors

The troughs concentrate sunlight onto a receiver tube, placed along the focal line of the trough. The temperature at the absorber tube is obtained at nearly 400o C. The absorber in these collectors is moving to receive the reflected radiations by reflector, while the concentrators (trough) remains fixed. Because of its parabolic shape, it can focus the sun at 30 to 100 times its normal intensity (concentration ratio) on a receiver. The heat transfer medium carries the heat at one central place for further utilization.

Parabolic Dish Collector

The collectors have mirror-like reflectors and an absorber at the focal point. These collectors are point focusing type. The concentrating ratio of these collectors is 100 and temperature of the receiver can reach up to 2000o C. These collectors have higher efficiency for converting solar energy to electricity in the small-power plant. In some systems, a heat engine, such as a Stirling engine, is connected to the receiver to generate electricity.

Advantages of concentrating collector over flat collector

• The size of the absorber can be reduced that gives high concentration ratio.
• Thermal losses are less than FPC. However small losses occur in the concentrating collector because of its optical system as well as by reflection, absorption by mirrors and lenses.
• The efficiency increases at high temperatures.
• In these collectors the area intercepting the solar radiation is greater than the absorber area.
• These collectors are used for high-temperature applications.
• Reflectors can cost less per unit area than flat plate collectors.

Disadvantages

• Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component cannot be reflected and is thus lost.
• In some stationary reflecting systems it is necessary to have a small absorber to track the sun image; in others the reflector may have to be adjustable more than one position if year round operation is desired; in other words costly orienting systems have to be used to track the sun.
• Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation etc.
• Non –uniform flux on the absorber whereas flux in flat-plate collectors in uniform.
• Additional optical losses such as reflectance loss and the intercept loss, so they introduce additional factors in energy balances.