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Mini Solar Towers using Fresnel Lenses

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Abstract

This paper aims to give an overview of the solar tower technology and its consequences along with a new concept of mini solar towers using Fresnel lens. Fresnel lens are used to concentrate the solar radiation falling on the aperture to a particular point. It contributes to update the economic status and technical status of molten salt solar tower technology. It has aspired to explain the solar power tower with an overview of energy, renewable energy, solar energy, solar photovoltaic, solar thermal and Fresnel Lenses.

Key Words– ST-solar tower, Fresnel lens, concentrated collectors

1. Introduction

The energy demand is growing rapidly. To meet out the demand, electricity generation also increases. Everyone started to move towards Renewable resources like solar, wind, hydro etc,. Because the sources like Coal, Petroleum is at the edge of their extinction. “Energy can neither be Created nor Destroyed whereas it can be transferred from one form to another.

2. Source of Energy:

There are two sources of energy,

A) Renewable source
B) Non-Renewable Source

2.1. Renewable sources of Energy:

In the past decades, the consumption of non-renewable sources of energy has caused more fatal damage to environment than any other human activity. Electrical Energy generated from fossil fuels such as coal and oil has led to increased concentrations of greenhouse gases in the atmosphere which in turn led to so much problems being faced now-a-days such as global warming and ozone depletion. Vehicular air pollution has also been a major problem. Therefore, renewable sources of energy have become relevant and very important to present days. Renewable sources, such as the sun and wind, can never be bankrupted. Most of the renewable sources of energy are likely non-polluting and considered clean though biomass, a renewable source, is a major polluter indoors. Renewable energy sources include the sun, water, wind, fuel wood, agricultural residue, and animal dung. Energy obtained from the sun is known as solar energy.

2.2. Solar Photovoltaic:

Photovoltaic (PV) is the method of converting light energy into direct current using semiconductors which exhibits the Photovoltaic effect. A group of solar cells connected in a specific arrangement to produce the desired output voltage and current by means of solar panels. Materials used in photovoltaic's are monocrystalline, polycrystalline, cadmium telluride, amorphous silicon gallium selenide /sulfide and copper indium.

2.3. Solar Thermal:

Solar Thermal Energy is an innovative and developing Technology for harnessing thermal (heat) energy from the sun. Solar Thermal Collectors are classified based on the temperature rating as follow: a) Low, b) Medium and c) High temperature collectors. Flat plates are Low-temperature collectors generally used to heat swimming pools which is less than 80 degree Celsius. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use over temperature of 200 degree Celsius. High-temperature collectors concentrate sunlight using mirrors or lenses or Heliostats and are generally used for electric power production at a temperature of 400 degree Celsius.

Figure.1. Solar tower with heliostats

3. History of Solar Towers:

Solar towers generates electricity from heat energy from sun's radiation by focusing concentrated radiation on a tower-mounted heat receiver. This system uses a thousands of sun tracking mirrors called heliostats to reflect the incident sun rays onto the receiver. These plants are mostly suited for utility-scale applications in the range of 10 to 100 MW. The Solar tower technology has been the subject of research and development in the United States since the 1970s.[1-4]

In the past two decades, solar towers are less commercial than parabolic trough systems, numerous component and system experiments have been fielded around the world, demonstrating the economic potential and engineering feasibility of the technology. Since the early 1980s, the solar towers had been situated in Italy, Russia, Japan, Germany, France, Spain and the United States.

Figure.2. Heliostat at Solar Tower

3.1. Receivers in Solar Tower:

The receiver is one of the most essential parts of solar tower plants. Generally, there are two types of receivers: volumetric and tubular. Volumetric receivers use air or supercritical carbon di-oxide (CO_2) as heat transfer fluid and tubular receivers are used for liquid heat transfer fluid such as water, thermic oil, molten salt, Hitec salt and liquid sodium.The type of receiver depends on the type of power cycle (Brayton or Rankine) and HTF (Heat Transfer Fluid) used in the system.

Figure.3. External Tubular Receiver

In tubular receivers, the heat transfer fluid passes through numerous vertical tubes and gets heated by the radiation reflected from the heliostats. Generally, there are two types of tubular receivers:

1. Cavity receivers and
2. External cylindrical receivers.

In External cylindrical receivers vertical tubes are arranged side by side, in a cylindrical manner and the radiation from the heliostats converges from all directions. The cavity receivers consists of Welded tubes placed inside a cavity orvacuum to avoid Convection losses by eliminating physical contacts.[5-8]

3.2 Heat Transfer Fluid:

Based on the power cycles and type of receiver, different types of Heat Transfer Fluids can be employed in the system. The heat transfer fluids used in the operational solar towers are molten salt, water, and air. In order to use water, it requires a heat exchanger which can give a output temperature of range 250^{o} C and 566^{o} C. In case of Molten Salt, The heat is transferred to the water then Steam is generated through which a temperature of 258^{o} C can be obtained. Volumetric Type receivers uses air as heat transfer fluid.Air at higher temperatures over 1000°C gives rise to high rate of heat transfer properties but the pipes carrying the heat transfer fluid is to be considered.

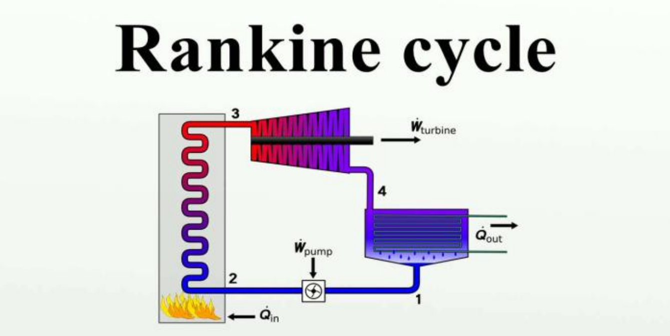

Figure.4. Rankine Cycle of Solar Tower

3.3. Power Cycle:

One of the most important component of the plant is the power block. The solar energy collected by the receiver is converted to a usable form of electrical energy. The two main power cycles used in solar tower plants are discussed in the following.

3.3.1. Rankine Cycle:

In the Rankine Cycle, water is the working fluid where the water is converted into Steam which is used to run the Turbines. After passing through the Turbine, the steam attains low pressure which is condensed and passed as high pressure fluid again to the tank using a pump.

3.3.2. Brayton Cycle:

The Brayton cycle has the similar processes as the Rankine cycle. It does not operate within the vapour dome. It operates at higher temperature and pressure.Generally, the working fluid used here is compressed gas. The carbon di-oxide Brayton cycle is being explored for solar tower technology and it is under Research & Development mode.

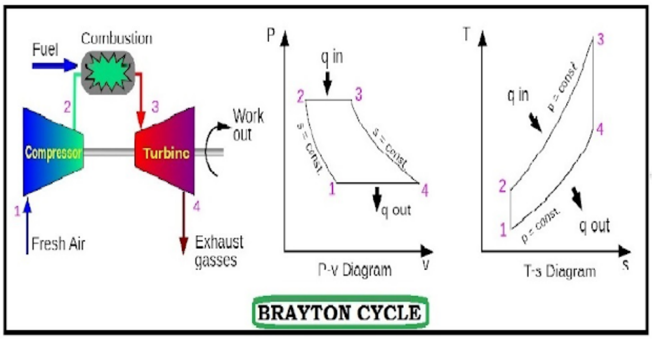

Figure.5. Brayton Cycle of Solar Tower

Table.1
MERITS & DEMERITS OF HEAT TRANSFER FLUID USED IN SOLAR TOWER PLANTS [8-12]

S.NO	HEAT TRANSFER FLUID	MERITS	DE-MERITS
1.	WATER	* For steam Rankine cycle, working fluid is the water, the necessity for heat exchanger is eliminated. *Reduces the costs associated with the salt or oil based Heat Transfer Fluids.	*Dissimilar heat transfer coefficient in saturated vapour, superheated gas phase and liquid.Frequent problems with thermal stress and temperature gradient to be

			faced. * As the solar flux varies problems arise with Flow control. *Thermal storage is difficult for long time.
2.	MOLTEN SALT (KNO_3 + $NaNO_3$)	*High Thermal conductivity and capacity. * Operating Temperatures can rise up to 560° C. *Stable and Non-Toxic & Environment Friendly.	* Auxiliary heating is required in order to avoid. solidification at high melting point (222 °C). * At elevated temperature it is highly corrosive.
3.	Air	*High Temperature over 1000 °C can be used.	*Compared to other fluids it has Poor heat transfer properties and complex receiver design.
4.	Liquid sodium	*Solar field outlet temperatures are high which results in higher power cycle efficiencies. *Low Melting Point (97.7°C)& High boiling point (873°C).	* Difficult in handling. *Accidental Leakage may result in highly hazardous condition.
5.	Hitec salt	* Melting point is 142 ° C.	*Temperature is restricted to less than 535 ° C.
6.	Synthetic oil	* Freeze at 15 °C.	*Operating temperature restricted to 390 °C which results in reduced power cycle efficiency.

4. ADVANTAGE OF SOLAR POWER TOWER

4.1. Environmental Neutrality:

Compared to other forms of renewable energy, solar towers have a negligible effect on the environment.

4.2. Easy to Operate:

One major advantage of solar towers are easy to implement compared to many other forms of energy generation.

4.3. Renewable Energy:

Additional advantage of solar towers over other conventional means of energy production is that it is a renewable form of energy, while others are not.

4.4. Falling Costs:

Solar towers are getting cost effective day by day. A report from the National Renewable Energy Laboratory estimated that by 2020 the levelized cost of energy produced by solar towers could be as little as 5.47 cents per kWh.

4.5. Predictable, 24/7 Power:

Solar Thermal Energy can produce power 24 hours a day. This is possible as solar thermal tower store the energy in the form of heat transfer fluids.

4.6. No Fuel Cost:

Solar Thermal Energy does not require any fuel like other sources of energy. This is a huge advantage over fossil fuels whose costs are increasing at a exponential rate every day.

4.7. System Benefits:

The availability of an inexpensive and efficient energy storage system may give power towers a competitive advantage.

Table provides a comparison of the predicted cost, performance, and lifetime of solar-energy storage technologies for hypothetical 200 MW plants.

Table.2.Comparison of Solar-Energy Storage System

	Cost of energy storage installed of 200 MW plant(□ /KW hrs)	Life-Span of Storage System (year)	Round Trip Storage efficiency (%)	Maximum operating Temperature (^{o}F)
Battery storage and connected	27,000 to 43,200	5 to 10	76	N/A
Synthetic oil Parabolic Trough	10,800	30	95	734
Molten-salt power tower	1,625	30	99	1,053

5. Fresnel Lens:

A Fresnel Lens is a category of Composite compact lenses. A Fresnel lens can be made thinner than a comparable conventional lens. The construction of Fresnel lenses of large aperture and short focal length which results in reduced mass and volume of material that would be required by a lens of conventional lens. It can capture more oblique light from any light source.

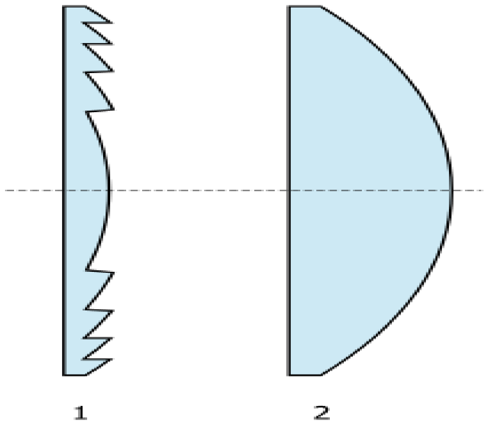

Figure.6:Cross-sectional of Fresnel lens
Fig 7:Cross-sectional of conventional spherical lens

An ideal Fresnel lens would have a numerous sections. They are made up of glass. Modern Fresnel lenses usually consist of almost all refractive indices. Their size varies from large to small. In most cases there are very thin and flat, almost flexible, around thickness of range 1 to 5 mm.

5.1. Types of Fresnel Lenses:

Mainly there are two types of Fresnel lens: *imaging* and *non-imaging*. Non-imaging lenses have segments with flat cross-sections, and do not give sharp images while imaging Fresnel lenses use segments with curved cross-sections which give sharp images. As the number of segments increases, the two types of lens become more similar to each other. In the abstract case of an infinite number of segments, the difference between curved and flat segments disappears.

5.2. Fresnel lens in Solar Power:

Plastic Fresnel lenses can be made larger than glass lenses, and also much cheaper and lighter. They can be used to generate steam or to power a Stirling engine. Fresnel lens can be also used to concentrate sunlight for heating in solar cookers, in solar dryer, and in solar collectors used to heat water for domestic use & commercial use. Fresnel lenses concentration ratio to single solar cell is almost 500:1. This allows the active solar-cell surface to be reduced more than desired rate and also lowering cost along with allowing the use of more efficient cells.

6. Ball Shaped Solar Tower:

Solar Tower is an emerging concept and environmental heating in that is the major disadvantage. Environmental Heating can be overcome by a new concept of solar lensballs. The Fresnel lens are used as a Focusing material to focus the sun's radiation on a particular spot where receiver can be placed. The Fresnel lens are arranged in a pentagonal structure as shown in the CAD model to achieve maximum concentration of the sunlight. The Maximum Temperature at the focal length point is 400^{o}C at peak sunshine. The Fresnel lens focusses the sunlight on the absorber tube with a focal length of 100 mm.

The Area of a Pentagonal Fresnel Lens is about 0.1 m^{2}. By the formula for Area of Pentagon mentioned below, the sides of the Pentagon is found to be 0.241 m.

Area of the Pentagon=$\frac{1}{4}\sqrt{[5(5+2\sqrt{5})]}\,a.a$

Where a-stands for Side of a Pentagon.

It contains 10 Pentagon of 0.1m$^{2.}$ So totally the area of the Structure is around 1m^{2}. It can Focus Sun's Radiation from all the direction and thus maximum Thermal Energy can be harvested.

6.1. Model View using Fusion 360:

The Design of the ball-shaped tower is drawn using Fusion 360 and mentioned below:

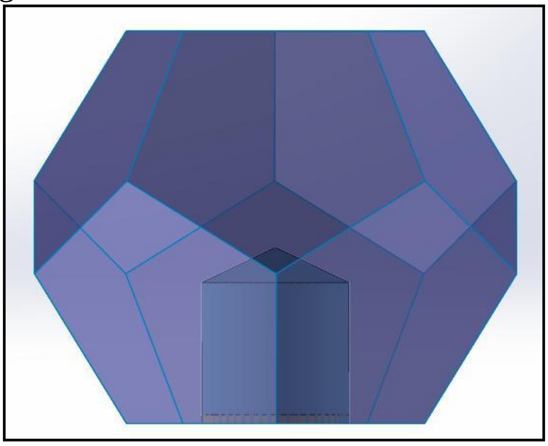

Fig.8. Front View

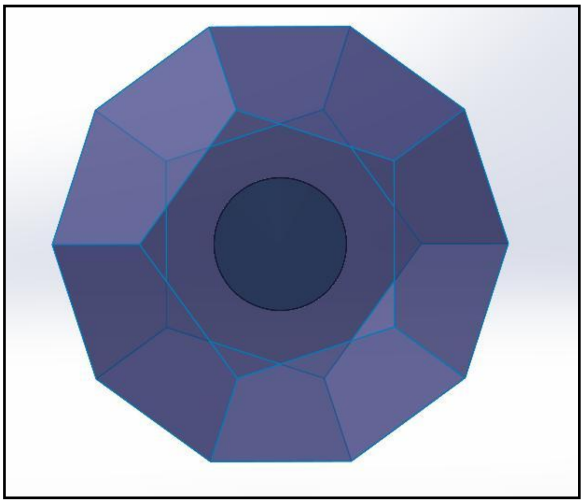

Fig.9.Top View

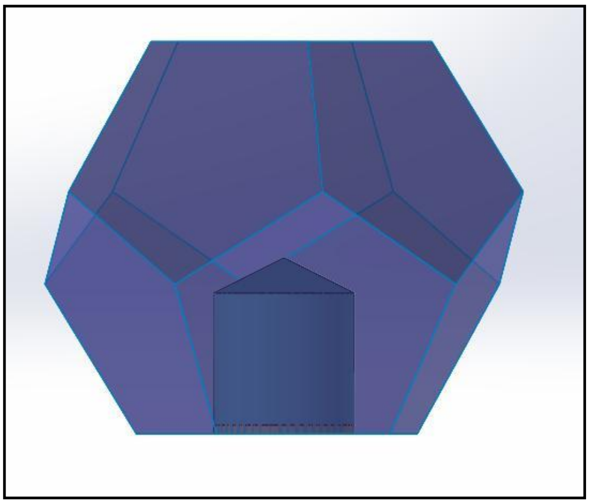

Fig.10.Side View

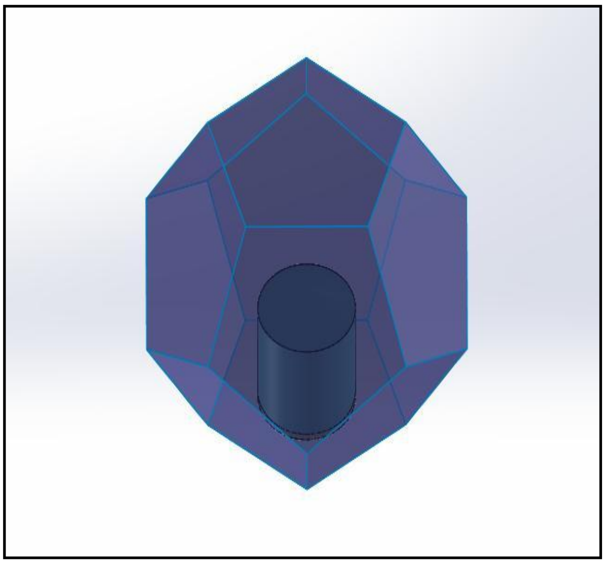

Fig.11.Orthogonal View

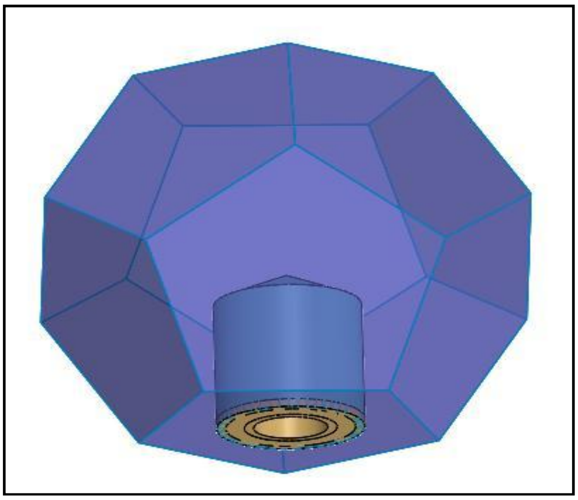

Fig.12.Orthogonal View

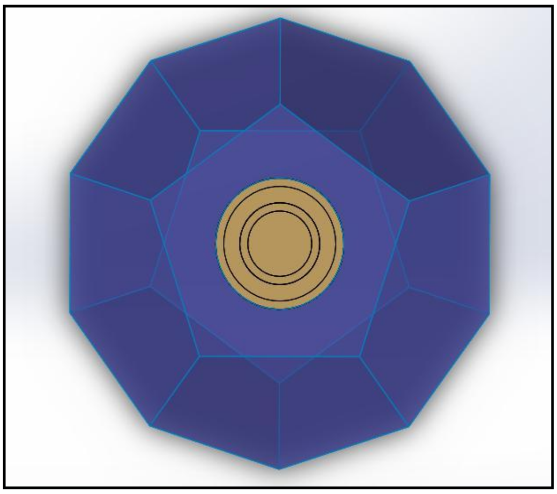

Fig.13.Bottom View

Conclusion & Future Work:

Here, The Solar energy is converted into Thermal Energy without involving any intermediate conversion state. This can be developed as mentioned below:

1. It can be used in Home appliances such as Solar Cooker and Solar Water Heater.
2. Huge Plants can be built, thus large amount of energy can be stored and consumed.

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