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Review on Solar Tower Technology

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Abstract: Solar tower technology, a type of concentrated solar power (CSP) system, represents a sustainable and efficient solution for renewable energy generation. It employs a central receiver tower surrounded by an array of heliostats (mirrors) that track and reflect sunlight to a focal point on the tower. This concentrated sunlight generates heat, which is used to produce steam that drives a turbine to generate electricity. Solar tower technology offers significant advantages, such as high thermal efficiency, scalability, and the ability to store thermal energy for power generation even during non-sunny periods. Recent advancements in materials, heat transfer fluids, and energy storage systems have further enhanced its performance and economic viability. This technology holds promise for reducing greenhouse gas emissions and transitioning to a clean energy future.
Keywords: Solar tower, concentrated solar power (CSP), renewable energy, heliostats, central receiver, thermal energy storage, sustainable energy, heat transfer, electricity generation, greenhouse gas reduction.

I. INTRODUCTION

The principle of the solar tower is the same as that of the solar trough: focus sunlight onto a solar receiver where a heat transfer fluid can be heated, and the heat carried away to generate electricity. With the solar tower the linear receiver is replaced with a single-point receiver mounted at the top of the central tower.1 This receiver must be able to capture all the heat energy from a large number of heliostats mounted at ground level around it. Fig. 1.1 shows the layout of a typical plant of this type.

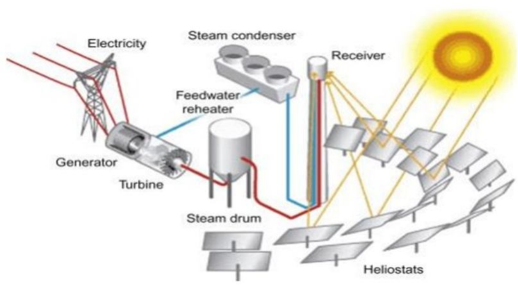

Fig.1.1 The layout of a typical plant

The solar tower takes a slightly different approach to solar thermal power generation. While the parabolic trough array uses a heat collection system spread throughout the solar array, the solar tower concentrates heat collection at a single central facility.
The central facility includes a large solar energy receiver and heat collector which is fitted to the top of a tower. The tower is positioned in the centre of a field of special mirrors called heliostats, each of which is controlled to focus the sunlight that reaches it onto the tower-mounted solar receiver. This type of solar thermal plant is referred to as a point-focussing solar thermal plant. The arrangement is shown schematically in Fig. 1.2

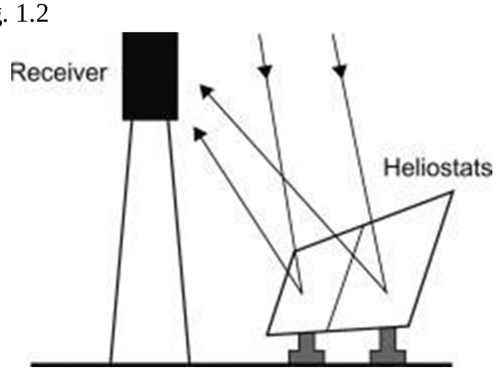

Fig.1.2 The arrangement of point-focussing solar thermal plant

A solar tower plant consists of a large field of mirrors, which track the sun in two axes. These mirrors reflect solar radiation to a common target, located at the top of a tower . Concentration is achieved both by overlapping of the images produced by the many individual heliostats and by slight curvature of each of these heliostats. Solar towers combine the possibility of having static reactors, as in solar furnaces, with a proven scalability, where systems of 100 MWth are normal. However, the state-of-the-art commercial solar tower power plants do not comply with some of the requirements of the thermochemical processes: on the one hand, the concentration ratio of a typical solar tower is relatively low to sustain the required temperatures, as they are designed to operate around 873 K with solar concentration ratios around 500 suns. To carry out a two-step thermochemical cycle for hydrogen production, typically temperatures above 1273 K are required, with concentration ratios above 1500 suns . On the other hand, locating a large chemical reactor atop a tower could be problematic because of weight considerations, which can increase significantly the costs of civil works. Also, continuous conveying of reactant particles to heights above 100 m could be energy consuming.

To solve the limitation on concentration ratio, a secondary concentrator can be used. This is generally a compound parabolic concentrator (CPC), with a concentration ratio up to five suns. Such concentrator is generally located at the entrance of the solar reactor, and needs to be cooled down, to avoid damage due to the small fraction of concentrated radiation it absorbs

II. HISTORY OF SOLAR TOWERS

The first solar tower was the National Solar Thermal Test operated by Sandia National Laboratories for the U.S. Department of Energy. Constructed in 1979 as a response to the energy crisis, it still runs today as a test facility that's open to scientists and universities to study. "The National Solar Thermal Test Facility (NSTTF) is the only test facility of this type in the United States. The NSTTF's primary goal is to provide experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants planned for large-scale power generation," according to Sandia's website.

The first commercial solar power tower was Solar One, which ran from 1982 to 1988 in the Mohave Desert. While it was able to store some energy into the evening (enough for start-up in the morning), it wasn't efficient, which is why it was modified to become Solar Two. This second iteration switched over from using oil as a heat-transfer material to molten salt, which is also able to store thermal energy and has the added benefits of being nontoxic and non-flammable.

In 2009, the Sierra Sun Tower was built in California's Mojave Desert, and its 5 megawatt capacity reduced CO2 emissions by 7,000 tons per year when it was running. It was built as a model but was shut down in 2015 because it was deemed to costly to operate.

Outside the United States, solar tower projects include the PS10 solar power plant near Seville, Spain, which produces 11 MW of power and is part of a larger system that aims to produce 300 MW. It was built in 2007. Germany's experimental Jülich solar tower, built in 2008, is the country's only plant using this technology. It was sold to the German Aerospace Center in 2011 and remains in use. Other U.S. and European projects are detailed below.

In 2013, Chile put $1.3 billion into the Cerro Dominador CSP project, Latin America's first solar tower project. It was begun in hopes of phasing out coal-fired power by 2040 and being completely carbon neutral by 2050. But delays due to a bankruptcy by the project's funder, meant that by the time the plant's construction was resumed, it's technology had already been outpaced by cheap solar panels from China, and widespread adoption of renewable technologies. The prices that Cerro Dominador would charge would already be three times higher than what other renewables could provide. The project is now on hold indefinitely.

III. OPERATION

As the sun shines down on a solar tower's field of heliostats, each of those computer controlled mirrors tracks the sun's position on two axes. The heliostats are set up so that over the course of a day, they efficiently focus that light towards a receiver at the top of the tower. Large, flat, sun-tracking mirrors known as heliostats focus sunlight onto a receiver at the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. (Photo: Office of Energy Efficiency and Renewable Energy/U.S. Department of Energy) In their first iteration, solar towers used the sun's focused rays to heat water, and the resulting steam powered a turbine to create electricity. Newer models now use a combination of liquid salts, including 60% sodium nitrate and 40% potassium nitrate. These salts have a higher heat capacity than water, so some of that heat energy can be stored before using it to boil the water, which drives the turbines.These higher operating temperatures also allow for greater efficiency and mean that some power can be generated even on cloudy days. Combined with some kind of energy-storage device, this means solar towers can produce reliable energy 24 hours a day.

Fig 3.1 Solar Tower

IV. HOW DO SOLAR TOWER POWER PLANTS OPERATE?

Firstly, you should know that solar towers are a part of solar power plants. These solar towers are basically central towers that receive the captured sunlight from the surrounding mirrors. A solar tower stands in the middle of a sizable arrangement of mirrors. These mirrors can be curved or flat. However, most solar tower power plants use flat mirrors due to their cost efficiency. These mirrors catch the directly falling sunlight as they follow the sun's rays.Afterward, the captured sunlight is reflected or redirected to the solar tower. Many of these mirrors concentrate a significant quantity of solar radiation onto the receiver, a small area of the tower where water is heated.Older solar towers used water as a direct heat-transferring medium. However, newer and more advanced solar towers use molten salts with significantly higher efficiency to heat water. Water plays a significant role in energy generation; once heated, it generates steam which turns the turbine. Consequently, this process generates electricity.

here is how solar tower plants work in a nutshell!

1) Mirrors capture sunlight.
2) The sunlight is directed to the solar tower.
3) The sunlight is used to heat the stored fluid (water or liquid sodium).
4) Steam is generated from heating the fluid.
5) The steam moves the turbine.
6) The rotation of the turbine produces electricity.

As explained briefly above, a solar power tower is one of the main components of a solar power plant. This tower is placed in the center of a large array of mirrors.

These mirrors can be curved or flat, but generally speaking flat mirrors that track the Sun are used as they are less expensive than curved mirrors. As these mirrors track the Sun, they "catch" the incident sunlight and reflect it back to the solar tower. A large number of these mirrors focus a large amount of solar radiation onto a small spot on the tower known as the receiver, heating up some fluid inside of it. This fluid is used to transfer the heat from the sunlight to the water. Old towers used steam as a heat transfer fluid, but newer designs use molten salts because of their increased heat transfer and energy storage abilities. When the heat is transferred to water, it turns to steam. This steam is then transported to a conventional turbine to produce electricity.

It is important to note that these solar power towers are heat engines as they take the energy from being warm in comparison to their surroundings and turn that heat into motion. More specifically, these solar power towers are external heat engines as the heat source (the Sun) is separate from the fluid that moves and does work. It is external combustion as heat from the Sun heats some fluid that is then turned to steam and used to turn a turbine.

V. BENEFITS OF SOLAR TOWER POWER PLANT

The primary benefit of solar towers is that they do not use fossil fuels for operation. The entire process of energy generation is reliant on sunlight. Therefore, it produces no emissions.

Moreover, newer solar towers that use molten salts for energy storage can continue producing electricity even without sunlight. Hence, solar towers can work 24/7 without any interruptions due to the weather, making them a very reliable energy source.

VI. DRAWBACKS OF SOLAR TOWERS

Solar tower power plants are indeed highly beneficial and a green source of energy generation. However, they still have certain drawbacks as well.

1) Solar towers need a constant water supply to generate steam that can turn the turbine to produce electricity.
2) The overall temperature around the solar tower can reach up to 550 °C, which is harmful to wildlife.
3) The components of the solar tower, such as heliostats, can produce harmful byproducts during manufacturing.

VII. APPLICATION OF SOLAR TOWER POWER PLANT

1) Solar tower power plants are large-scale setups, making them perfectly suitable for commercial applications. Among the most notable solar tower plants, one of the biggest solar towers produces 650 GWh of energy per year.
2) In addition to commercial applications, there have been numerous attempts to use them for other innovative applications as well.
3) Using solar energy in both domestic and commercial spaces can significantly reduce yearly carbon emissions.
4) In addition, systems generating solar energy, like the solar tower power plant, are sustainable and comparatively cheaper than conventional Photovoltaic systems.

VIII. ENVIRONMENTAL IMPACT

There are some obvious environmental advantages to solar towers. Compared to fossil-fuel burning plants like coal or natural gas plants, there's no air pollution, water pollution or greenhouse gases typically created in the energy generation process. (There are some emissions created in the building of a solar tower, just as there would be in another type of power plant, since materials have to be moved to the location and built, all of which requires energy, usually in the form of fossil fuels.)

Negative environmental impacts are similar to other power plants: Some toxic materials are used to make the components of the plant (in this case photovoltaic cells). When you clear land for a new plant, the animals and plants that live there are impacted, and their habitat destroyed — though some of this impact can be mitigated by choosing a location that has minimal impact on local plants and animals. Solar towers are often constructed in desert landscapes, which by their very nature are somewhat fragile, so special care must be taken in siting and construction.

Some solar towers are air-cooled, but others use ground water or available surface water for cooling, so while the water isn't polluted with toxic waste as it can be at other power plants, the water is still being used, and that can impact the local ecosystem. Some solar towers might also need water for cleaning the heliostats and other equipment. (Those mirrors work best to concentrate and reflect light when not covered in dust.) According to the US Energy Information Center, "solar thermal systems use potentially hazardous fluids to transfer heat." Ensuring those chemicals don't make their way into the environment in the event of a storm or other unusual circumstance is important.

An environmental issue unique to solar power towers is bird and insect deaths. Due to how the heliostats concentrate light and heat, any animal flying through the beam as it is transmitted to the tower will be burned or killed by the high temperatures (up to 1,000 degrees Fahrenheit). A simple way to minimize bird deaths is to ensure that no more than four mirrors are aimed at the tower at the same time.

IX. CONCLUSION

Solar tower technology, also known as concentrated solar power (CSP) tower technology, represents a promising avenue for sustainable energy production. It harnesses solar energy through a centralized receiver system, where an array of heliostats reflects sunlight onto a receiver at the top of a tower. This concentrated energy is then used to heat a working fluid, which powers turbines to generate electricity.

This technology offers several advantages, including the ability to integrate thermal energy storage systems that allow for energy production even during cloudy periods or after sunset. This makes it a reliable alternative to conventional energy sources. Moreover, solar towers can produce high temperatures, enabling efficient power generation and applications beyond electricity, such as desalination and industrial heat processes. Despite its potential, challenges such as high initial investment, land requirements, and dependency on specific climatic conditions (like high direct solar irradiation) hinder its widespread adoption. Advances in materials, heliostat design, and hybridization with other renewable energy sources can mitigate these limitations and make the technology more cost-effective.

Solar tower technology plays a significant role in reducing greenhouse gas emissions and promoting the global transition toward renewable energy. With continued research and development, it holds the promise of contributing to a sustainable and energy-secure future, particularly in regions with abundant sunlight. Emphasizing policies and investments in CSP technologies could unlock their full potential and accelerate the shift to cleaner energy systems.

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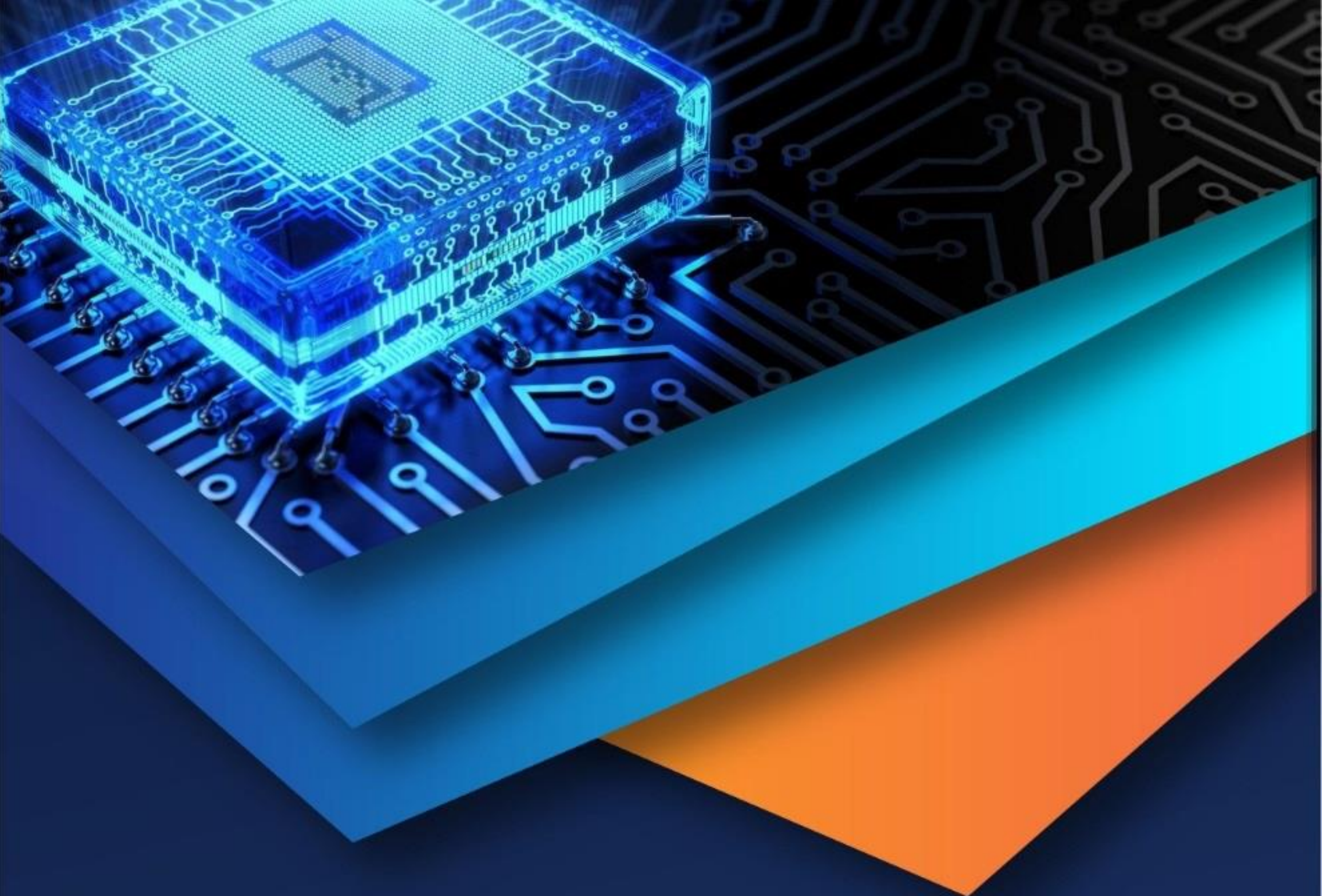

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