Scope and Methodologies to improve the performance of Concentrated Solar Power (CSP) Systems
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Abstract — Renewable energy (RE) is non-polluting energy that comes from inexhaustible resources, such as wind, sunshine, and falling water. Now a day available solar energy abstraction & utilization throughout earth is topic of keen interest of researchers as to increase the performance of solar power plants and it is gaining its popularity worldwide. The world map provides information about the solar radiations across the world and it is found that around most of the countries have enough potential to establish solar power plants. There are a variety of technologies that have been developed to take advantage of solar energy. These include concentrating solar power systems, passive solar heating and day lighting, photovoltaic systems, solar hot water, and solar process heat and space heating and cooling. Conventional power plants use fossil fuels as a heat source to boil water. The steam from the boiling water spins a large turbine, which drives a generator to produce electricity. However, a new generation of power plants with concentrating solar power systems uses the sun as a heat source. Solar Power is one of the fast growing renewable energy source in India and the world. But now the scenario is changing very fast because of the new suitable material has been invented and manufacturing technologies are improves so as to increase the performance. So the solar energy is the becoming the first choice for the commercial and domestic applications. Researches are being done to improve the performance of Solar PV and CSP systems. Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun’s light energy and convert it into heat to create steam to drive a turbine that generates electrical power. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts the heat energy to electricity. Since very fast reduction in cost is taking place, these are gaining popularity very fast. There are four major techniques are used for CSP system. The possibility of integrated thermal storage is an important feature of CSP plants, and virtually all of them have fuel-power backup capacity. Thus, CSP offers firm, flexible electrical production capacity to utilities and grid operators while also enabling effective management of a greater share of variable energy from other renewable sources like photovoltaic and wind power.

Keywords— Renewable Energy(RE), Concentrating Solar Power (CSP), Parabolic trough, Central receiver, Linear Fresnel, Fresnel lens and paraboloidal dish concentrator systems.

I. INTRODUCTION

“More energy from sunlight strikes the Earth in one hour than all of the energy consumed by humans in an entire year” (Lewis, 2007). Solar energy is one of the trending renewable energy sources. The sun’s heat and light provide an abundant source of energy that can be harnessed in many ways. These include concentrating solar power systems, passive solar heating and day lighting, photovoltaic systems, solar hot water, and solar process heat and space heating and cooling. [9]

![Solar resource for CSP technologies (DNI in kWh/m²/yr)](https://www.iea.org/publications/freepublications/publication/csp_roadmap.pdf)

The basic concept of concentrating solar power is relatively simple: CSP devices concentrate energy from the sun’s rays to heat a receiver to high temperatures. This heat is transformed first into mechanical energy by turbines or other engines and then into electricity. CSP also holds potential for producing other energy carriers (solar fuels). The sunlight hits the Earth’s surface both directly and indirectly, through numerous reflections and deviations in the atmosphere. On clear days, direct irradiance represents 80% to 90% of the solar energy reaching the Earth’s surface. On a cloudy or...
foggy day, the direct component is essentially zero. The direct component of solar irradiance is of the greatest interest to designers of high temperature solar energy systems because it can be concentrated on small areas using mirrors or lenses, whereas the diffuse component cannot. Concentrating the sun’s rays thus requires reliably clear skies, which are usually found in semi-arid, hot regions. The solar energy that CSP plants use is measured as direct normal irradiance (DNI), which is the energy received on a surface tracked perpendicular to the sun’s rays. It can be measured with a pyrheliometer. DNI measures provide only a first approximation of a CSP plant’s electrical output potential. In practice, what matters most is the variation in sunlight over the course of a day: below a certain threshold of daily direct sunlight, CSP plants have no net production, due to constant heat losses in the solar field.[6]

II. TECHNOLOGIES OF CONCENTRATED SOLAR POWER (CSP) SYSTEM:

Global investments in clean energy generation are continuing to increase with global energy producers (and users) now experiencing strong signals to develop a clean energy future. Over the last three decades, the world wind industry has grown at an average rate of approximately 30% per year to reach a total installed capacity of 239 GW by the end of 2011. This represents nearly 3% of total world electricity annual generation (WWEA, 2012) and wind capacity is now being installed at a faster annual rate than nuclear. Over a shorter period, the solar photovoltaic (PV) industry has grown with comparable or higher rates of growth but from a lower base and in 2011 had a worldwide installed capacity of approximately 69 GW (EPIA, 2012). CSP technology saw a first surge of commercial development between 1984 and 1995, but then no further commercial deployment until 2005, although in that time considerable research, development and demonstration took place. Since then, commercial CSP deployment has recommenced and gained considerable momentum. Total installed capacity is, however, an order of magnitude smaller than PV, given that commercialization of the technology is a decade or so behind. By 2050, with appropriate support, CSP could provide 11.3% of global electricity, with 9.6% from solar power and 1.7% from backup fuels (fossil fuels or biomass). In the sunniest countries, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of base-load power by 2025 to 2030.[6]

Conventional power plants use fossil fuels as a heat source to boil water. The steam from the boiling water spins a large turbine, which drives a generator to produce electricity. However, a new generation of power plants with concentrating solar power systems uses the sun as a heat source. Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun’s light energy and convert it into heat to create steam to drive a turbine that generates electrical power. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts the heat energy to electricity. Since very fast reduction in cost is taking place. These are gaining popularity very fast.[12],[13]

2.1 Parabolic Trough CSP[14]

Parabolic Trough (PT) technology currently accounts for 95% of the global installed CSP share, with total capacity of 2657 MW. In Parabolic Trough system, the receiver tube is positioned along the focal line of each parabola-shaped reflector.
The tube is fixed to the mirror structure, and the heated fluid—either a heat-transfer fluid or water/steam—flows through and out of the field of solar mirrors to where it is used to create steam (or, in the case of a water/steam receiver, it is sent directly to the turbine).

The largest individual trough systems generate 80 megawatts of electricity. However, individual systems being developed will generate 250 megawatts. In addition, individual systems can be co-located in power parks. Their capacity would be constrained only by the transmission capacity of nearby power lines and the availability of contiguous land. Trough designs may incorporate thermal storage. In these systems, the collector field is oversized to heat a storage system during the day that can be used in the evening or during cloudy weather to generate additional steam to produce electricity. Parabolic trough plants can also be designed as hybrids, meaning that they use fossil fuel to supplement the solar output during periods of low solar radiation. In such a design, a natural gas-fired heater or gas-steam boiler/re-heater is used. In the future, troughs may be integrated with existing or new combined-cycle natural-gas- and coal-fired plants.

2.2 Linear Fresnel CSP:

2.2.1 Principal of Linear Fresnel Collector/ Reflectors (LFR): In the CSP which uses Fresnel collectors, Flat or slightly curved mirrors mounted on trackers on the ground are configured to reflect sunlight onto a receiver tube fixed in space above the mirrors. A small parabolic mirror is sometimes added atop the receiver to further focus the sunlight. These mirrors are capable of concentrating the sun’s energy to approximately 30 times its normal intensity. This concentrated energy is transferred through the absorber into some thermal fluid. The fluid then goes through a heat exchanger to power a steam generator. [1]

The Fresnel reflectors make use of the Fresnel lens effect, which allows for a concentrating mirror with a large aperture and short focal length while simultaneously reducing the volume of material required for the reflector. Hence a CLFR project is generally less expensive to build because it uses fewer receiver tubes, less land and less expensive mirrors than any other CSP Technology.

Main components of the system are:
1. Supporting structure
2. Primary reflectors
3. Receiver, consisting of secondary reflectors and vacuum absorber tubes
4. Control systems for the primary reflector tracking and the solar array output.

2.2.2 Efficiency:
The heat losses from the receiver are an important factor which should be evaluated while measuring the performance of the solar collector. To achieve high efficiency in a concentrating solar collector, there should be high absorption and minimum thermal losses from the absorber. During operation, the hot absorber tube emits long-wavelength radiation into
the cavity that is absorbed mainly by the bottom wall, which in turn heats up. This promotes buoyancy-driven flows within the cavity, resulting in convection losses and a further reduction in thermal efficiency.[2]

2.2.3 Advantages of CLFR Technology:
1. Design Simplicity
2. Lower Cost
3. Land efficiency
4. The ability to generate superheated steam at high temperatures and pressures
5. Use of standard commodities available locally
6. Environmental benefits

In many of the solar thermal plants, Linear and concentrating linear fresnel technologies are being used because of the above mentioned advantages.

2.4 POWER TOWER: [1]
Power tower systems also called central receivers, use many large, flat heliostats (mirrors) to track the sun and focus its rays onto a receiver. The receiver sits on top of a tall tower in which concentrated sunlight heats a fluid, such as molten salt, as hot as 1,050°F. The hot fluid can be used immediately to make steam for electricity generation or stored for later use. Molten salt retains heat efficiently, so it can be stored for days before being converted into electricity. That means electricity can be produced during periods of peak need on cloudy days or even several hours after sunset.

[Image: Fig.5 Power Tower CSP System (Source: www.eere multimedia.energy.gov)]

2.5 DISH ENGINE: [2]
Solar dish systems consist of a dish-shaped concentrator (like a satellite dish) that reflects solar radiation onto a receiver mounted at the focal point. They consist of clusters of small mirrors set into modular, circular arrays to pinpoint solar energy onto a receiver situated above each dish. The receiver may be a Stirling engine (a machine used to provide power or refrigeration, operating on a closed cycle in which a working fluid is cyclically compressed and expanded at different temperatures.) and generator (dish/engine systems) or it may be a type of solar PV panel that has been designed to withstand high temperatures. The Stirling engine uses heat (Temperature 250-700°C) to vary the pressure inside a hydrogen-filled sealed chamber. This drives pistons to produce mechanical power. Dish systems can often achieve higher efficiencies than parabolic trough systems partly because of the higher level of solar concentration at the focal point.

[Image: Fig.6 Dish engine CSP system (Source: www.cspworld.com)]

Attributes and Challenges:
1. It has the highest efficiency of any form of CSP, converting up to 32% of incoming solar power to electricity, compared to around 15% or 16% for power tower or parabolic trough designs.
2. It’s often made with widely-available low-cost materials, mostly steel and glass, what makes it suitable to be manufactured and installed anywhere in the world.

3. Another advantage of dish Stirling technology is that because it has a turbine on each concentrator it is a highly modular design.

4. But it has some significant drawbacks. Because dish Stirling engines produce electricity directly, the technology does not require a heat sink and so lacks the energy storage capabilities of other CSP designs.

5. Without storage, dish Stirling essentially delivers power in the same way as PV. And PV, right now, is considerably cheaper. Just as importantly, too, PV is a more established and reliable technology.

The receiver contains gas that has to move through a closed cycle. That means there must not have any leaks and there is a lot of friction and wear.

III. SCOPE & TECHNOLOGIES TO IMPROVE PERFORMANCE OF CONCENTRATED SOLAR POWER (CSP) SYSTEM [6]

Technology advances are under development that will enable CSP to boost electricity production and reduce costs, notably through higher temperatures that bring greater efficiency. Other technologies now under development will enable the production of liquid or gaseous fuels by concentrating solar energy. With concerted effort, these milestones can be achieved in the next two to five years.

<table>
<thead>
<tr>
<th>Milestones for technology improvements</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Demonstrate direct steam generation (DSG) in parabolic trough plants</td>
<td>2015 - 2020</td>
</tr>
<tr>
<td>2. Large-scale solar tower with molten salts as heat transfer fluids and storage</td>
<td>2010 - 2015</td>
</tr>
<tr>
<td>4. Demonstrate three-step thermal storage for DSG solar plants</td>
<td>2015 - 2020</td>
</tr>
<tr>
<td>5. Demonstrate solar tower with supercritical steam cycle</td>
<td>2020 - 2030</td>
</tr>
<tr>
<td>6. Demonstrate solar tower with air receiver and gas turbine</td>
<td>2020 - 2030</td>
</tr>
</tbody>
</table>

Fig. 7 CSP technologies improvement milestones

![Fig. 7 CSP technologies improvement milestones](image)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Optical efficiency</th>
<th>Annual solar-to-electric efficiency</th>
<th>Land occupancy</th>
<th>Water cooling (L/MWh)</th>
<th>Storage possible</th>
<th>Possible backup/ hybrid mode</th>
<th>Solar fuels</th>
<th>Outlook for improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parabolic troughs</td>
<td>**</td>
<td>15%</td>
<td>Large</td>
<td>3000 or dry</td>
<td>Yes, but not yet with DSG</td>
<td>Yes</td>
<td>No</td>
<td>Limited</td>
</tr>
<tr>
<td>Linear Fresnel receivers</td>
<td>a</td>
<td>8-10%</td>
<td>Medium</td>
<td>3000 or dry</td>
<td>Yes, but not yet with DSG</td>
<td>Yes</td>
<td>No</td>
<td>Significant</td>
</tr>
<tr>
<td>Towers (central receiver systems)</td>
<td>**</td>
<td>20-35% (concepts)</td>
<td>Medium</td>
<td>2000 or dry</td>
<td>Depends on plant configuration</td>
<td>Yes</td>
<td>Yes</td>
<td>Very significant</td>
</tr>
<tr>
<td>Parabolic dishes</td>
<td>***</td>
<td>25-30%</td>
<td>Small</td>
<td>none</td>
<td>Depends on plant configuration</td>
<td>Yes, but in limited cases</td>
<td>Yes</td>
<td>Through mass production</td>
</tr>
</tbody>
</table>

Fig. 8 Comparison of main CSP technologies

3.1 TROUGHS AND LFR :

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In an on-going effort to increase performance and lower costs, all components of parabolic troughs need to continue to make incremental improvements, particularly solar field elements. Effective but costly back-silvered, thick-glass curved mirrors could be replaced with troughs based on less expensive technologies such as acrylic substrates coated with silver, flexible aluminium sheets covered with silver or aluminium, or aluminium sheets glued to a glass fibre substrate. Wider troughs, with apertures close to 7 m (versus 5 m to 6 m currently) are under development, and offer the potential for incremental cost reductions.

Other proposed innovations are more speculative, but merit further research. The current glass-to metal welding of the evacuated tubes that collect solar energy could be replaced with a mechanical seal, if it proved capable of preserving the necessary vacuum for 20 years or more. Selective coating of the tubes could also make small performance improvements. More fundamental advances should be pursued as well, including replacing the costly heat transfer fluid currently used by trough plants; synthetic oil limits the steam temperature to about 380°C as it degrades at higher temperatures. The challenge to produce steam at temperatures close to 500°C, thereby feeding state-of-the-art turbines without continuous backup from fuel.

Direct steam generation (DSG) in the collector fields would allow high working temperatures and reduce investment costs, as no heat transfer fluid and heat exchangers would be necessary. DSG needs to be demonstrated in troughs on a large scale, but more work is needed to design specific options for storage with DSG, ensure the separation of water and steam, and handle the circulation of high-temperature, high-pressure working fluids, which is a challenge with mobile receivers. Other options involve advanced heat transfer fluids, including:

- **PRESSURISED GAS**, currently under testing at the Plataforma Solar de Almeria, Spain. Additional work is needed to improve heat transfers in the receiver tubes, and to ensure control of the solar field, which is more complex than the standard design.
- **MOLten SAltS** used in the collector field simplify storage, as the heat transfer fluid becomes the storage medium. Salt mixtures usually solidify below 200°C, however, so work is needed to reduce the pumping and heating expenses needed to protect the field against freezing.
- **NEw LIQuID FlUIDS, IN PARTICULAR NANO FLUIDS**, should actively be investigated.
- **LINEar FREsnel REFLECTORS (LFR)** is a nascent technology with large room for improvement. Although LFR lend themselves to DSG because of their fixed receivers, LFR developers should explore options similar to those being considered for trough plants.

### 3.2 TOWERS AND DISHES:

CSP towers, which already reach working temperature levels, can achieve higher temperatures still, opening the door to better power cycle efficiencies. Storage costs can also be drastically reduced with higher temperatures, which allow more heat to be converted into electricity and less lost due to limited storage capacity. Improved efficiency also means a lower cooling load, thus reducing water consumption by wet cooling in plants in arid areas. It would also reduce the performance penalty of dry cooling. The possibilities of these higher temperatures should be explored using different receiver technologies. One option is supercritical steam (or carbon dioxide) cycles such as those used in modern coal-fired power plants, which reach thermal-to-electricity efficiency levels of 42% to 46% with supercritical and ultra-supercritical designs. The application of this technology to solar towers, however, requires that it be adapted. Direct steam generation (DSG) will pose particular challenges in synchronising solar fields with receivers and supercritical steam turbines. A continuous management of solar collectors will be needed to avoid problems during start-up and variations caused by clouds and at sunset. Solar towers with high-temperature heat transfer fluids and storage may prove more capable of fulfilling these requirements, as they disconnect solar heat collection and power generation.9 Super heating with some fuel could also help address these challenges.

High-temperature tower concepts also include atmospheric air as the heat transfer fluid (tested in Germany with the Jülich solar tower project) with solid material storage. Solar-to-electricity efficiencies of up to about 25% can be delivered by such towers, but for supercritical steam turbines below 400 MW, the gain in efficiency may not compensate for the cost and complication of the cycle.

Solar-based Brayton cycles offer a relatively different way of exploiting the higher working temperatures that towers can achieve. Pressurised air would be heated in the solar receivers, and then sent directly to a gas turbine. Excess heat could be sent to a steam cycle running a second generator. The solar-to-electricity efficiency could be as high as 35%. Heat storage, however, is still an unresolved issue for such plants, while fossil fuel (or biomass) backup is more straightforward. Backup fuel heating the air from the solar receiver could be used to manage solar energy variations, and if necessary continuously raise the temperature level. The main ongoing work on dishes aims at reducing costs through mass production and demonstrating long-term reliability, consolidating their specific advantages of excellent efficiency and no need for cooling water. They could also be improved by making them more compatible with thermal storage and hybridisation, as has been experimentally demonstrated on a few large dishes.[14],[6]

### 3.3 THE VITAL ROLE OF TRANSMISSION
This roadmap sees long-range transportation of electricity as an important way of increasing the achievable potential of CSP. Large countries such as Brazil, China, India, South Africa and the United States (Figure 7) will have to arrange for large internal transmission of CSP-generated electricity. In other cases, high-voltage transmission lines will cross borders, opening export markets for CSP producing countries and increasing energy security for importing countries. Australia might feed Indonesia; the Central Asian countries supply Russia; Northern African countries and Turkey deliver power to the European Union; northern and southern African countries feed equatorial Africa; and Mexico provide CSP electricity to the United States.

<table>
<thead>
<tr>
<th>Countries</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia, Central Asia, Chile, India (Gujarat, Rajasthan), Mexico, Middle East, North Africa, Peru, South Africa, United States (Southwest)</td>
<td>5%</td>
<td>12%</td>
<td>30%</td>
<td>40%</td>
</tr>
<tr>
<td>United States (remainder)</td>
<td>3%</td>
<td>6%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Europe (mostly from imports), Turkey</td>
<td>3%</td>
<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Africa (remainder), Argentina, Brazil, India (remainder)</td>
<td>1%</td>
<td>5%</td>
<td>8%</td>
<td>15%</td>
</tr>
<tr>
<td>Indonesia (from imports)</td>
<td>0.5%</td>
<td>1.5%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>China, Russia (from imports)</td>
<td>0.5%</td>
<td>1.5%</td>
<td>3%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Fig.8 Electricity from CSP plants as shares of total electricity consumption[6]

The transfer of large amounts of solar energy from desert areas to population centres has been promoted, in particular, by the DESERTEC Foundation (Figure 8). This idea has inspired two major initiatives in Europe, the Mediterranean Solar Plan and the DESERTEC Industry Initiative. The first, developed within the framework of the Barcelona Process: Union for the Mediterranean, aims to bring about 20 GW of renewable electricity to EU countries by 2020 from the various developing economies that adhered to this recently created intergovernmental organisation.

IV. CONCLUSION:

Though solar energy is a green, clean, environment friendly renewable energy. It faces many challenges as stated above. Hence efforts are needed to search new materials and sophisticated manufacturing techniques to improve the overall performance of PV solar systems.

As the various methods and manufacturing technologies for CSP are discussed in this paper. It has been observed that technique has its own pros and cons. The major parameters of selection of a CSP are the efficiency and cost.

Fig.8 Growth of CSP production by region (TWh/y)[6]

The emerging technology known as concentrating solar power, or CSP, holds much promise for countries with plenty of sunshine and clear skies. Its electrical output matches well the shifting daily demand for electricity in places where air-conditioning systems are spreading. When backed up by thermal storage facilities and combustible fuel, it offers utilities electricity that can be dispatched when required, enabling it to be used for base, shoulder and peak loads. Within about one to two decades, it will be able to compete with coal plants that emit high levels of CO2.
For CSP to claim its share of the coming energy revolution, concerted action is required over the next ten years by scientists, industry, governments, financing institutions and the public. This roadmap is intended to help drive these indispensable developments.

From 2010 to 2020, the global rollout of CSP initiated before 2010 is expected to accelerate, thanks to on-going industry efforts and the adoption of suitable incentives for CSP in sunny countries. From 2010 to 2020, the global solar resource potential is investigated more accurately due to expected advancements in satellite algorithms, which offer higher spatial resolution and better DNI maps. These estimates are validated by many high-quality solar radiation measurement stations.

Such reference stations are installed in all countries and regions of interest for CSP, including those currently lacking adequate coverage, such as China, India, Turkey, Africa, the Middle East and Latin America. The deployment of CSP takes many forms, from assisting fossil-fuel plants in fuel savings to solar only CSP plants in regions with excellent sunlight. Some off-grid or remote-grid CSP systems are built, but large on-grid plants comprise more than 90% of overall CSP capacity. Thermal storage is further developed but in most cases remains limited to what is necessary to cover almost all intermediate and peak loads from solar resources only. CSP is not yet fully competitive with coal power plants for base load, as CO2 emissions are not yet priced highly enough. Backup, usually from natural gas, is used in some cases to enhance the efficiency of the conversion of solar thermal energy to electricity. In other cases, it is used only to guarantee the plant’s production capacity – during the day in summer to compensate for cloud cover, but also in the evening or at night, essentially to compensate for variability of a growing share of wind power on most grids. The global installed capacity reaches 148 GW by 2020, with an average capacity factor of 32% (2 800 hours per year), thereby providing 414 TWh annually. Primary energy from fossil-fuel backup or hybridisation in CSP plants accounts for 18% of this amount; the “solar share” in CSP electricity is thus 82% or 340 TWh. This represents 1.3% of the global electricity production expected by 2020. The limiting factor for deployment during this period is the global capacity of the industry, which must rapidly increase from about 1 GW per year in 2010 to more than 20 GW per year by 2020.

Dedicated HVDC lines are developed and built to bring solar electricity from distant regions to consumption centres. Some lines link North African countries to Europe. A north-south line links Lagos to plants in Mali or Niger. Other HVDC lines are built within large countries. In India, Mumbai and Delhi – as well as Lahore in Pakistan – could be supplied from Rajasthan. In the United States, Atlanta could be reached from the Southwest. In Brazil, Sao Paulo and Rio de Janeiro; in China, Xining, Chengdu and Chongqing could be supplied with CSP electricity.[6]

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