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Review of some Case Studies of Concentrated Solar Thermal Power Technologies: Status of CSP in India

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ABSTRACT: Solar energy is the most abundant form of energy available freely. It is clean in nature and becomes more attractive considering the current scenario of global warming and climate change worldwide. This paper aims at understanding the technical aspects of the solar thermal technologies like solar reflectors, Heat transfer fluid etc.. The text explores the existing and proven Concentrated Solar Power (CSP) Technologies like Parabolic Trough Collector (PTC) and Linear Fresnel Reflector (LFR), Paraboloid Dish and Solar Power Tower. The current state of CSP Plants in India are explored along with review on some case studies for the existing solar thermal power plants in India and the world.

KEYWORDS: Concentrated Solar Power (CSP), Parabolic Trough, Linear Fresnel, Paraboloid Dish, Rankine Cycle,

I. INTRODUCTION

The problem with fossil fuel is not only that it is limited in nature but also the emission from it which produces Carbon-Di-oxide.CO_2 is one of the most important candidate responsible for Global Warming. It can be estimated that with the increasing concentration of CO_2 the earth can gets warmer by 1-5°C with the advent of the next century [1].The emission emanating from fossil fuels is also dangerous for human health as it causes the air pollution. So the need of hour is that we need to mainstream an energy resource which is not only abundant but also clean in nature. Solar energy has solution for both the concern.

The four commonly used CSP Technologies are parabolic trough collector (PTC), Linear Fresnel Reflector (LFR), Paraboloid Dish and Solar Power Tower (SPT) out of which the first two are belongs to line focus system and last two point focus systems. The PTCs are primarily used in industry since they are the most developed and cheap compared to other CSP Technologies [5]. However, its cost is still more expensive than that of the conventional fossil fuel power plants. Second most installed is SPT technology after PTC, and growing at faster rate among all CSPs technologies [6]. High efficiencies are obtained because the receiver operates at high temperatures and reduced losses. There is a lot of similarity between Linear Fresnel Reflectors and Parabolic Trough Collectors. The difference is the geometry of LFRs which is a long flat or slightly curved mirror placed for concentration of sunlight.

LFR has lower efficiency than other CSP Technologies. The concentration ratio in LFR is significantly lower than that of PTCs. But simplicity of LFR means that they are easy and cheaper to manufacture makes them advantageous over others in certain conditions [7].The Parabolic Dish Reflector (PDR) or Dish Engine is a concave mirror, focuses the incoming sunlight onto a point receiver [2].Paraboloid Dish Systems give the highest efficiency among CSP Technologies.

II. SOLAR THERMAL TECHNOLOGIES

There are four important Solar Thermal Technologies utilizing concentrated for generating energy used by industry.
They are parabolic trough collectors, linear Fresnel reflector, power towers or central receiver systems, and dish/engine.

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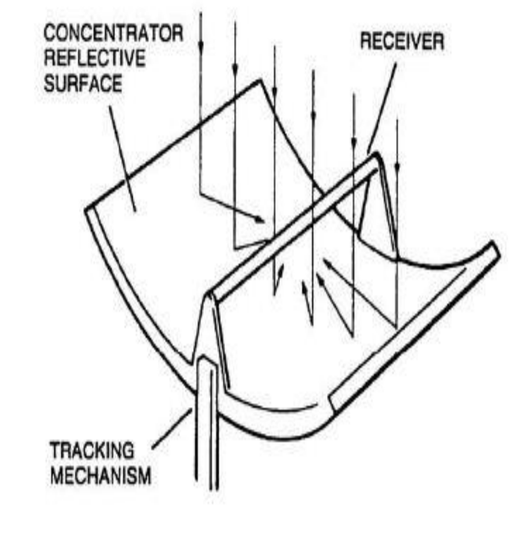
A. Parabolic trough collector (PTC)

PTCs is a proven technology used for process heating and other applications commercially around 90 % of the solar thermal power plants are based on parabolic trough systems.[CSP Today, 2013]



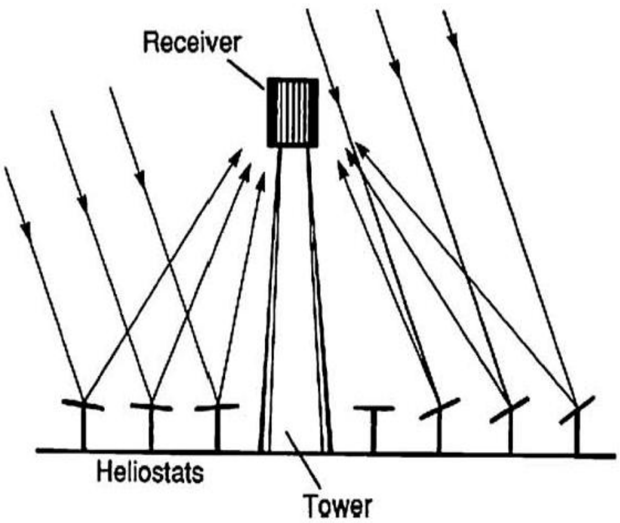


Fig. 1. Parabolic trough system**Fig.2.** Central Receiver Tower System

The main components of PTCs are a parabolic reflecting plate, a transparent cover on reflecting plate and an observer, which passes heat energy to Heat transfer fluid (HTFs). The absorber is fixed permanently at the focus of the parabolic concentrator. The absorber tube is protected by the transparent cover from the heat losses. The Parabolic concentrator is settled on a fixed structure and the single-axis tracking mechanism follows the sun's trajectory. Every cross-section of a PTCs has a focal point. These focal point when joined makes a focal line (Fig.1) . The solar Radiation that passes parallel to optical plane is reflected from the plate in such a way that it passes through the focal line [3].PTC can concentrate direct sunlight to generate working temperatures up to 400°C and achieve concentration ratios in the range of 30-100 [4].

B. Central Receiver Tower

The Solar power tower consists of a field of thousands of mirrors (heliostats) surrounding a tower which holds a heat transfer fluid to concentrate light on a central receiver atop a tower. An array of heliostats concentrate the sunlight onto a receiver settled at the top of a tower. Central Receiver tower is a point focus system (Fig.2). High efficiencies are obtained because the receiver operates at high temperatures and reduced losses. They provide better energy storage capability among CSP technologies. The individual inbuilt tracking mechanism keep the heliostat focused on tower and fluid is heated which runs a turbines. General concentration ratios ranges from 300 to 500 [10].

C. Linear Fresnel Reflector (LFR)

LFRs uses a long flat or nearly flat reflector and a receiver assemble which is fixed to some structure. The assembly may contain single linear receiver tube or multiple linear receiver tubes depending upon the size of the plant. The reflectors are placed at different angles to concentrate the incoming radiation on receiver tubes. Each line of reflectors

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has its own single-axis tracking system to concentrate the radiation correctly on the receiver (Fig.3). Due to its geometric properties the optical efficiency of LFR Field is always lower than that of PTCs Solar field.General concentration ratios is around 30 [11], which is low compared to other CSP technologies.

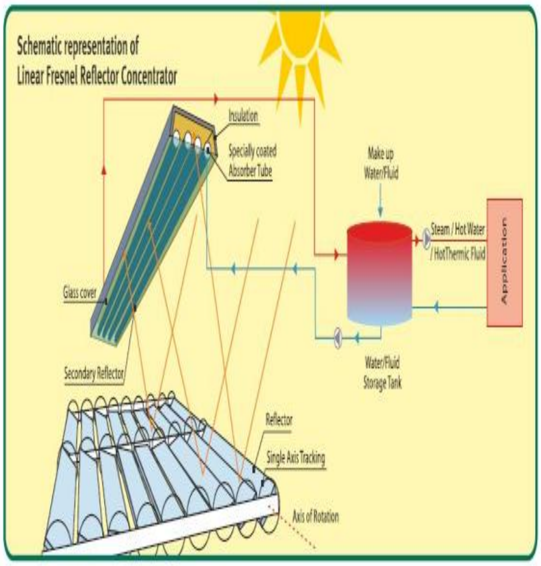

Fig. 3. Schematic representation of Linear Fresnel Reflector Concentrator [8].

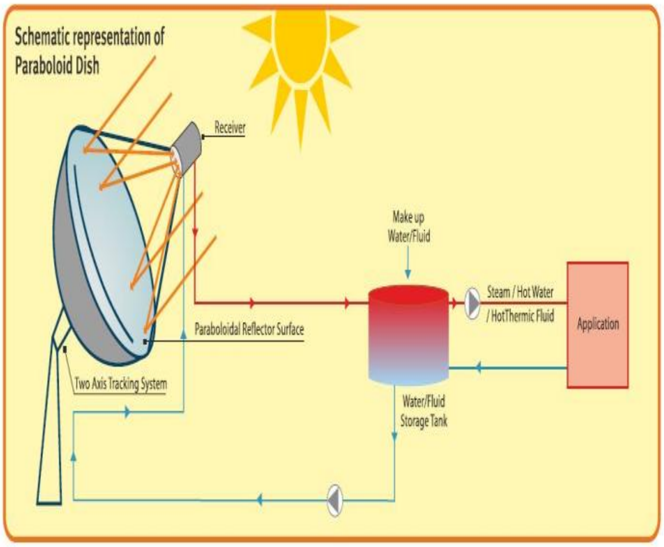

Fig. 4. Schematic representation of Parabolic Dish Reflector [9]

D. The Parabolic Dish Reflector (PDR)

The four main units of PDR is concentrator, receiver, Stirling engine and generator (Refer Fig.).The Stirling engine, receiver, and generator are enclosed in Power Conversion Unit (PCU). The concentrator (which is outside the PCU) focus the solar radiation into the cavity of the receiver. By concentrating the solar energy to actuate the Stirling engine the system produces the electricity.The Parabolic Dish Reflector system is integrated with the dual axis tracking system for tracking the solar radiation [12].The advantage the system lies in the fact that the higher solar to electric efficiencies is achieved. As the ongoing research suggest the Dish Engine has the tremendous potential. The efficiency of 31.25% has been achieved with one PDR, which set the world record for the solar to electrical efficiency [13].
Since the PDR System uses 2-axis tracking mechanism, it capture the highest solar radiation among all CSP Technologies and optical efficiency can be as high as 94%.This lead to higher concentration ratio which is around 500 to 2000 [10].The concern about using this technology is the high cost of mirrors. Some alternative method are being explored to use cheaper mirrors.
The PDR based Solar Industrial process heating system can be installed at automobile industrial plants with high DNI values to make automobile production more green and environment friendly. [25]

III. HEAT TRANSFER FLUIDS (HTFs)

In CSP System the heat is collected from the receiver by a thermal energy carrier called heat transfer fluids (HTFs). The HTF can be taken directly to drive a turbine for production of power or, more often, be used in a heat exchanger to transfer its heat to an another fluid known as the cycle fluid.Desired properties and characteristics of a HTF are: high boiling point, low meltingpoint, and thermal stability, low vapor pressure (<1 atm) at high temperature, low viscosity,

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low corrosion with metal alloys used to contain the HTF, high heat capacity for energy storage, high thermal conductivity and low cost.
The main HTFs based on type of material used are-[14]-(1) water/steam, (2) Organics, (3) molten-salts

A. Water or steam

The use of water or steam as both HTF and working fluid of cycle removes the complexities from the system and leads to enhanced efficiency, with less cost of electricity production. It is used as both HTF and working fluid in the recent and the world's largest CSP plant – the Ivanpah solar power facility which was launched in February 2014. The main issue with the water steam HTF is the scarcity of water in desert regions, and since for better Direct Normal Irradiance (DNI) throughout the year these CSP plants are mostly located in deserts, using water as a HTF poses serious challenges.

B. Organics

Organic materials are also used widely as HTFs in CSP systems. For example Therminol VP1 (Biphenyl/Diphenyloxide) is commonly used in commercial CSP systems. Biphenyl/Diphenyl oxide is a eutectic mixture of two very stable organic compounds; Biphenyl (C12H10) and Diphenyl oxide (C12H10O).
The first solar thermal plant with this organic material as the HTF was commissioned in 2009 at Badajoz, Spain and was named as 'Alvarado 1'.

C. Molten-salts

The most widely used HTF is the Molten Salt. They possess excellent properties like high working temperature (more than 500^{o}C) and heat capacity, low vapor pressure and corrosive property, and good thermal and physical properties at elevated temperatures, which are quite desirable for any HTF [15].Currently the most common molten salt HTF and thermal energy storage media are a mixture of 60% $NaNO_3$ and 40% KNO_3.The first molten-salt as a HTF based power tower systems launched in 1984. They were THEMIS tower (2.5 MW) in France and Molten-salt ElectricExperiment (1 MW) in the United States [16].
The main disadvantage of this salt mixture is the high melting point. The salt can freeze and block the pipeline during winter nights. In order to overcome this problem, auxiliary facilities need to be installed, which could increase the investment and operational costs.

IV. CSP TECHNOLOGIES IN INDIA

Table.1. Status of CSP technologies in India [17].

S. No	Project and name of place	Company/ manufacturer	Capacity	Technology type	Year of commencement
1	Abhijeet Solar Project, Phalodi (Rajasthan)	Corporate Ispat alloys Ltd	50 MW	Parabolic trough	Under construction
2	ACME Solar Tower, Bikaner (Rajasthan)	ACME Group	2.5 MW	Solar tower	Operational 2011
3	Dhursar, Dhursar (Rajasthan)	Reliance Power	125 MW	Linear fresnel reflector	Operational 2014
4	Diwakar, Askandra (Rajasthan)	LancoInfratech	100 MW	Parabolic trough	Under construction
5	Godawari Solar Project, Nokh (Rajasthan)	Godawari green Energy Limited	50 MW	Parabolic trough	Operational 2013
6	Gujarat Solar One, Kutch (Gujarat)	Cargo Solar Power	25 MW	Parabolic trough	Under

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					construction
7	KVK Energy Solar, Project Askandra (Rajasthan)	KVK Energy Ventures Ltd.	100 MW	Parabolic trough	Under construction
8	Megha Solar Plant, Anantapur (Andhra Pradesh)	Megha Engineering and Infrastructure	50 MW	Parabolic trough	Operational 2014
9	National Solar Thermal Power Facility, Gurgaon (Haryana)	IIT, Bombay	1 MW	Parabolic trough	Operational 2012

Currently India has 228.5MW installed capacity of CSP basedpower plants of different capacities and based on the parabolictrough collector, LFR and solar tower technologies. A 275MW CSP power plants capacity based on PTC field technology is under construction.Research is going on in Stirling engine based power plant to test in Ministry of New and Renewable Energy(MNRE) is also taking new initiativesfor the solar thermal electricity by providing new researchfacility for CSP and pilot project on Stirling engine to be tested in Indian climatic condition by MNRE in collaboration with ONGC at National Institute of Solar Energy, Gwalpahari,Gurgaon, India has nine CSP powerplants, seven of them are based on parabolic trough collector, one ison solar tower technology and one is on LFR. According to the collected and communicated data it turns out that parabolic trough collector and LFR are performing well as compared to solar powertower technology [17].

V. EXAMPLES: A REVIEW

A. Godawari Solar Project, Nokh

Godawari CSP Plant of 50 MW is the first ever CSP plant in India located near the Nokh Village in Jaisalmer district of Rajasthan (India).The project started in June 26, 2011 and started giving power supply in June 5, 2013 coinciding with the world environment day.Technical Specification of the project is written in the table.2.

It employs Parabolic Trough CSP Technology with state of-the-art SKAL-ET 150 trough structure. The total aperture area of the trough is 3, 92,400m² with 480 Solar Collector Assemblies (SCAs) and total occupied land is 150 hectares. The plant runs on Rankine cycle. Dowtherm A is used as a HTF which gather heat from parabolic trough and transfer it to cycle fluid i.e. water to generate steam. The steam generated flows through the pipe and strike the turbine blades to generate power. This Project is capable of lighting 2.5 million homes in India. System Advisory Model (SAM) for plant performance analysis. Is used which observes the real power output of the plant. [18]

Godawari power is the first successful CSP plant in India and one of the finest example of concentrated solar thermal power in the country.

Table.2. Overview and technical characteristics of Godawari Solar Project, Nokh [19]

Project	Godawari Solar Project
Location and country	Nokh, Rajasthan (India)
Lat/Long Location	27°36′ 5.0″ North, 72°13′ 26.0″ East
Land Area	150 hectares
Technology	Parabolic Trough
Turbine Capacity	50 MW
Heat Transfer Fluid Type	Dowtherm A
Cooling Method	Wet cooling
Solar Field Inlet Temperature	293 ^{O}C
Solar Field Outlet Temperature	390°C
Storage Type	None
Solar-Field Aperture Area	392,400 m²
# of Solar Collector Assemblies (SCAs)	480
# of Loops	120
# of SCAs per Loops	4

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SCAs Aperture Area	817 m²
SCA Length	144 m

B. National Solar Thermal Power Facility

CSP plant National Solar Thermal Power Facility of 1MW is commissioned at Gurgaon near New Delhi, India. The plant has the unique feature of integration of two different solar fields- parabolic trough collectors and linear Fresnel reflectors- without having the conventional fossil fuel backup. [21] Overview and technical characteristics of the plant is given in the table.3.The parabolic trough collector (PTC) field having 8175 m^2 of total aperture area heat-up the synthetic oil (as HTF) which enters the PTC field at about 232°C and exits at 393°C.
The linear Fresnel reflector (LFR) having total aperture area of field 7020 m^2 with direct steam generation (DSG) produces saturated steam at 44 bar and 256°C and together with the hot oil from PTC field superheated steam is formed at 350°C, 42 bar. This saturated steam runs a turbine to generate electricity. The PTC field contributes around 60 % and LFR field around 40 % of the heat. The plant was developed as a research-cum-demonstration facility. [22]

Table.3. Overview and technical characteristics of National Solar Thermal Power Facility, Gurgaon [19]

Project	National Solar Thermal Power Facility
Location and country	Gurgaon, Haryana (India)
Lat/Long Location	28°25′ 39.0″ North, 77°9′ 33.0″ East
Technology	Parabolic Trough, Linear Fresnel Reflectors
Turbine Capacity	1 MW
Heat Transfer Fluid Type	Therminol VP-1
Solar Field Inlet Temperature	293 ^{O}C
Solar Field Outlet Temperature	393°C
Storage Type	None
Solar-Field Aperture Area	8000 m²
# of Solar Collector Assemblies (SCAs)	12
# of Loops 3	
# of SCAs per Loops	4
SCAs Aperture Area	667 m²
SCA Length	120 m

C. ACME Solar Tower

ACME CSP Power Plant of 2.5 MW is based on power tower technology and located in Bikaner, Rajasthan. The construction of the project started in 2009 and became operational in year 2011. Technical Characteristics of the plant are mentioned in table.4.The 46m high solar tower gets solar radiation from 14,280 heliostats with each heliostat aperture area of 1.136 m² which makes approximately 16,222 m² (14,280 X1.136)of solar field aperture area.
This solar thermal plant is considered as the first demonstration project India had after the launch of Jawaharlal Nehru National Solar Mission (phase-I bidding) on January 11, 2010. [24]
The plant works on the steam Rankine cycle with wet cooling (cooling tower is used) and maximum cycle pressure reaches to 60 bar and temperature to 440°C

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Table.4. Overview and technical characteristics of ACME Solar Tower Project, Bikaner [19]

Project	ACME Solar Tower
Location and country	Bikaner, Rajasthan (India)
Lat/Long Location	28°11′ 2.0″ North, 73°14′ 26.0″ East
Land Area	12 hectares
Technology	Power tower
Turbine Capacity	2.5 MW
Heat Transfer Fluid Type	Water/Steam
Cooling Method	Wet cooling (Cooling Tower)
Receiver Inlet Temperature	218 ^{O}C
Receiver Outlet Temperature	440°C
Power Cycle Pressure	60 bar
Storage Type	None
Heliostat Solar-Field Aperture Area	16,222 m^2
# of Heliostats	14,280
Heliostat Aperture Area	1.136 m^2
Tower Height	46 m

D. Julich Power Tower

CSP plant Julich Power Tower of 1.5 MW is situated in Julich, Germany and is the country's only plant based on solar power tower technology. Overview and technical characteristics of the plant is given in the table.5.Construction of the Julich Power Tower was begun in July 2007 and installed in December 2008. Heliostat field is composed of total 2153 heliostats having each one of 8.2 m^2 aperture area which makes around total aperture area of 17650 m^2.On the top of the 60 m tower the power block steam turbine coupled with generator produces power in the form of electrical energy. The air as a HTF is heated to 680 ◦C and is used to heat water in the power cycle up to 480 ◦C. The efficiency of the plant is not much high since the heat transfer coefficient of air is low. The plant is equipped with 1.5 hour heat storage capacity by a packing of ceramic elements which are heated by hot air flowing between them. [20]

Table.5. Overview and technical characteristics of *Jülich* Solar Tower, *Jülich* [19]

Project	Saguaro Power Plant
Location and country	*Jülich*, Rhineland (Germany)
Lat/Long Location	50°54′ 54.0″ North, 6°23′ 16.0″ East
Land Area	17 hectares
Technology	Power Tower
Turbine Capacity	1.5 MW
Heat Transfer Fluid Type	Air
Cooling Method	Dry cooling
Receiver Outlet Temperature	680°C
Storage Type	Ceramic heat sink (Capacity-1.5hour)
Heliostat Solar-Field Aperture Area	17,650 m^2
# of Heliostats	2,153
Heliostat Aperture Area	8.2 m^2
Tower Height	60 m

E. *Ivanpah*Solar Power Plant

The world's largest solar thermal Ivanpah CSP plant based on solar power tower of 377 MW is located at Mojave Desert in Primm, Nevada.The construction work started in October 2010, and started producing power in February 2014. The facility is comprised of three separate plants built in phases between 2010 and 2013 [20]. Overview and technical characteristics of the plant is given in the table.6.The 392 MW gross capacity plant in 3,500 acres deploys 173,500 heliostats with total solar field aperture area of 2,600,000 m^2 focuses incident solar radiation on the boiler of three centralized tower of 140 m height. The produced steam runs turbine and in turn power is generated [19].Ivanpah solar plant uses dry cooling process to condense the steam back to liquid water and feed into boiler, thus around 90 % of the water is conserved as compared to other solar thermal technologies using conventional wet cooling systems. Dry cooling system comprises air cooled condenser having large forced draught fans to circulate air into the heat exchanger (condenser) to cool and condense the steam [23].

Table.6. Overview and technical characteristics of *Ivanpah* Solar Power Plant,*Primm* [19]

Project	*Ivanpah* Solar Electric Generating System
Location and country	*Primm*, Nevada (USA)
Lat/Long Location	35°33′ 8.5″ North, 115°27′ 30.97″ West
Land Area	3,500 Acres
Technology	Power Tower
Turbine Capacity	377 MW
Heat Transfer Fluid Type	Water
Cooling Method	Dry cooling
Receiver Inlet Temperature	249
Receiver Outlet Temperature	566°C
Power Cycle Pressure	160 bar
Storage Type	None
Heliostat Solar-Field Aperture Area	2,600,000 m^2 m^2
# of Heliostats	173,500
Heliostat Aperture Area	15.0 m^2
Tower Height	140

VI. CONCLUSION

Concentrated solar power plants have great potential for supplying and fulfilling a significant energy demand in near future. The excellent thing about CSP is the clean and carbon emission free energy. The portfolio of CSP technologies comprises of mature parabolic trough technology, Linear Fresnel System and Central receiver Tower systems. The Paraboloid dish system have high solar to electricity conversion efficiencies but not tested for large industrial scale. Heat Transfer fluid like water and organics are used in specific purpose. Molten Salt is most widely used HTF.
The development of CSP based power plants in India is not very inspiring and needs proper research focusing and adapting Indian conditions. Finally some case studies proved that the successful installation and operation of solar thermal power plant is possible and can be seen as a demonstration plant.

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