Hybrid-CSP in India: Technological and Economic Aspects

Sandip S Deshmukh[1]‡, Onkareshwar Mishra[1], Vatsal Agrawal[1*], Khalid Anwar[1]

[1]Department of Mechanical engineering, BITS Pilani Hyderabad Campus, Telangana-500078, India

(ssd@hyderabad.bits-pilani.ac.in, onkareshwarmishra@gmail.com, vatsagrawal@gmail.com, khalid@hyderabad.bits-pilani.ac.in)

‡ Sandip S Deshmukh; BITS Pilani Hyderabad Campus, Telangana-500078, India, ssd@hyderabad.bits-pilani.ac.in

Received: 08.10.2018 Accepted:12.01.2019

Abstract- India has an enormous potential for employing concentrated solar power (CSP) technology for energy generation. A great advantage of CSP is that it can be conveniently installed in parallel with existing fossil fuel power plants, which will enable us to increase the efficiency of the existing plants without making major changes in the plant setup and machinery. India has not yet utilised this resource to its full capacity. This paper discusses the status of CSP in India and the possible ways in which we can hybridize it with the existing conventional plants by simulating and optimizing different CSP technology and their economic feasibility. Further, the methodology of the system and different factors and aspects of the technology are discussed, that affect the performance and efficiency of the system. The various environment conditions like solar direct normal irradiance, wind-speed, land availability and economic factors like fixed cost expenses, inflation have been considered and areas suitable for CSP technology has been identified.

Keywords- Renewable energy, Solar thermal power, Hybridisation, HOMER, Energy Economics.

1. Introduction

The whole world is shifting towards cleaner energy sources because of the pollution and increasing global warming, whose adverse effects can be seen across the globe, as well as a greater demand for energy since the middle of the last century owing to industrial development, globalization and population increase [1]–[3]. There is a need to look for alternate, cleaner and sustainable fuels. Right now, fossil fuels power 80% of the world's energy needs [4], which evidently is a major cause of global warming. Renewable sources of energy are an excellent solution to this problem, such as solar, wind, hydropower, geothermal, etc. In past considerable effort has been put into identifying the various hybrid technologies that can be incorporated with solar energy [5]–[7]. As far as India is concerned, we have enormous potential for solar power. Solar power can be harnessed in two popular methods, using solar photovoltaic technology or using concentrated power plant technology [8], [9]. India has a solar potential of 750GW, out of which CSP holds a share of 12GW as of March 2017 [4]. India has laid uneven emphasis on SPV, due to cheap imports of thin film solar cells that come at lower costs. Similar work [10] by Purohit et al. discuss the solar potential in India from technological and economical point of view, in this paper the policy and frameworks by government has been discussed to shed light on the importance of a government in supporting renewable energy. However, they have lower efficiency and are more susceptible to wear and tear, with approximately 1% being required to be replaced every year. CSP technology lasts longer and is more efficient than solar PV [8]. Foreign manufacturers are dumping low quality equipment in the country in the guise of low prices and even enjoying state subsidy. Furthermore, India has focussed on large scale solar plants. Not only do these require large areas of land but also these are also not suited to uninterrupted grid

power. For this, we need to look at small-decentralised plants that are strategically distributed to provide energy to a widespread region. Figure 1, shows the distribution of energy through various resources in India.
Solar energy is periodic source of energy, as a particular region gets sunlight only during the day. So along with appropriate collector technologies, it is also very important to have adequate heat storage facilities to store the power generated. Various heat storage methods are possible and have been discussed by B.H. Goortani *et al.* in their study [11], [12].

Policies by the government also play a major role in the development of the solar technology in a country, without the support of the government it is very difficult for public and private sector companies to venture in this field of technology, as the initial investment is eminent. Jawaharlal Nehru National Solar Mission (JNNSM) is a major government initiative undertaken by the centre as well as state governments to address the energy security of the country. It also constitutes a major contribution by India towards the global effort of combating climate change [13].

In the short term, we can focus on using hybridization techniques to improve the efficiency of currently operational plants. Such systems are called Hybrid Renewable Energy Systems (HRES); different HRES combinations are possible depending on the requirement and availability of resources [14]. CSP is an excellent technology for hybridization purposes as it is relatively easy to store thermal energy. CSP involves heating of a heat transfer fluid using the heat energy from the solar irradiation and using this energy to generate steam and subsequently run a turbine to generate power. In this primary focus has been put to explaining the viability and applicability of hybrid solar systems. Solar energy can be used in the oil and gas industry to provide electricity for the plant as well as provide required heat for enhanced oil recovery [15].

National Power Co-operation Limited (NTPC), Dadri, has been simulated in HOMER software in order to determine the most suitable CSP technology [16]. HOMER has been selected due to its flexibility and usability [17]. It is a simulation tool that helps us plan and design renewable micro-grids. The software determines technical feasibility and life cycle costs of the micro-grid of every hour of the year [18]. It has already been used in studies in the same domain and thus, is a trusted tool [17]–[19].

This work presents the investigations on techno-economic analysis of Hybrid-CSP systems in Indian context using Hybrid Optimization of Multiple Energy Resources (HOMER) technique. The various technologies that can be used to extract solar power through thermal means have been studied. The work involves integration and comparison of all the available solar technologies with existing conventional power plant, which have not been analysed together. This work will also simplify the decision-making process of hybridizing in conventional plants as we conducted a sensitivity analysis as well as cost comparison of the feasible solar technologies. To simulate real-life scenarios, a model plant identical to NTPC, Dadri has been considered. This paper also gives an insight of how the integration of solar with older conventional power plant can be modelled in developing country like India to improve the present efficiency, where there is abundant potential for solar power.

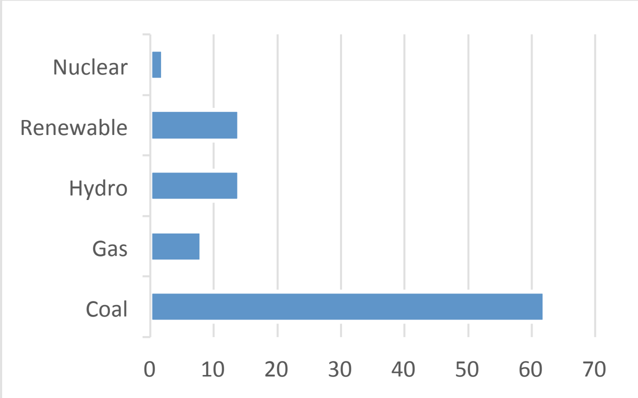

Fig. 1. Renewable energy distribution in India in percent

1.1. Status of CSP Globally

Most renewable energy technologies available presently, such as solar thermal, photovoltaic, micro-wind turbine, heat pumps, CHP, etc. have already been in development for many years now and we have a profound understanding of the science and engineering of these technologies [20].

Fig. 2. Miraah Solar Project.

Recent years have seen an encouraging increase in the development of solar photovoltaic, with 2016 witnessing an increase of 75 GW in photovoltaic capacity reaching a global capacity of about 303 GW [21]. However, CSP has better efficiency than SPV and the manufacturing of its components is not harmful to the environment unlike that of SPV. Right now, CSP is still in a developmental stage globally as compared to other technologies. Concentrated solar technologies were also implemented for efficient utilization of solar energy in the United Kingdom, Turkey, Algeria and Zimbabwe [22]. However, it holds the caliber to provide for 6% of world's energy needs by 2030 and 12% by 2050, if it grows at the current rate.

As of February 2016, CSP plants were operational worldwide. The major barrier is that equatorial countries do not have sufficient solar resources for extensive CSP development, however, the tropical countries that have the necessary resources must move to utilise these resources.

At present, Spain (2300 MW as of 2016) and United States (1738 MW as of 2016) are the global leader in the CSP domain, followed by Oman, India, Morocco and South Africa. The largest installation of CSP in the world is the Miraah Solar Thermal Project in South Oman [23]; figure 2, which has a capacity of 1021 MW. Petroleum Development Oman (PDO) and Glass Point Solar constructed it. The phase 1 of the construction is complete and it began steam generation in August 2017.

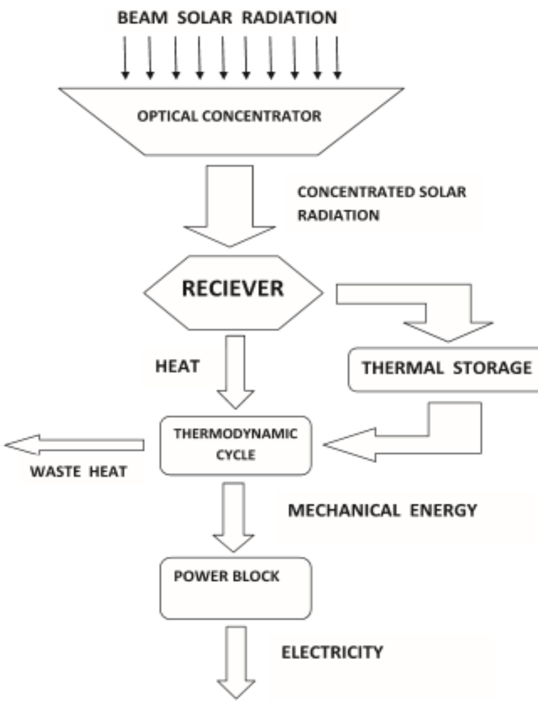

Fig. 3. Working of CSP [24]

2. CSP Technology

CSP technology is depended on solar radiation like other solar technologies. The energy acquired by radiation is transferred to fluid, which in turn transfers the energy to form steam to run generators. There are several components involved in the process, the main ones being: collector, receiver, thermal storage unit and the power generation block. The schematics are shown in the figure 3 [24]. The incoming beam radiation is incident on the collector, where it is concentrated following it goes to the receiver. The receiver absorbs the thermal energy of the solar radiation and transfers it to the heat transfer fluid and it is subsequently used to run a turbine, which is attached to a generator from where we get the power generation. The heat energy generated is then used for steam generation. There are four main types of solar collectors, each is suited to different situations, and hence, we have to assess the surrounding parameters like available irradiation, topology, available land, etc. before finalising on the solar collector technology to be used. The different types of collectors are parabolic trough collector, linear Fresnel reflector, solar parabolic dish and solar tower/central receiver system.

2.1. Parabolic Trough Collector (PTC)

This technology works on single axis and employs line focus i.e. the collectors focus the radiation along a line. Single axis collectors have a single degree of motion. This is done through rows of parallel parabolic trough collectors, which concentrate the incident radiation [25]. The concentrated radiation falls on the receiver tube, which usually made of stainless steel with selective coating. The selective coating is used to reduce thermal losses from the pipes. The heat transfer fluid (synthetic oil, mineral oil, water, molten salts, etc.) get heated in turn to produce steam and generate power through a turbine. The temperatures may attain values in the range of 400 °C to 600 °C depending on the working fluid [24].

Currently, PTC systems are popular, dominating the market and being installed in more than 78% of plants, operational and under construction. There are several advantages of PTC technology over others. One of the most important being that the technology is scalable, i.e. it can easily be scaled to higher capacities without extensive technological and labour investments [10]. PTC systems also have higher solar to electricity conversion efficiency value as compared to linear Fresnel and solar towers. In India, as of March 2016, the operational PTC utilizing plants were: Godawari Solar Project (50 MW) Rajasthan and Megha Solar Plant (50 MW) Andhra Pradesh.

2.2. Linear Fresnel Reflector (LFR):

This reflector also works along a single axis and thereby results in line focus of incident radiation. The apparatus consists of fixed receiver, which is mounted over the tracking mirrors that reflect the radiation onto the receiver. The system operates at temperatures around 500 °C [24]. The LFR is a cost effective setup and eliminates the requirement of heat transfer fluid and heat exchangers. It is less efficient than PTC but the reduced capital cost, lighter equipment and less concern from wind effects make up for the drawback to some degree [26], [27]. It is the most viable technology after PTC and it can be modified, for instance, to maximize land usage we can use the compact linear Fresnel reflector. It can also be installed with a secondary reflector receiver to increase the solar concentration factor (using which it may attain a higher factor than a PTC system).

2.3. Parabolic dish system (PDS):

It is a double axis system, i.e. the system has two degrees of freedom that act as axes of rotation. The two axes are usually perpendicular to each other. This system focuses the solar radiation to a single point i.e. the receiver placed at the focal point of the dish. Understandably, these systems have a higher efficiency than a parabolic trough system as they are able to concentrate the radiation over a smaller area with maximum temperature around 1500 degree Celsius. This hot fluid is used to run a sterling engine to generate power. It has the highest frequency among the four. In India, this technology has yet to gain popularity. One of the major plants using this technology is Dalmia Solar Plant in Jodhpur, Rajasthan (100 MW) which largest solar power plant in the state under 'Make in India' mission [28].

2.4. Central Receiver System (CRS):

This technology uses a double axis tracking system. In this case, heliostats are used to concentrate the solar power to the collector. The heliostats are arranged in a circular fashion around the detector to concentrate the light at the centre. There is only one receiver because of which there is minimal thermal energy transportation. Due to this, the concentration ratio is also high. If pressurised gas or air is used as heat transfer medium at temperatures of around 1000 °C, they can directly be used in a gas turbine [10].

The major advantages of CRS include its ability to store thermal energy for a short period, thereby helping maximize power generation. Due to high concentration factors, this system is also capable of high generating power up to 10 MW. It is also a notable fact that this is the second most mature solar collector technology after PTC. In India, a CSP project of ACME Solar has implemented a CSP project in Rajasthan.

2.5. Storage of thermal energy for CSP

CSP can be conveniently coupled with thermal energy storage systems. This means that it will be functional even in non-daylight hours, which is one of the biggest hurdles of employing solar systems [29]. This enables us to have a highly dispatchable arrangement. Thermal energy storage can be done in 3 ways: specific heat, latent heat and bond energy method as shown in figure 4 [30]. Specific (Sensible) heat method stores energy using the heating and cooling properties of liquids, given that they do not change their phase in the process. Common examples are water, inorganic molten salts, heat transfer oils and solids like rock and pebbles. The material chosen for storage depends on the temperature we are handling. For example, water was conveniently used for the temperature below 100 Celsius and refractory bricks around 1000 Celsius. Latent heat method has Phase Change Materials (PCM) are substances which are used for thermal energy storage. As the material was melted, it absorbs the latent heat of fusion. When it was solidified again, the energy is recovered. The main advantage is that the system has a high storage density. Bond energy method uses some chemical compounds absorb and release energy during bond reactions. We use systems having one or more such compounds to store energy. The minimum requirement for this is for the reaction to be endothermic reversible reaction. In addition, for the process to feasible, the reactants should be cheap and the chemicals easy to transport.

Type of Thermal Energy Storage	Functional Principle	Phases	Examples
Sensible Heat	Temperature change of the medium with highest possible heat capacity	• Liquid	Hot water, organic liquids, molten salts, liquid metals
		• Solid	Metals, minerals, ceramics
Latent Heat	Essentially heat of phase change	• Liquid-Solid	Nitrids, clorides, hydroxides, carbonates, flourides, entectics
		• Solid-Solid	Hydroxids
Bond Energy	Large amount of chemical energy is absorbed and released due to shifting of equilibrium by changing pressure and temperature	• Solid-Gas	CaO H_2O, MgO/H_2O, $FeCl_2$/NH_3
		• Gas Gas	CH_4 H_2O
		• Liquid-Gas	LiBr/H_2O, NaOH/H_2O, H_2SO_4/H_2O

Fig. 4. Types of thermal storage techniques.

3. The Indian Context of CSP

The major hindrances to CSP development majorly lie in the categories: technical, cost and environmental. Technical barriers include issues such as lack of sufficient data [31], for instance, we do not have the DNI data for all parts of the country. This also includes lack of appropriate infrastructure. Cost barriers have that the capital needed for the installation of CSP plant is much higher than that needed for an SPV plant, with CSP being more than 60 million more expensive per MW on average. Environmental barriers pose problem that solar plants require large, plain areas of land. This may lead to widespread displacement of communities, as it may not always be possible to acquire large areas of unoccupied and barren land. CSP also requires large quantities of water for cleaning purposes and steam generation.

3.1. Policies and initiatives:

Ministry of new and renewable energy (MNRE) is majorly responsible for the adaptation and support of newly developing renewable energy through generation based incentives (GBI), capital subsidies, concessions, and viable gap funding (VGF). JNNSM was launched on 11 January 2010 is yet another initiative taken by the government to promote solar energy in India [32]. Under this initiative, India is investing heavily in research and development. It is three-phase plan; Phase 1 is from 2012-13, Phase 2 is 2013-17 and Phase 3 is 2017-22. The target of this three-phase plan is to establish India as a global leader in Solar Energy [13], [33].

Incentives offered by Government for the development of the Solar Energy sector include:

1. Interest subsidy will be provided i.e. loan will be granted on zero or low-interest rates.
2. Renewable Purchase Obligation (RPO): A fixed percentage of electricity has to be generated by renewable energy resources.
3. No taxation for a period of 10 years for solar power plant,
4. Concession on wheeling charges. Wheeling is another term for the transfer of electric power generated at a power plant over the transmission of the grid. If the power plant does not own its own power lines, it can pay someone who does own the lines and utilize its services [34].
5. Government provides concession on excise duties on all the equipment purchased by Power Plants
6. Power Purchase agreements: Under this, all the details of the projects are recorded for the sake of funding and long-term agreement provided by JNNSM.
7. Under renewable sector, specific SEZ (Special Economic Zones) incentives in exports are provided.
8. Incentives for more than 1 MW power plants.
9. The government for off-grid solar power plants provides a subsidy of 30% of a project's full expense.
10. Feed in tariffs (FIT): for the firms that are recognized under this category the government provides them tariffs for a period of 25 years.
11. Renewable Energy Certificates (RECs): these documents are proof that a definitive amount of power was generated using renewable sources.

3.2. Regions best for CSP in India:

Taking into account the consideration the Direct Normal Irradiance (DNI) factor, it has been found by Ministry of New and Renewable Energy (MNRE), that regions with annual 1800 kWh/m^2 and WPD (Wind Power Density) higher than 200 W/m2 are most suitable for CSP projects [10]. According to the data collected from Meteonorm 7.0, classification of such land was done as follows. States in India like Gujarat, Rajasthan, Andhra Pradesh, etc. where DNI conditions are favourable along with suitable wind resource is good for power generation. A list of annual DNI has been listed in table 1 [10].

3.2.1. Low potential locations: Regions with Annual DNI less than 1600 kWh/m^2 is not recommended for CSP, and other sources of energy shall be explored.

3.2.2. Long-term potential locations: Regions with annual DNI between 1600-1800 kWh/m^2. These regions are not feasible in the current scenario but shall serve as a noticeable prospect in the future.

3.2.3. Moderate potential locations: Regions with annual DNI between 1800-2000 kWh/m^2 are feasible with current technology and are sectors that are ventured by many investors.

3.2.4. High potential location: Regions with annual DNI greater than 2000 kWh/m^2. These regions attract a large number of investors and most of the Solar Power Plants are based on these areas.

4. Hybridization

Hybridisation refers to the process of combining multiple processes to obtain a system that is more proficient than the individual systems. In the case of power generation, this refers to combining two types of power plants to attain a plant that is better than the stand-alone plants. This is because CSP has higher efficiency and lower costs as compared to SPV and because it is easier to store the thermal energy. In addition, CSP can use a lot of the conventional power generation equipment, hence, the capital costs are significantly lowered [35]. The collector technology used depends on the temperatures at which the system operates; for high temperature (>500 °C) we usually use solar towers, for temperatures around 400 °C parabolic trough collectors are often used, and finally, for low temperatures (<300 °C) we usually apply linear Fresnel reflectors. The advantages of hybridizing with CSP are sharing of common equipment helps reduce capital cost. This arrangement leads to a synergetic system; hence, the performance of the plant is improved. If a conventional power plant is hybridized, the emissions given out are reduced. The plant deploys a greater proportion of green energy. The hybridization can be done in both directions i.e. we can hybridise a coal plant with solar technology so the major generation is done using conventional or we can also use solar technology to produce the greater proportion; this will depend on what is more feasible for the plant in question. Light medium synergistic systems have a lower solar share and can operate independent of CSP but not vice versa. However, in synergistic plants, the host is dependent on CSP and cannot be operated independently. CSP can be hybridised with all energy resources to some extent including thermal, bio fuels, geo thermal etc. Two major types of hybridisations are present, one is the plant that uses thermal integration, and here water is heated to super-heated state using solar energy. This type of hybridisation is already being employed around the globe. The second is the thermos chemical integration. There are several methods by which, we can deploy the hybridization process in power plants, depending on the type of power plant.

4.1. Hybridization in coal plants

Hybridization with coal may lead to 18% cost saving and 25% more power generation as compared to a stand-alone coal plant. Solar energy is used to generate steam and enhance the steam generation through coal. Solar heat can also be used to pre-heat boiler feed water. Pre-heating feed water improves thermodynamic efficiency of the system; hence, this hybridization technique is better than generating steam using solar heat. Solar heat may also be used to preheat air to supply in coal-fired boiler. At low temperatures, solar heat can be used for the removal of carbon dioxide from the system. This is also quite easy to install in pre-existing plants.

4.2. Hybridization in natural gas plants:

Energy flow chart 2050, shows the forecasted usage of oil by 2050 in million tonnes of oil equivalent in UK [36], which is scary considering the current environmental scenario and it gives an overall idea of how continuous use of oil will affect the environment in India and all over the world. Solar aided gas turbines have scope for high solar shares. However, the main obstacle is that gas turbines operate at high temperatures (around 1000 °C) and solar collectors provide temperatures around 400 °C or lower. We can directly solar generated steam into the combustion chamber. This requires lower temperatures, which are feasible from collector end, but it has a lower solar share.

4.3. Hybridization with biofuels:

Solar hybridisation with bio-fuel opens the gateway for 100% clean energy generation. The hybridisation techniques are those similar to Natural Gas and have an appreciable level of economic potential. CSP can be used to generate steam alongside boiler setup. From efficiency, point of view solar tower system is best but Fresnel System is more economical having 69% lower cost than a standalone CSP plant.

5. Simulation of a Model Coal Based Thermal Power Plant

India has a large reserve of fossil fuels, especially coal, India had estimated coal reserves of 306.6 billion metric tons as of 31 March 2015, and it is the fourth largest producer of coal. Coal India (CIL) is one of the largest coal producer companies in the world and accounts for 82% of the total coal produced in India. National Thermal Power Corporation Limited (NTPC Ltd.) is the largest power company in India with an electric power generating a capacity of 51,410MW [13]. Meeting the energy demands of such hugely populated nation comes with a price. Emission of pollutants like SO_2, CO and CO_2 are depleting the quality of life and it is taking a toll on the environment. In order to reduce these emissions and for saving capital NTPC Dadri, Uttar Pradesh is planning a 15MW CSP integrated power plant by using compact Fresnel Collector.

Table 1. Solar DNI in different states of India (W/m^2)

S No.	State	District	Min. DNI	Avg. DNI	Max. DNI
1	Andhra Pradesh	23	1184	1529	1867
2	Arunachal Pradesh	16	870	1077	1220
3	Assam	23	1154	1576	1916
4	Bihar	35	1213	1394	2020
5	Chhattisgarh	16	1621	1694	1824
6	Delhi	1	1913	1913	1913
7	Goa	2	1806	1806	1806
8	Gujrat	25	1548	1967	2321
9	Haryana	21	1653	1922	2052
10	Himachal Pradesh	12	995	1709	2195
11	Jammu and Kashmir	14	1075	1661	2015
12	Jharkhand	24	1395	1613	1779
13	Karnataka	27	1643	1845	2040
14	Kerala	14	1389	1642	1825
15	Madhya Pradesh	45	1524	1847	1943
16	Maharashtra	33	1473	1696	1947
17	Manipur	9	1317	1567	1736
18	Meghalaya	7	1152	1576	1714
19	Mizoram	8	1842	1944	2063
20	Nagaland	7	1154	1274	1422
21	Orissa	28	1295	1494	1808
22	Punjab	20	1337	1527	1961
23	Rajasthan	32	1454	1935	2330
24	Sikkim	4	1884	1318	1399
25	Tamil Nadu	30	1454	1680	1864
26	Tripura	4	1701	1733	1780
27	Union territory	10	1233	1661	2081
28	Uttar Pradesh	70	1201	1642	2362
29	Uttarakhand	13	1773	2305	2620
30	West Bengal	18	1223	1412	1849

The solar field will feed solar thermal energy into water-steam cycle of 210MW unit of power station.

Table 1 contains information about minimum (min), Maximum (max) and average (avg), Direct Normal Irradiance (DNI) of various states of India using Meteonorm 7.0 software.

In this paper, we have assumed a model CSP integrated thermal power plant in Uttar Pradesh with average annual DNI 1642 kWhr/m^{2-}yr [37], with thermal capacities of 10MW, 11MW, 12MW, 13MW, 14MW and electrical capacity of 1MW, 2MW, 3MW, 4MW, and 5MW. We then obtained the most economically suitable CSP technology for different plant capacities. Figure 5 is a diagram representing the proposed hybrid CSP system working hand in hand with thermal plant. The major parts of the system are steam turbine, boiler, solar collectors and solar heaters used to produce steam. In our analysis, we have used HOMER (Hybrid Renewable and Distributed Generation System) software to optimise and point out the most feasible alternatives. It performs simulation, optimization and sensitivity analysis of a hybrid-solar plant. A steam Rankine cycle has been assumed in which using heat exchangers, the solar energy is fed into the steam generators (heaters) and bear a part of the thermal load and carried to turbine from where electricity is generated. The temperature output of the solar plant has to be around 250°C. A configuration of the system has been shown figure 6.

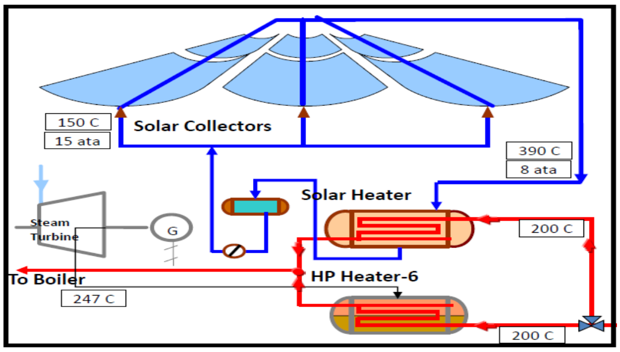

Fig. 5. Diagram of working of Hybrid-CSP with Thermal Power plant

A single module of each technology has been assumed to be 21.6 m^2 for analysis based on the average annual DNI of 1642 kWh/m^2 by Meteonorm 7.0 database [37]. The capacities of Fresnel Collector, Solar Dish and Parabolic Trough have been assumed to be 9 kW, 7.87 kW and 8.1 kW respectively. The economic parameters of CSP components are taken from Central Electricity Regulatory Commission (CERC) for 2016-17, irrespective of the technologies as shown in table-3. The simulation on HOMER was run by taking inflation rate of 3.18% project lifetime of 25 years. The peak months of power consumption were assumed to be December and January as described in the figure 6 for a 10MW capacity plant.

Table 2. Economic Factors affecting Solar Technologies

Economic Parameter	Unit	Value
Capital	Million INR/ MW	120
Life	Years	25
Interest rate	Percent	13
Repayment	Years	12
Discount	Percent	10.81
O&M	Million INR/MW	1.87

For 10MW capacity plant, Sterling Dish Collector (SDC) was found to be most cost efficient with net present cost (NPC) of 591 million, followed by Compact Linear Fresnel Collector at 599 million. For 14MW plant, Solar Dish Collector (SDC) was found to be most economically efficient with NPC of 737 million, followed by Compact Linear Fresnel Collector (CLFR) at NPC of 747 million. The table 2 also gives estimates of Initial capital, Operation & Maintenance (O & M), Operation cost and Cost of Energy per KW (COE). The detailed data is mentioned in table 3, table4 and table 5. The overall result of the simulation indicates that the most economically feasible technology for CSP-hybrid coal plants is SDC, followed by CLFR and PTC.

Based on this simulation we have also identified a few thermal power plants in Uttar Pradesh, India with annual DNI of 1642 kWhr/m^2 that would profit greatly and where Hybrid-CSP is feasible. NTPC Singrauli is one of them with a capacity of 2000 MW. It already has a solar PV plant of 15 MW, commissioned in December 2014. However, installation of a Hybrid-CSP plant in Singrauli, like the one in Dadri plant will be much more profitable and feasible for the plant. NTPC Ltd. is targeting to achieve a total of 10,000 MW of renewable energy by 2022. NTPC Rihand (Capacity 3000 MW) [13] and Vindhyachal Thermal Power Station (capacity 4760MW) [13] are also two major players that can exploit solar energy of the region.

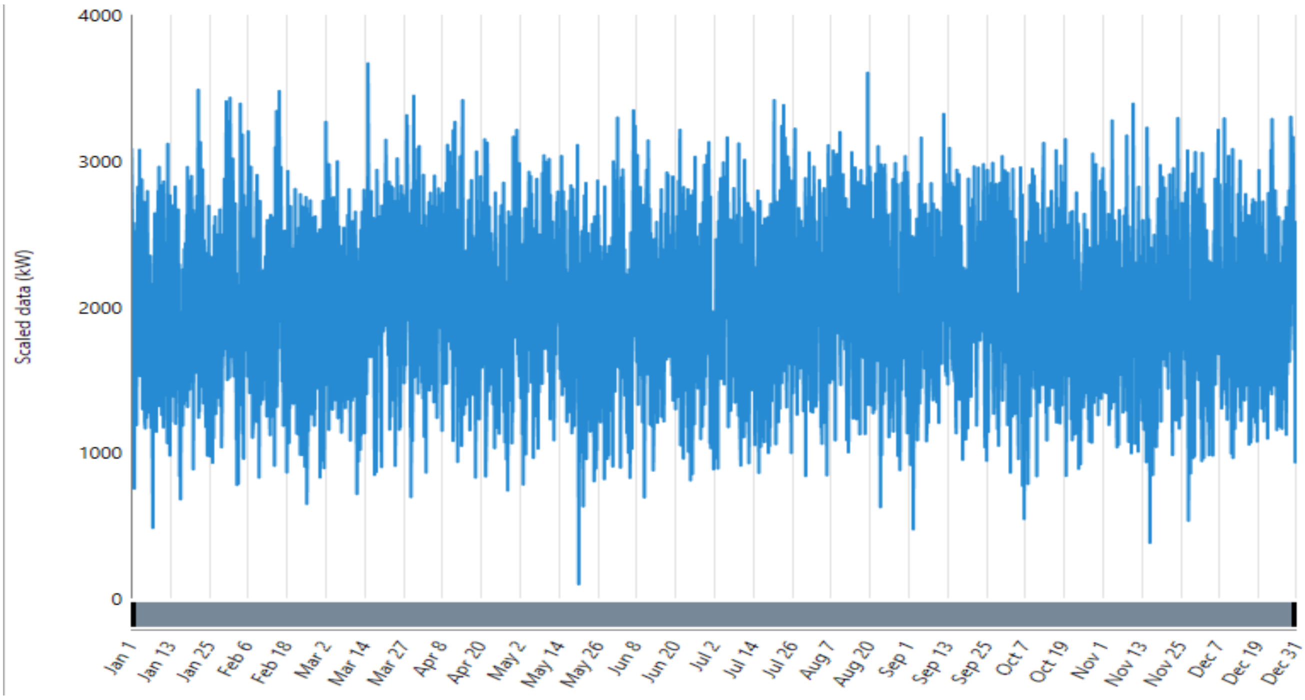

Fig. 6. Energy Demand Distribution in NTPC, Dadri

Table.3 Sensitivity analysis of CLFR

Sensitivity/ Electric load (kWh/day)	Sensitivity/ Thermal load (kWh/day)	Architecture/ CLFR	Cost/ CLFR in Rs	Cost/ Operating Cost in Rs (10^7)	Cost/ Initial Cost in Rs (10^8)	SDC/ Capital Cost in Rs (10^8)	SDC/ Production (kWhr/year) (10^7)	Boiler/ Fuel Consumption (L)
120000	312000	800.00	1.705	1.36	8.00	8.00	6.31	19787.3
144000	336000	800.00	1.421	1.37	8.00	8.00	6.31	21309.4
48000	240000	245.83	1.310	0.45	2.46	2.46	1.94	15220.9
72000	264000	366.34	1.301	0.65	3.66	3.66	2.89	16743.1
96000	288000	491.67	1.310	0.86	4.92	4.92	3.88	18265.2

Table.4 Sensitivity analysis of SDC

Sensitivity/ Electric load (kWh/day)	Sensitivity/ Thermal load (kWh/day)	Architecture/ SDC	Cost/ SDC in Rs	Cost/ Operating Cost in Rs (10^7)	System/ Ren Fraction	SDC/ Capital Cost in Rs(10^8)	SDC/ Production (kWhr/year)(10^7)	Boiler/ Fuel Consumption (L)
120000	312000	698.24	1.28	1.11	27.78	5.94	4.81	19787.29
144000	336000	837.89	1.28	1.32	30.00	7.12	5.78	21309.39
48000	240000	279.29	1.28	0.47	16.67	2.37	1.93	15220.99
72000	264000	418.94	1.28	0.68	21.43	3.56	2.89	16743.1
96000	288000	558.59	1.28	0.89	25.00	4.75	3.85	18265.2

Table.5 Sensitivity analysis of PTC

Sensitivity/Electric load (kWh/day)	Sensitivity/Thermal load (kWh/day)	Architecture /PTC	Cost/PTC in Rs	Cost/Operating Cost in Rs (10^7)	Cost/Initial Cost in Rs (10^8)	SDC/Capital Cost in Rs (10^8)	SDC/Production (kWhr/year) (10^7)	Boiler/Fuel Consumption (L)
120000	312000	683.6548	1.407	1.11	6.65	6.65	4.85	19787.3
144000	336000	828.125	1.421	1.33	8.05	8.05	5.87	21309.4
48000	240000	273.4985	1.408	0.47	2.66	2.66	1.94	15220.9
72000	264000	410.2783	1.408	0.68	3.99	3.99	2.91	16743.1
96000	288000	554.6875	1.428	0.91	5.39	5.39	3.93	18265.2

6. Conclusion

India has tremendous solar potential and there is a desperate need of harnessing this energy to minimise the load on fossil fuel, considering the pollution levels in recent years and constant and inevitable threat posed by global warming due to greenhouse gases, there is a need of an alternate source of energy now more than ever. In this work, we have covered the various hybrid CSP technologies and their implementations, which may intern be beneficial for industries to work hand in hand with the environment. Hybrid CSP with coal plants, natural gas, and bio fuel has been discussed along with eminent plants using that technology was mentioned. Major solar collector systems like PTC, LFR, PDS, and CRS were analysed and their merits and demerits were stated along with their working and performance characteristics. PTC and LFR use single axis tracking system whereas PDS and CRS use double axis tracking system as a result are able to generate higher temperature with better efficiency. Various methods to store thermal energy have also been discussed. In this paper, we have identified the solar DNI of various regions of India which are more than enough for producing a considerable amount of energy. Based on the data gathered for Thermal Power Plants in Uttar Pradesh i.e. Solar DNI, wind speed, land availability, capital, life, discount, repayment and O&M, a multi-grid software HOMER was exploited and the data was simulated for obtaining the most efficient system. HOMER created a module with given technology and energy requirements, then simulates the module for different amounts of solar energy equipment, and finds out the most efficient usage of that particular technology, further the results were compared and the best system was established. We concluded that Sterling Dish Collector is the most suitable technology for setting a solar plant of 10-14 MW in the state of Uttar Pradesh, followed by Compact Linear Fresnel Collector and Parabolic Trough Collector. We also identified the scope of exploiting solar energy in the region, with other Thermal Plants of Uttar Pradesh, some of which are actively using or planning to use solar PV in future. We further discussed various CSP technologies, their characteristics and identified how they can be hybridised with different technologies.

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