A review on advancement of concentrated solar power in India

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Abstract: The electricity produced by concentrated solar power (CSP) yearly is increasing at a considerable rate in India. India has huge solar power potential for solar electricity generation per watt set up because it has solar radiation of 1700–1900 kW h per kilowatt peak with around three hundred clear sky days in year. The government had set a target of extra solar power generation of 10,000 MW till 2017, and 100,000 MW till 2022. In this paper, a brief overview of the various installed CSP based electricity generation plant in India has been outlined.

Keywords: Concentrated solar power (CSP), Electricity generation, Solar radiation, India, Target.

I. INTRODUCTION

The demand for energy is increasing exponentially, and the depletion of nonrenewable energy resources is on an ever high. Therefore, it is essential to find an alternative source of energy viz. renewable energy. These are environment friendly and available in plenty on earth [1]. More than 80% of world's energy is supplied by the fossil fuels, and its use will be a grave issue in near future. Developing countries also have international pressure to limit the carbon emission [2]. India is one of the developing countries where energy utilization rate has grown notably in last few decades. India is highly dependent on fossil fuels for generation of power. Power from coal constitutes 53.4% of the total power production, hydropower constitutes 22.6%, gas constitutes 10.6%, atomic energy constitutes 2.8%, oil constitutes 0.6%, and non-conventional energy resources 10%. To decrease the gap between energy supply and demand, it is essential to opt for renewable energy as alternative energy sources. India is world fifth largest renewable energy based electricity generator [3]. There is ample availability of solar radiation of 1700–1900 kW h per kilowatt peak for around three hundred clear sky days in year. Solar energy can generate electricity in two ways. The first is by photovoltaic and the second is concentrated solar power. India has huge potential for the development of the CSP based plants. The total installed capacity in India is 12,288.83 MW till March 31, 2017. Among the Indian states, the leader in the utilization of the CSP based technologies with installed capacity of 1812.93 MW is Rajasthan, followed by Gujarat and Tamil Naidu with 1249.37 MW and 1691.83 MW respectively. The growth of CSP based plants in India has been very fast. On 31st March, 2015, the total installed capacity of CSP based plant was merely 3743.97 MW. Therefore in two years, the installed capacity has increased four times [4]. Solar photovoltaic based power generation system has some major disadvantages like large surface, low efficiency, et cetera. These two drawbacks are eliminated in the CSP. CSP systems are based on different technologies; the

solar tower technology, the linear Fresnel system, the parabolic trough technology, the dish Stirling system. A number of researchers are studying the capabilities and applications of CSP technology in various parts of the world. United States of America, Spain, and India are the top three nations in the employment and implementation of CSP technology [5]. The geographical information suggests that the CSP technology as parabolic trough collector has huge potential in South Africa. It can generate electricity up to 547.6 GW. Various studies suggests that CSP system has financial support for north western side of the country and it gives around 1800kWh/m2 which is best suited for the CSP technologies [6]. Potential evaluation studies indicate that this technology has a great prospects at dry places of mid-latitude areas. But it cannot be used in torrid zones with high diffuse fraction of worldwide radiation [2]. India has also embarked on many projects for the installation of CSP technology on large scale [7]. As we can see, there is huge opportunity for development of CSP in India. The present review paper will help advancing further reformation of policies, planning and implementation of CSP based power plants in India. The study will also be helpful in drawing investments for the development of CSP as distributed power source in remote and non-grid area from potential investors.

II. CONCENTRATING SOLAR POWER (CSP) TECHNOLOGY

The working methodology of CSP to produce electricity is shown in Fig. 1. Beam solar radiations fall on optical concentrator plates, they combine together and become concentrated solar radiation, moving to the receiver. The receiver absorbs the thermal energy of the solar radiation from this and the absorbed thermal energy is transferred by the working fluid which drives the turbine-generator system. In this way electricity is generated [8].

Concentrated solar power plant based on: parabolic trough; parabolic dish; solar tower; and linear Fresnel reflectors, are discussed in the following section. Table III depicts a summary of performance of the various CSPs.

A. Parabolic Trough System:

Concentrated solar power can be further classified in two, viz.: point focus and line focus. Parabolic trough collector (PTC) system is based on line focus and follows a single axis. The system comprises of: receiver tube, mirror, and focal line [9].

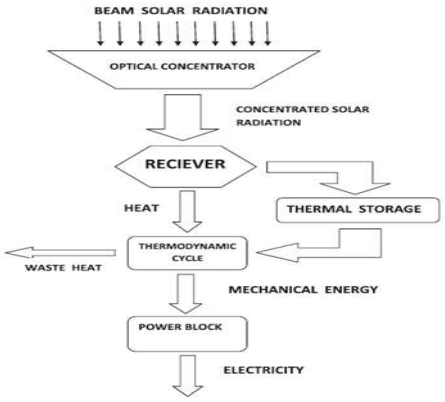

Figure1. Schematic diagram of CSP for parabolic trough Collector [27].

The sun rays strike the mirror, and in turn are reflected by the mirror on a black coated metallic tube (absorber) which heat sup and thus heat is transferred. The absorber is located just above the mirror. The reflector is used to track and follow the sun in the daylight via single axis. The heat exchanger pumps the heat transfer fluid which produces steam to rotate the turbine and generator [10]. The receiver tube reaches to a temperature of about 400 °C. Across the solar field, a number of parallel rows of troughs are situated. Egypt was the first country to develop a parabolic trough collector type concentrated solar power plant of 500 kW capacity in the year 1912. Since then, there have been various advancements, and the PTC system dominates about 90% of the global CSP market [9].

TABLE I .ENERGY DEMAND PROJECTIONS IN INDIA [20]

S. No	Source	Unit	1991-1992	2009-2010	2020-2021
1	Electricity	TWh	231	725	1300
2	Coal	Mt.	229	690	1345
3	Petroleum Products	Mt.	57	165	335
4	Natural Gas	bcm	18.6	65	130

TABLE II. ELECTRICITY FROM CSP PLANTS AS SHARES OF TOTAL ELECTRICITY CONSUMPTION [19]

Countries	Share%			
	2020	2030	2040	2050
Australia, Central Asia, Chile, India (Gujarat, Rajasthan), Mexico, Middle East, North Africa, Peru, South Africa, United States (Southwest)	5	12	30	40
United States (remainder)	3	6	15	20
Europe (mostly from imports), Turkey	3	6	10	15
Africa (remainder), Argentina, Brazil, India (remainder)	1	5	8	15
Indonesia (from imports)	0.5	1.5	3	7
China, Russia (from imports)	0.5	1.5	3	4

B. Parabolic dish system:

A Parabolic dish system is based on point focus and follows two axes. The receiver is located on the focal point. The heat transfer fluid is heated to a temperature of 750 °C. The receiver is connected to the generator and turbine, which converts heat to electricity. The capacity of parabolic dish system plants ranges from 0.01 to 0.4 MW. Since they work with point focus, i.e., the mirror is always pointed towards the sun, dish systems are more efficient than trough systems. Thermal efficiency ranges from 25% to 30%. The maximum temperature achieved by dish system is 1500 °C [10].

The merits of the dish system are:

1. They are the most effective collector systems as they are based on point focus.

2. Their concentration ratio ranges from 600 to 2000 and the absorption of thermal energy is highly effective.

3. They consist of modular collector and receiver system, hence are able to function independently without the help of any system [11].

TABLE III. DESCRIPTION OF CSP SYSTEMS [8].

Technology	Temperature (^{o}C)	Hybrid operation	Cost ($/kW)	Efficiency (%)
Parabolic Trough	400	Possible	4156	10-15
Solar Towel	1000	Possible	4500	14-17
Parabolic Dish	750	Under developing phase	6000	18-25

Linear Fresnel	270	Possible	22000	09-15

C. Solar power tower:

Central receiver based solar collector or heliostat field collector are commonly called solar power tower. They function as point focus. The rays of the sun strike on the heliostat and move back to the central receiver located in the center of the system. Therefore, it taps all the rays reflected by the heliostat mirrors. Somewhat concave mirrors are used in the system in order to maximize energy directed to the steam generator for the production of steam at high temperature and pressure [12].

The solar power tower system has following advantages:

1. Thermal-energy transportation is minimized as the radiation is collected optically by the system and is sent to a single receiver.

2. The ratio of concentration ratio ranges from 300 to 1500 for solar power collection and its conversion to electricity.

3. Thermal energy can be stored for some time.

4. Huge amount of energy (around 10 MW) can be generated.

D. Linear Fresnel reflector

Linear Fresnel reflector (LFR), like parabolic trough, is a two dimensional concentrating system, and works on a single axis mirror. The solar receiver is located on the focal line tracking mirrors. Ratio of concentration ratio ranges from 30 to 80. It operates at about 500 °C. The capacity of the plant ranges from 30 to 700 MW [14]. LFR consists of different array of mirrors, similar to that of Fresnel lens used for penetration of light into the receiver located on a tower. Linear Fresnel reflectors are pieces of parabolic trough with modification which improves their efficiency and results in capital cost reduction. Their thermal efficiency ranges from 8% to 12%. Increase in tower height results in optimization of area of land used and minimization of shadow, but increases cost. Hence, an alternative is used, called compact linear Fresnel reflector (CLFR). It consist of two receivers along with interleavingmirrors. This modification helps in the utilization of maximum land area [15].

III. GLOBAL PROSPECTS OF CSP TECHNOLOGY

In recent times, we are facing global climate change and the rate of consumption of crude oil consumption is on an ever high. Around 40% of earth's energy is obtained from crude oil. Fossil fuels are the main reason of global warming, and are responsible for about 40% of global warming [16]. CSP is a new implement in non-conventional energy systems which is seen as a major technology in generation of electricity in near future. The system is ecofriendly, clean, and relevant. CSP is a better system for electricity generation in comparison to solar photovoltaic

(PV) [17]. Compared to photovoltaic, CSP system does not produce electrical energy with the help of diffuse solar radiation. It employs solar beam radiation only. Size of the plants ranges from kW to MW [18].

Some countries do not lie in the zone of high solar radiation. In many tropical areas, fog reduces the yearly generation of CSP plants drastically [19]. Because of this problem it is very difficult for the countries located near the equatorial area to construct and exploit CSP plants. In contrast to this, tropical countries still have enough solar resources to harness CSP technology. Almost all countries barring Russia, South Korea, Canada and Japan have significant regions for CSP as shown in Table II.

IV. CSP SCENARIO IN INDIA

The renewable sources of energy are of utmost importance to India to boost our economy situation and make India an energy secure country. Energy demand in past and projection of demand in future is shown in Table I [20]. It is predicted that by the year 2032, India's primary energy requirement will be 3 to 4 times the current requirement. Hence, it is need of the hour to rapidly shift towards renewable energy. Solar radiation is available in adequate amount in Rajasthan, Maharashtra, Andhra Pradesh, Ladakh, Gujrat, and Madhya Pradesh. They receive maximum amount of average annual solar radiation as compared to other states [20]. India is gifted with sun light assets. Solar radiation strength in India is 200 MW/km2 and it experiences close to three hundred clear bright days annually. CSP is presently under development stage in India [11]. Though still in developing phase, many plants have been installed already and functioning properly. A summary of these plants is shown in Table IV.

V. CONCENTRATED SOLAR POWER PROSPECTS IN INDIA

CSP converts solar energy into electricity on a large scale and requires huge capital investment. But CSP is capable of producing economical electrical energy and drastically minimize carbon emissions. CSP plants are perfect for the regions which receive direct sun light and the number of days with clear skies are more [21]. The establishment of Jawaharlal Nehru National Solar Mission (JNNSM) by Ministry of New and Renewable Energy (MNRE), Government of India was the first step towards the development of solar energy in India. JNNSM has set a target to achieve 22,000 MW by solar energy by the end of year 2022, in which 20,000 MW is to be generated by grid connected solar systems and the remaining 2000 MW is to be generated by off grid systems [22]. The complete process is subdivided into three parts, which is summarized in the Table V [22]. In India, CSP faces some challenges, classified in three categories, viz.: technical threats, marketing threats, and environmental threats [23]. Technical threats include lack of relevant DNI data, etc. resulting in inability to accurately estimate the quality and future relevance of CSP plants. Various studies show that the minimum DNI needed for CSP is 5 kWh/m2/day. The marketing threats include high capital and operating cost. When compared to PV system, expenditure of PV system installation is around 5.87 crore per MW, and CSP is 12 crores per MW [24]. The environmental threats include availability of water in required amounts for cleaning of mirror and steam generation. CSP plants are equipped with cooling towers for compression of water as in thermal power plant. International energy agency has shown that parabolic trough and linear Fresnel system need water around 3 m3/MWh of electrical energy production [25].

TABLE IV .COMPARATIVE ANALYSIS OF THE CSP PROJECT IN INDIA [26].

Parameters	Abhijeet Solar Project	ACME Solar Tower	Dadri ISCC Plant	Dhursar	Diwakar	Godawari Solar Project	Gujrat Solar One	KVK Energy Solar Project	Megha Solar plant	National Solar Thermal Power Facility
Technology	Parabolic trough	Power tower	Linear Fresnel reflector	Linear Fresnel reflector	Parabolic trough	Parabolic trough	Parabolic trough	Parabolic trough	Parabolic trough	Parabolic trough
Status	Under construction	Operational	Under construction	Operational	Under construction	Operational	Under construction	Under construction	Operational	Operational
City	Phalodi	Bikaner	Dadri	Dhursar	Askandra	Nokh	Kutch	Askandra	Anantapur	Gurgaon
Region	Rajasthan	Rajasthan	Uttar Pradesh	Rajasthan	Rajasthan	Rajasthan	Gujarat	Rajasthan	Andhra Pradesh	Haryana
Lat/Long Location	26°49′ 40.0″ North, 70°55′11.0″ East	28°11′ 2.0″ North, 73°14′ 26.0″ East	28.5462°N, 77.5562°E	26°47′ 8.5″ North, 72°0′ 30.0″ East	27°21′ 53.0″ North, 71°43′ 53.0″ East	27°36′ 5.0″ North, 72°13′ 26.0″ East	23°34′ 45.0″ North, 70°39′ 0.0″ East	27°21′ 53.0″ North, 71°43′ 53.0″ East	16°59′ 19.0″ North, 80°8′ 36.0″ East	28°25′ 39.0″ North, 77°9′ 33.0″ East
Owner(s)	Corporate Ispat Alloys Ltd. (100%)	ACME Group (100%)	NTCP	Reliance Power (100%)	Lanco Infratech (100%)	Godawari Green Energy Limited (100%)	Cargo Solar Power (100%)	KVK Energy Ventures Ltd (100%)	Megha Engineering and Infrastructure (100%)	IIT Bombay
Turbine Capacity	Net: 50.0 MW Gross: 50.0 MW	Net: 2.5 MW Gross: 2.5 MW	14 MW	MW Gross: 125.0 MW	Gross: 100.0 MW	Gross: 50.0 MW	Gross: 28.0 MW	Gross: 100.0 MW	Gross: 50.0 MW	Gross: 1.0 MW
Thermal storage	None	None	None	None	Yes	No	Yes	Yes	None	None

TABLE V.THREE PHASES OF JNNSM [22].

Application segment	Target for phase-1 (2010-13) (MW)	Target for phase-2 (2013-17) (MW)	Target for phase-3 (2017–2022) (MW)
Utility grid power, including roof top	1000–2000	4000–10000	20,000
Off-grid solar application	200	1000	2000

VI. CONCLUSION

India has seen fast advances in CSP. In India CSP has a capacity to produce about 1000 GW. A number of CSP plants are already working. But most of the plants are confined to Gujrat Rajasthan, and Andhra Pradesh. Presently, the total CSP plant capacity installed in Rajasthan is about 475 MW. The Government of India is promoting CSP and other solar applications and has setup Jawaharlal Nehru National Solar Mission under Ministry of New and Renewable Energy Indian to that effect. The Government of India formulates new policies and revises existing policies on a regular basis to promote CSP. Therefore, CSP has the potential to help solve the power requirements of India and make India energy secure.

REFERENCES

[1] Prakash O, Kumar A, Sharaf-Eldeen YI Review on Indian solar drying status n.d.doi:http://dx.doi.org/10.1007/s40518-016-0058-9.

[2] Izquierdo S, Montañs C, Dopazo C, Fueyo N. Analysis of CSP plants for the definition of energy policies: the influence on electricity cost of solar multiples, capacity factors and energy storage. Energy Policy 2010;38. http://dx.doi.org/10.1016/j.enpol.2010.06.009.

[3] Mancini T, Heller P, Butler B, Osborn B, Schiel W, Goldberg WGAssociates V, et al. Dishstirling systems: an overview of development and status n.d.doi:10.1115/1.1562634.

[4] Minister P, Modi N, Minister P, Modi N, Alliance IS, Isa T, et al. Sol Power India 2017:1–21.

[5] Buck R, Bräuning T, Denk T, Pfänder M, Schwarzbözl P, Tellez F. Solar-Hybrid Gas Turbine-based Power Tower Systems (REFOS). J Sol Energy Eng 2002;124:2. http://dx.doi.org/10.1115/1.1445444.

[6] Romero M, Buck R, Pacheco JE An update on solar central receiver systems, projects, and technologies n.d.doi:10.1115/1.1467921.

[7] Aruna Kumarankandath NG. The State of concentrated solar power in India. Cent Sci Environ; 2015.

[8] Brenna M, Foiadelli F, Roscia M, Zaninelli D Evaluation of solar collector plant to contribute climate change mitigation. In: Proceedings of the IEEE international conference sustainable energy technology, ICSET; 2008. doi:http://dx.doi.org/10.1109/ICSET.2008.4747001.

[9] Khan J, Arsalan MH. Solar power technologies for sustainable electricity generation – a review. Renew Sustain Energy Rev 2016. http://dx.doi.org/10.1016/j.rser.2015.10.135.

[10] Mills D. Advances in solar thermal electricity technology. Sol Energy 2004. http://dx.doi.org/10.1016/S0038-092X(03)00102-6.

[11] Siva Reddy V, Kaushik SC, Tyagi SK. Year round performance and economic evaluation of solar power plant for Indian tropical condition. J Renew Sustain Energy 2012. http://dx.doi.org/10.1063/1.4733568.

[12] Kaushika ND, Reddy KS. Performance of a low cost solar paraboloidal dish steam generating system. Energy Convers Manag 2000;41. http://dx.doi.org/10.1016/S0196-8904(99)00133-8.

[13] Petrescu S, Petre C, Costea M, Malancioiu O, Boriaru N, Dobrovicescu A, et al. A methodology of computation, design and optimization of solar Stirling power plant using hydrogen/oxygen fuel cells. Energy 2010;35. http://dx.doi.org/10.1016/j.energy.2009.10.036.

[14] Gupta PK. Renewable energy sources-a longway to go in India. Renew Energy 1999;16. http://dx.doi.org/10.1016/S0960-1481(98)00486-8.

[15] Kongtragool B, Wongwises S. A review of solar-powered stirling engines and low temperature differential Stirling engines. Renew Sustain Energy Rev 2003;7. http://dx.doi.org/10.1016/S1364-0321(02)00053-9.

[16] Trieb F, Schillings C, Sullivan MO', Pregger T, Hoyer-Klick C. Global potential of concentrating solar power n.d.

[17] AdminDK. B2498123213. International J Eng Adv Technol n.d.

[18] Liu Q, Yu G, Liu JJ. Solar radiation as large-scale resource for Energy-short World. Energy Environ 2009;20. http://dx.doi.org/10.1260/095830509788066466.

[19] Majeed Muzathik A, Mohd Norsani Wan Nik W, Samo K, Zamri Ibrahim M. Hourly Global solar radiation estimates on a horizontal plane. J Phys Sci 2010;21:51–66.

[20] Ramachandra TV, Kamakshi G, Shruthi BV. Bioresource status in Karnataka. Renew Sustain Energy Rev 2004. http://dx.doi.org/10.1016/j.rser.2003.09.001.

[21] Ramanathan R, Ganesh LS. Energy resource allocation incorporating qualitative and quantitative criteria: an integrated model using goal programming and AHP. Socioecon Plan Sci 1995;29:197–218. http://dx.doi.org/10.1016/00380121(95)00013-C.

[22] Bhattacharyya SC. An overview of problems and prospects for the Indian power sector. Energy 1994;19:795–803. http://dx.doi.org/10.1016/0360-5442(94)90018-3.

[23] Saaty TL. Decision making with the analytic hierarchy process. Int J Serv Sci 2008;1:83–98.

[24] Nelson DT, Evans DL, Bansal RK. Linear Fresnel lens concentrators. Sol Energy 1975;17.http://dx.doi.org/10.1016/0038-092X(75)90045-6.

[25] Wallenius J, Dyer JS, Fishburn PC, Steuer RE, Zionts S, Deb K. Multiple criteria decision ,making, multiattribute utility theory: recent accomplishments and what lies ahead. Manag Sci 2008;54. http://dx.doi.org/10.1287/mnsc.1070.0838.

[26] NREL . Database 2014:1–2.

[27] Brenna M, Foiadelli F, Roscia M, Zaninelli D. Ieee evaluation of solar collector plant to contribute climate change mitigation; 2008. doi:10.1109/icset.2008.4747001.