Status of Concentrated Solar Power in India

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Abstract - *Fossil fuel consumption emits harmful gases in the atmosphere. Toxic gases impact the environment negatively. The world is in a dire situation to inhibit the use of fossil fuels by substituting it with clean renewable energy. India's solar energy potential is unparalleled. Solar energy can be harnessed by SPV (Solar photovoltaic) and CSP (Concentrated solar power). However, CSP has many perks over SPV, including higher efficiency and feasibility to dispatch stored energy. This paper aims to investigate the status of CSP in India. Our results indicate that CSP had an unsuccessful run in the last two decades. The barriers which constrained growth of CSP are identified. It is concluded that the lack of auxiliary support structure for successful deployment of CSP is responsible for slower growth. This includes no reliable data, reverse auction policy, no indigenous manufacturing. The assessment of the regime's action to combat these challenges is done. The study concludes that indigenous manufacturing, research, and development activities must be promoted to increase the share of CSP in the country's overall energy security.*

***Key Words*: Concentrated solar power, Status, Challenges, Progress of concentrated solar power, Potential of CSP, Barriers to CSP, Solar thermal**

1. INTRODUCTION

Energy is the backbone of economy. India is one of the leading developing countries. With growing GDP (Gross domestic product), energy consumption is also increasing. India's energy consumption was 32450 PJ (Peta joules) in 2018-19, which means per capita energy consumption increased to 19669 MJ (Mega joules) in 2018-19, showing an increase of 3.67% over 2017-18. Out of this, coal accounted for 48%, natural gas, and crude oil when combined contributed a share of 40%. Renewable energy sources, including hydro, nuclear stood least with 12% portion only [1]. This shows that fossil fuels dominate energy mix. This is leading to the depletion of fossil fuels and heavy reliance on importing the same. Also, use of fossil fuels puts the environment at risk. Global warming, smog, air pollution are all results of burning fossil fuels. It is estimated that global temperature rise above the preindustrial level must be limited below 20C. To combat this, India, along with 190 nations, signed Paris climate accord in 2015. This lead to an increasing interest in harnessing renewable energy [2].

Sun has been the origin of all forms of energy, including fossil fuel. Earth receives about 885 million TWh energy from sun per annum. This is in several multiples of world's energy consumption. Solar energy falling on earth's surface is in the form of solar radiation. Solar radiation travels through space to reach earth's surface. Due to the atmosphere, 30% of radiations scatter away, and such radiations received on earth called diffused radiations [3]. A major part of radiations travel in a straight line to earth. These are beam radiations. A large number of solar radiations are reflected back to space or clouds called albedo phenomenon. The radiations received on earth are classified into three types as global horizontal irradiance (GHI), direct normal irradiance (DNI), diffused horizontal irradiance (DHI). As mentioned earlier, DNI is a direct portion of solar radiation that strikes the earth's surface at the right angle. DHI represents scattered irradiance. GHI compromises both DNI and DHI.

Solar energy is harnessed by either using solar photovoltaic (SPV) cells or solar thermal collectors. SPV cells convert solar energy directly into electricity. Collectors utilize solar rays' heat energy, which can be used as process heat or as an input for thermal power plants. SPV cell industry is currently dominated by silicon and thin-film solar cells. The efficiency of such panels is 17% to 21% [4]. However, SPV technology has shown the highest learning curve among all renewable energy technologies. Third and fourth-generation cells like tandem and perovskite cells have shown 35% - 47% efficiency. Nevertheless, reliability of these cells is questionable; since these cells degrade within 2-3 years [5]. Due to this, first and second-generation cells are the only viable option for SPV industry currently. On the contrary, CSP is a mature technology and an old player in the solar industry. Efficiency of CSP varies from 7% to 21% [6]. The winning point for CSP is to facilitate dispatchable power. During low power demand, energy from CSP can be stored and utilized during peak hours. This improves reliability of technology by reducing intermittency of solar radiation. The ability of CSP to suppress grid shocks in peak hours is strength against SPV [7]. This makes CSP an attractive technology in the investment aspect. The minimum DNI above which CSP plants become operational is 200 W/m2 [8]. The average DNI in India is approximately 4.4 KWh/m2/day. This shows 13780 TWh of energy per day. This translates into 633000 TWh of thermal energy generation annually [9]. This depicts that India has a high potential for the development of CSP. Provided the above facts, CSP can play a vital role in India's mission of sustainable development. Hence the focus of paper lies in assessing the current status of CSP in India. The study also identifies possible challenges in the wide-scale implementation of CSP and recommendations to triumph those challenges.

2. CONCENTRATED SOLAR POWER

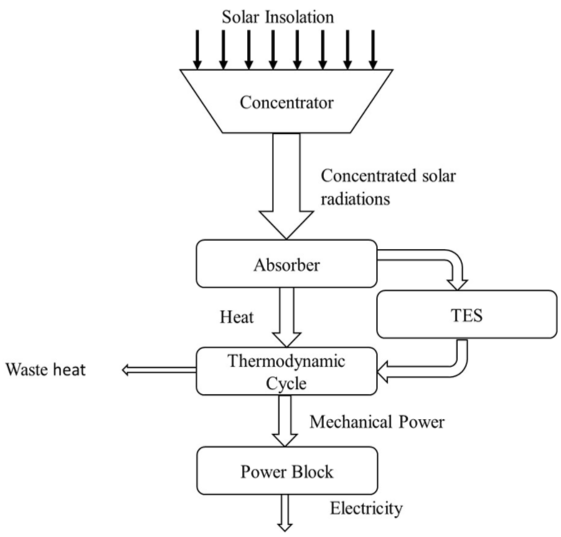

Fig -1: Working of CSP plant

As aforementioned, CSP technology uses heat energy of solar radiations. The working of the CSP plant is illustrated in Fig 1. Solar energy is optically concentrated either by reflector or refraction with the aid of concentrators. The reflected or refracted light is beamed on a minimal absorber area, thus increasing the energy flux in the receiving area [10]. Due to which fluid flowing in absorber gets heated. During off-peak hours high-temperature fluid goes to the thermal energy storage (TES) unit. Further, it is supplied to the thermodynamic cycle. It is worth pointing out that in peak hours; the whole flow of working fluid is directed to the thermodynamic cycle only. In thermodynamic cycle, heat energy is converted to mechanical power by the multistage turbine system. The mechanical power drives generator to produce electricity. Some amount of energy is lost to the environment. Power block does the function of the integration of electricity into the consumer's grid system. CSP plants can be classified based on the type of collector used. They are explained below.

2.1 Parabolic trough collector (PTC)

PTC is a line focusing single-axis tracking collector. Temperature between 50-4000 0C can be achieved with PTC. A sheet of reflective material is bent into a parabolic shape to form PTC. A black metal tube covered with an anti-reflective coating is placed at the focal line of the receiver. PTC is the most mature technology among all solar thermal technologies [10].

2.2 Linear fresnel reflector (LFR)

It is a line focusing multi-axis tracking collector. LFR is capable of reaching temperatures up to 500oC. It is manufactured as an array of linear mirror strips that concentrate light onto a linear receiver. LFR is the cheapest collector since it uses flat strips rather than elastically curved strips as in PTC [11].

2.3 Parabolic dish reflector (PDR)

It is a point focusing, multi-axis tracking device. PDR is composed of a large number of mirrors arranged on a dish like structure. PDR can achieve concentration ratio from 600-2000 and can deliver temperature greater than 1500 0C. This is the most efficient collector in optical as well as thermal aspects. The receiver is present at the focal point of collector on which solar radiations are concentrated. Most commonly, PDR is used for electricity generation from the Stirling engine. This is cutting edge technology in the solar industry, and more research is needed to test the viability of this approach.

2.4 Heliostat field collector (HFC)

As the name suggests, HFC performs as a collective action of several reflectors arranged in the field to focus on a single receiver. The receiver is made up of a tower-like structure. A large amount of heat energy is generated at the receiver tower from where it is supplied to the power cycle. These systems can achieve concentration ratios in the 300-1500 range. The system facilitates TES, which reduces the cost of power plant. However, this system is suitable for large applications only.

3. STATUS OF CSP

According to a report published by Ministry of new and renewable energy (MNRE) and Ministry of statistics and program implementation (MOSPI), total installed grid-connected renewable power in India has reached 78316.44 MW. Out of which installed generation capacity of renewable energy, solar energy accounts for 36% producing 28.18 GW [1]. At the end of 2019, CSP installation has reached 6421 MW worldwide. Spain leads the way with 2300 MW, whereas U.S stood second with a 27% share. It is worth mentioning that India holds a small share of only 2% [12]. To upscale solar-based energy, India launched Jawaharlal Nehru National Solar Mission (JNNSM) on January 11, 2010. Initially, the national solar mission (NSM) aimed at 20000 MW grid-connected solar capacity by 2022. The mission has been divided into 3 phases. Detailed information is given in Table 1. In its first phase, CSP and SPV shared equal share of 500 MW each. At the end of 2014, 470 MW CSP capacity was commissioned, but the phase I conceived only 200 MW. Due to CSP's poor performance in JNNSM phase-I, MNRE reduced CSP's share to 30% in phase-II. However, when MNRE announced phase-II guidelines, it became clear that the second phase will only compromise SPV. In 2014 MNRE announced an off-grid decentralized solar thermal application scheme to promote off-grid solar thermal applications [13].

Application segment	Target for phase-I (2010-2013)	Target for phase-II (2013-2017)	Target for phase-III (2017-2022)
Solar collectors	7 million m^2	15 million m^2	20 million m^2
Utility grid power including solar roof top	1000-2000 MW	4000-10000 MW	20000 MW
Off-grid solar applications	200 MW	1000 MW	2000 MW

Table-1 Details of JNNSM

In the budget presentation of the financial year (FY) 2015-16 government set an ambitious target of 100 GW of solar energy installation to be achieved by 2022. Howbeit 40 GW were allocated to SPV alone. Besides, there is no information on whether the remaining 60 GW will be SPV or CSP. This turned down all hopes of the CSP industry to uphold its venture in India's energy market. In February 2018, MNRE announced the expansion of the off-grid decentralized solar thermal application scheme with a new target to add 90000 m^2 collector area by 2019-20. As a result, India's currently installed capacity of CSP remains at 262.5 MW only. Indeed there are 300 MW of CSP projects under construction, and 28524 m^2 area equivalent to 19 MW has been sanctioned [14]. Table 2 provides details of CSP projects [15][11].These statistics deduce that CSP had bad run in the country. The difficulties which hampered the growth of CSP are discussed below.

4. CHALLENGES AND RECOMMENDATIONS

The earlier discussion has high lightened India's massive potential for CSP implication. This implies that CSP makes sense for India. However, status of CSP is in doldrums owed to lack of long term vision. The following section covers challenges faced by India's CSP market and recommendations to overcome the same.

4.1 No reliable DNI data

DNI data plays vital input in project planning. During the first phase of JNNSM, MNRE was unable to provide accurate DNI data to project developers. Consequently, project developers had to rely on satellite modeling data provided by NASA. However, ground measurement DNI at the time of project execution was 10% - 15% less than estimated. For instance, ACME solar who demonstrated first project after JNNSM phase-I realized that India's DNI is lower than estimated by NASA. Hence this impacted the financial viability of project. Godawari green project faced a similar situation. The developer had to increase the number of reflector loops by 40 [16]. This added financial burden on the developer. According to the World Bank report unavailability of solar radiation data is the second most crucial barrier [17]. Therefore to solve the problem, National Institute of Wind Energy (NIWE) with support from MNRE, established 111 Solar Radiation Resource Assessment (SRRA) stations throughout the country. Moreover, four Advanced Measurement Stations (AMS) have been set up in the country. NIWE has released solar atlas of India, manifesting solar resources and annual production from

Project name	Capacity	Technology	Owner	Status
Dhusar	125	Fresenel reflector	Reliance Power	Operational
Godawari solar project	50	Parabolic trough	Godawari Green Energy Ltd.	Operational
Megha solar plant	50	Parabolic trough	Megha Engineering and Infrastructure	Operational
ACME solar tower	2.5	Solar tower	ACME solar Group	Operational
National solar thermal power facility	1	Parabolic trough	IIT Bombay	Operational
Diwakar	100	Parabolic trough	Lanco Infratech	Under construction
KVK energy solar project	100	Parabolic trough	KVK Energy Ventures Ltd.	Under construction
Abhijit solar project	50	Parabolic trough	Corporate Ispat Alloys Ltd	Under construction
Gujarat solar one	25	Parabolic trough	Cargo Solar Power	Under construction
Dadri ISCC plant	14	Fresenel reflector	NTPC	Under construction
Rajasthan solar one	10	Parabolic trough	World renewal spiritual trust	Under construction

Table-2 Status of CSP

solar plant at that location [18]. Many stakeholders have acknowledged this effort from MNRE.

4.2 Low investor confidence

Void in investor's confidence is a significant cause for slow CSP growth. This could be owed to a few demonstrations of projects based on CSP. It is worth considering that India did not have any plant which tested the techno-economic feasibility of CSP at the time of JNNSM phase-I bidding [16]. This translates that there had not been enough Research and Development (R&D) on CSP when bidding came out. Indeed Indian companies did not have any prior experience dealing with CSP [19]. This resulted in a significant loss for Godawari green power and ACME solar, the early birds in market. This set shockwave among investors debilitating their confidence. Although there are five operational projects currently, it is too early to conclude on the sustainability of these projects. Investors play an important role in commercializing any technology. Hence rebuilding the confidence of investors is crucial for successful penetration of CSP in the country. Taking this into account, MNRE is focusing on R&D in CSP sector. IIT Bombay has set PTC CSP plant of 1 MW for research purpose. Moreover, IIT Jodhpur is setting up three projects each of 5 MW for testing viability of LFR, solar tower and beam down CSP technology. These are positive moves in developing successful demonstration [16].

4.3 Concerns about policy

The World Bank gave 63% weightage to policy and regulatory aspects as a barrier for CSP growth [17]. MNRE employed reverse auction policy for project allocation. The reverse auction helped to bring down cost of CSP at such a low level that India became the country with the cheapest CSP tariff worldwide. The average tariff from bidders was 36.49% lower than the previous Fit in tariff (FIT) [20]. Low bids can be attributed to unawareness about upcoming challenges and inexperience of developers. This resulted in difficulties in sourcing technologies financially and project delays. This shows that India won to keep the cost low to the public but failed to ensure certainty and speed of deployment. The aggressive reverse auction brought forth winning bids but not viable for sustainable operation [21]. Therefore serious modification is needed in the policy framework. It is suggested to have stricter qualification for bidders in both financial and technical aspects, enforcing penalties more strictly for delayed projects [22].

Besides, there is an increasing interest of the Indian government in SPV application where CSP is getting completely ignored. This needs to be addressed immediately and forcefully for the bright future of CSP in India.

4.4 No local manufacturing

Lack of indigenous manufacturing facilities for critical components like receiver tubes, mirrors, tracking devices is a major barrier for the growth of CSP. All projects commissioned in JNNSM phase-I relied on the import of these components. Continuously raising import duties posed a severe threat to the completion of the projects. Hence there is a high demand for indigenization of CSP components to ease supply chain strain. A study conducted by Energy sector management assistant program (ESMAP) reported high savings resulting from local manufacturing through lower custom duties for equipment, raw and processed material, and lower cost of logistics and labor power. Possible cost reduction potential is projected to be 15%-20%. Also, there is a socio-economic benefit of job creation [23]. Even in the most pessimistic scenario, 19000 jobs will be added due to local manufacturing. To stimulate local manufacturing, low-cost financing bank, fiscal incentives, are expected. It is recommended to plot sponsored research projects in educational institutions, conduct CSP workshops, and international collaboration [24].

4.5 Competition from SPV

It is well known that the learning curve of SPV is much faster than CSP. SPV is cheaper than CSP in the capital, operation, and maintenance costs as well. Investors are familiar with financial risks associated with SPV. SPV has a lower gestation period than CSP. This creates an additional impediment in development of CSP. The only solution is making CSP cost-competitive with SPV. This can be enabled by the hybridization of CSP-Coal plants [25]. Hybridization improves capital efficiency. Consequently, 30%-40% cost reductions are possible in the cost of CSP plant. This can help CSP to gain momentum in the country.

4.6 No skilled workforce

Skilled workforce is fundamental to any industry. It is noticed that the lack of knowledge about handling components caused delays in the completion of projects. For example, Jyoti structures took a contract for the fabrication of mounting structure of Godawari green project. However, company took more time than anticipated to complete project [16]. Such delays are always uninvited and owed to the absence of in-house skills. Unfortunately, there has not been any activity in this direction. It is advised to commence masters programs as well as short-term courses with specific agenda for CSP awareness.

4.7 Environmental constraint

This includes water and land scarcity. Water is crucial for solar thermal power plants. According to Central Electricity Agency (CEA), CSP consumes 2-3 m3/MWh water. However, the ground reality is that all CSP plants in India consumed

19.9 m3/MWh approximately [26]. It is essential to mention that states with high DNI are exposed to a high level of water scarcity. Water procurement responsibility is always outsourced to external vendors. This compounds capital cost. Under such circumstances, it is recommended to use dry cooling and anti-soiling coating for modules at the expense of lower efficiency and increased capital, respectively [26].

5. Conclusions

This paper presents a detailed overview on the progress of CSP in India. The key findings are as follows,

- India is endowed with huge potential for CSP. CSP can fulfill India's growing energy demand.
- However, India constitutes a very small percentage of the installed capacity of CSP. This is due to several barriers like unreliable DNI data, high competition with SPV, and policy issues.
- Low confidence of investors on CSP technology resulted in a major setback for development of CSP in the country. Reverse auction policy is successful for the deployment of projects but failing to ensure implementation of projects.
- India has shifted its focus to SPV, and no attention is being paid to CSP. This has put nearly a full stop to the CSP market. Therefore drastic changes in policy framework are needed. Policies with a specific agenda for CSP are suggested.
- Indeed, indigenous manufacturing is growing throughout the country. It can provide the necessary experience to local CSP developers and make CSP cost-competitive.
- Hybridization with existing coal plants, low-cost finance, e-loans, and reliable DNI data, if provided, can ensure successful penetration of CSP through the country.
- In the end, it can be concluded that, despite several barriers CSP has a bright future in India. The total installed capacity of CSP is forecasted to reach 1.3 GW by 2024.

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