ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12 Issue 09 September 2025

Concentrated Solar Power Technologies: A Comprehensive Review

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Abstract*— Concentrated Solar Power (CSP) systems are seen as dependable substitutes for large-scale renewable energy production, particularly in areas like western India that have a high content of Direct Normal Irradiance (DNI). This study reviews the technological maturity, efficiency characteristics, and operating principles of the four most important CSP technologies: Parabolic Trough Collectors, Linear Fresnel Reflectors, Solar Tower (ST) Systems, & Parabolic Dish (PD) systems. As of today, LFR and PTC technologies rule over CSP capacity in India owing to their maturity in commercialization, moderate cost, and robust operational experience; ST and PD technologies provide relatively high operating temperature and efficiency, thus potentially well-suited for niche and modular applications. The study is based on the operational experience of large-scale projects in India's Andhra Pradesh, Gujarat, and Rajasthan. CSP offers the possibility of generating electricity and high value high-pressure industrial steam (131 bar, 521 °C) from solar energy with no direct carbon emissions, utilization of non-arable land and potential for hybridization. The biggest stumbling blocks are expensive upfront costs, large amounts of water used in arid areas and policy uncertainty. The schematic flowchart to represent the sequence of operation for a CSP plant. Thermal storage, precise tracking, and receiver design improvements are recognized as methods to enhance CSP's functionality & performance in the Indian renewable energy grid.

***Index Terms*— Concentrated Solar Power Systems, Clean Energy, Renewable Energy, Technologies**

I. INTRODUCTION

The high demand for cost efficient and land-intensity solar thermal technologies has focused the attention (both worldwide and at regional levels) on the Linear Fresnel Reflector (LFR) systems, in particular in sun-rich countries like India. LFR technology is known for its small footprint, simplicity of design, and lesser installation cost as in other CSP systems parabolic troughs and solar tower. In the Indian scenario, Bijarniya et al. (2016) stressed the techno-economic viability of the LFR plants via a review of the operation of 125MW Reliance Dhursar Plant in Rajasthan India - the largest commercial LFR installation in the previous context. The study emphasized benefits in modular installation, single-axis tracking with low complexity, and possibilities for direct steam generation in high DNI regions [1]. Purohit and Purohit (2017) also performed a spatial solar resource assessment and found a number of Indian districts suitable for LFR deployment based on the DNI threshold and land availability, indicating the possibility of a technical potential well beyond 200GW, if policy mechanisms would be in place to drive deployment [2].

Recent advanced technological developments have concentrated in optical enhancement and inclusion of thermal energy storage. The efficacy of CLFR systems was examined by Kumar et al. (2017), who suggested that twin receivers could further enhance thermal energy collection and have potential for hybrid CSP applications in off-grid rural electrification and industrial process heat [3]. In addition, pilot-scale studies by MNIT Bhopal indicate that CLFR-type direct steam technology could operate with a thermal efficiency of up to 12% under Indian climatic conditions further underlining their suitability for decentralized solar thermal application [4].

One of the most efficient technologies in CSP applications is the PTC technology, that's widely used in India. It accomplishes this by utilising parabolic mirrors to focus sunlight onto a receiver tube, producing enough heat to power steam cycles and produce electricity. The majority of CSP units constructed as part of Jawaharlal Nehru National Solar Mission Phase I, including the 50 MW Godawari and Megha Engineering projects, were based on PTC, according to Prakash and Kumar. These projects qualified as "moderately successful" in terms of thermal storage and grid integration, demonstrating that PTC has potential to the Indian energy portfolio [5]. Dabhi et al. (2020) investigated the performance aspects and economic analyses related to a 1 MW PTC test plant in Gujarat (India) focusing on the customized design of the receiver, next generation HTF and ambient conditions (temperature and wind speed) on optical efficiency [6]. Nayak and Sharma et al. Optimization in an Arid Region of Western India', they offered hybrid configurations with biomass or gas heating and 2-tank molten salt storage to raise year-around performance and decrease LCOE [7]. Patel and Patel (2021) performed TRNSYS and MATLAB simulations and found high agreement with the real DNI data, while emphasizing the importance of accurate solar tracking for constant performance in India climates [8].

The growing worldwide demand for dispatchable and utility-scale clean electricity sources has increased attention towards central receiver power plants, also called Solar Tower (ST) CSP plants. The possibility to run the system at high temperature and the integration with thermal storage systems make the plant favourable for high DNI region such as Western India. In contrast to linear concentrating systems, In order to reach temperatures above 550C, The solar tower technique gathers sunlight reflected from a field of heliostats and transmits it to central receiver at top of tower. which are ideal for high efficiency Rankine cycles. The 2.5 MW ACME solar tower at Bikaner, India is a significant step toward commercial d Learn more ACME tower Solar-powered steam generation at 550 C A field full test of the solar steam generator Mark Mehos, Yulong Mui, Scott Kuszmaul present solar tower technology use in India and suggests that this technology is technically feasible bake ACME solar tower in operation at Fall 2016 and that insights gained from the operation of the facility Located at Bikaner, the country first on commercial demonstration international experience in the operation of advanced tower systems have a high potential for success in India [9]. Alekhya et al. (2017) suggested a hybrid solar tower-wind power system for independent islands electrification and emphasized the operational availability provided by cachess technology [10]. Their study demonstrated the significance of hybrid desevilfn and energy storage integration in dealing with intermittency. Sudhakar and Bijarniyaet al. (2016) showed that while solar towers demand higher level of investments and control costs compared with parabolic troughs, their optical efficiency and potential for large scale deployment are also favours to invest more in Indian CSP R&D [11]. 5 MW solar tower at IIT Jodhpur has been approved by Ministry of New & Renewable Energy, or MNRE. in which indigenous capacity is promoted to solve heliostat design, storage dynamics, cost reduction under Indian operating conditions [12].

Parabolic Dish Solar Concentrator (PDSC) is one of the most efficient solar concentrating systems, which can provide the excellent thermal and optical performance attributes to its exact point – focus geometry. When combined with Stirling engines or thermal receivers, these designs are well suited for modular Concentrated Solar Power (CSP) applications in high DNI areas. Here, make a short review at key research advances in PDSC-based CSP systems. Lovegrove et al. (2011) constructed this 500m² dish at ANU with greater than 2000 concentration ratio, designed for manufacturability and commercial deployment [13]. Yan et al. (2017) developed a 38kW dish-Stirling system of 204m² aperture, reaching an efficiency of 26.6% with the establishment of a linear relationship between DNI and power output [14]. Pengand Cheng et al. (2018) elaborated the same system by the use of aluminum honeycomb mirrors, and used laser alignment to evaluate the stabilization of performance and the easiness of installation [15]. Rajan and Reddyet et al. (2024) created the optical-thermal model of ray tracing+CVD for the 40 m² parabolic dish collector and studied its performance by considering different operating conditions. A thermal efficiency Derivative was also predicted by a deep learning model [16].

Table 1. Evaluation of various CSP technologies in comparison [17] [18]

CSP Feature Parameters	Linear Fresnel Reflector (LR)	Parabolic Trough (PT)	Solar Tower (ST)	Sunlight Dish
Operating Temperature Range (°C)	150 to 400	150 to 400	400 to 1000	400 to 1200
Ratio of Solar Concentration	35 to 170	50 to 90	600 to 1000	1000 to 3000
method for tracking the sun	One Axis	One Axis	Two Axis	Two Axis
Cycle of power	Low Rankine of Steam	Low Rankine of Steam	Advanced Steam Rankine	Ultra-High Stirling Engine and Steam Rankine
Range of Power Capacity (MW)	5 to 250	10 to 300	10 to 200	0.025 to 1
Electricity Conversion Efficiency of Solar Energy (%)	8–12	10–16	10–22	16–29
Relative price	Low	Low	High	Very high
Advantages	Simple design and incurs relatively minimal installation expenses.	The most commercially adopted CSP technology with comparatively low installation costs.	It achieves superior efficiency owing to its high operating temperature.	High efficiency from elevated operating temperatures and maintains strong performance even at smaller scales.

Table 1 compares the major performance parameters for the four CSP technologies, showing the variation with respect to temperature range, concentration ratio, tracking system, efficiency, and cost. It demonstrates that although LFR and PTR are cheaper and most installed, Solar Tower and Solar Dish offer higher efficiencies for high temperature and Solar

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12 Issue 09 September 2025

dishes can match them even at small size.

II. THE CSP OF THE PARABOLIC TROUGH COLLECTOR

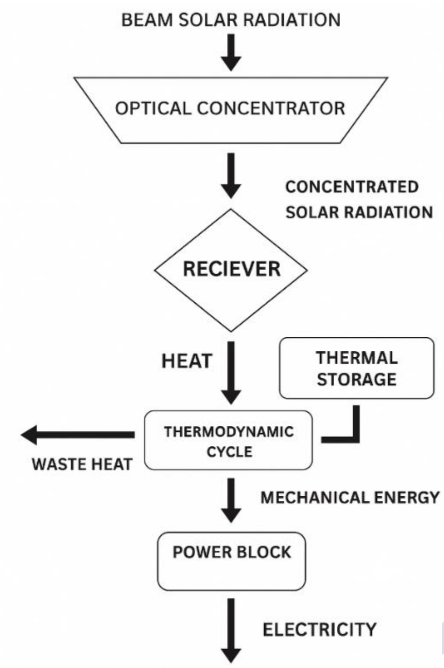

Fig.1: Schematic diagram of CSP [19]

III. CONCENTRATING SOLAR POWER (CSP) TECHNOLOGY

This is an example of a CSP plant that converts sunlight to electricity using a parabolic-trough collector. The sunlight is captured and reflected onto an optical concentrator that would refocus the radiation on a receiver for concentration. A receiver exposed to Heat Transfer Fluid (HTF) absorbs this high energy, enabling fluid heat storage. That heat can be added to a thermal storage system, such as molten salt tanks for use during no sunshine, or it can be used directly in the thermodynamic cycle. The HTF is used to heat a working fluid, typically steam, which powers turbine. Steam moving through the turbine, it enlarges (in volume), converting thermal energy to mechanical work and rejecting the remaining energy as waste. The power block converts the mechanical power into electricity and provides electricity to the grid or local power system, through an electrical generator. Reliability and efficiency of the system are increased in this arrangement, as both immediate energy and stored energy can be used.

Parabolic Trough System

A more typical working principle of CSP (concentrated solar power) with parabolic trough collector to generate power is presented in Fig. 1. Incoming beam solar radiation is directed onto the curved reflective surface of the trough, which concentrates the sunlight onto a centrally positioned absorber tube running along the focal line. This absorber tube, coated with a selective black surface to maximize heat absorption and minimize losses, transfers the captured thermal energy to a heat transfer fluid (HTF) circulating inside it. The trough structure is mounted on a single-axis tracking system, enabling it to follow the sun throughout the day and maintain optimal focus. The heated HTF is then pumped to a heat exchanger, where it generates steam to drive a turbine–generator assembly for electricity production. In typical operation, the absorber tube reaches temperatures of around 400 °C. PT achieves the solar-to-electricity conversion efficiency of about 10–16%. Large solar fields consist of multiple parallel rows of such trough assemblies, working in unison to supply the thermal energy required for continuous power generation.

Linear Fresnel Reflector (LFR)

Long, narrow mirrors that follow the path of the sun and focus sunlight onto an immovable receiver positioned above the mirror field make up a linear fresnel reflector (LFR), a one-way solar concentrating device. LFR plants have concentration ratios between 35-170 with operating temperatures reaching 400 °C, comprised between 5 MW and 250 MW of power output. Developed as a low-cost alternative to parabolic troughs, LFR has some degree of solar-to-electricity conversion efficiency from 8 to 12%. The last type of CSP plant, Similar to the LFR, the Compact Linear Fresnel Reflector (CLFR) minimizes land consumption and shadowing losses by using two receivers and interleaved mirrors.

Solar Power Tower

One kind of solar boiler that uses a tower to receive concentrated sunlight is the power tower, sometimes referred to as "central tower" power plants, "heliostat" power plants, or power towers. It focusses the sun's beams on a collecting tower (the target) using a system of flat, moveable mirrors called heliostats. The receiver, where a heat transfer medium absorbs the load, is exposed to a considerable amount of solar energy through the heliostats, which are usually somewhat concave. A turbine-generator generator is then powered by the superheated, high-pressure steam produced by the thermal energy. Typical concentration ratios are in the order of 600 to 1000 and empower to cover a high fraction of the energy needs with solar light. Effectiveness The solar-to-electricity conversion ratio measures how well sunshine is converted into electrical power, and in the case of a solar power tower system, this will fall somewhere between 10% and 22%. One particular advantage of the orientation is that all heat collected is harvested towards a single receiver, reducing parasitic heat transport losses and facilitating the implementation of thermal storage.

Parabolic Dish Solar System

The application of the parabolic dish Using two-axis tracking technology and the point-focus concept, the receiver maintains its position and atmospheric conditions at a precise

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12 Issue 09 September 2025

point in space, or the dish's focal point. Once it is collected and concentrated, the solar thermal energy is delivered to a receiver, which is usually placed at the focus of the mirrors, and then heats a working fluid to typically 1200°C for current technology and may reach temperatures as high as 1500°C in advanced designs. The thermal power captured here is converted to electrical through a direct connection with the turbine–generator assembly via a receiver. Plant capacities usually between 0.01 and 1 MW. Due to its accurate focusing and high concentration ratio (about 1000–3000), the parabolic dish has achieved thermal efficiencies of 25–30%, which is higher than that of trough systems. Due to its independent collector–receiver units operable, independent allows good flexibility and effectiveness for distributed power generation.

IV. CURRENT STATUS OF CSP IN INDIA:

Of the several Concentrated Solar Power (CSP) technologies available worldwide, the most widely used one, parabolic trough collectors (PTC), accounts for the majority of the 4.4 GW total installed capacity of 5.2 GW. Around 0.2 GW is produced globally by the combination of LFR and parabolic dish systems, while 0.6 GW is produced by solar tower (ST) systems. About 125 MW of the about 228.5 MW of installed capacity of CSP in India is attributable to LFR, 101 MW to PTC, and nearly 2.5 MW to ST technology [2]. The Ministry of New and Renewable Energy frequently works with the Oil and Natural Gas Corporation, India, to develop and construct parabolic dish systems based on Stirling engine technology. They are frequently referred to as demonstration projects.

The near-term development of future CSP plants in the country is heavily concentrated on PTC-based plants and represents some 275 MW under construction show a preference for PTC because of its existing technology base and supply chain. But as indicated by operational and planned projects, CSP deployment in India is modest when compared with global leaders like Spain and the United States, and many technical, economic, and policy challenges continue to thwart significant expansion.

Table 2: The present condition of India's several CSP plants [20]

Project and Location Name	MW of Capacity	Technology	Owner
Dhusar (Rajasthan)	125.0	Reflector Fresnel	Reliance Power
Godavari solar project (Rajasthan)	50.0	Parabolic trough	Green Energy Godavari Ltd..
Megha Engineering and Infrastructures Ltd. (MEIL). Andhra Pradesh	50	Parabolic Trough Collector	Megha Infrastructure and Engineering
ACME solar tower in Rajasthan	2.50	Tower of solar	ACME Group
National Solar Thermal Power Plant in Haryana	1.0	Parabolic Trough Collector	IIT Bombay
KVK Energy Solar Project in Rajasthan	100.00	parabolic trough	Ventures in Energy, KVK Ltd.
Diwakar (Rajasthan)	100	Parabolic trough	Lanco Infratech
India One solar power plant (Rajasthan)	1	Parabolic dish	Brahma kumaris trust
Kutch, Gujarat Solar One (Gujarat)	25	Parabolic trough	CARGO Power and Infrastructure

The capacity, technology type, and ownership of the CSP facilities now operating in India are listed in Table 2. The largest of these is 125 MW capacity Dhusar project in Rajasthan which is based on Fresnel reflector technology developed by Reliance Power. 100 MW KVK Energy and Diwakarprojects and the 50 MW Godawari and Megha projects represent a several high-capacity parabolic trough 50% of India’s CSP capacity. Among the more recent projects, the Rajasthan Solar ACME tower (2.5 MW) is the forerunner of the country’s solar tower technology utilization and the India One at (1 MW) project in Rajasthan is exhibit of parabolic dish for decentralized generation. (25 MW) in the Kutch district of the state of Gujarat, Gujarat Solar One, which adds to the already existing CSP base in western India.

V. STRENGTHS AND OPPORTUNITIES OF CONCENTRATED SOLAR POWER

CSP has many environmental, technical, and social-economic advantages [21]. The main advantages include:

1. Substantial reduction of greenhouse gas emissions, such as CO_2, NO_x, and SO_2, in comparison with traditional fossil fuel plants.
2. Optimal utilisation of arid, semi-arid and wasteland areas for clean energy generation.
3. Ability to dispatch power with built-in thermal energy storage which also allows for better grid stability.
4. JOB CREATION (Over the lifetime of construction, operation & maintenance) 6.1.
5. Contributions to Energy Security in terms of decreased reliance on imported fossil fuels.

6. Ability to accommodate hybrid configurations by providing a link to biomass or fossil backup for consistent power provision.

VI. CONCLUSION

An examination of solar towers, parabolic dishes, linear fresnel reflectors, & parabolic trough collectors demonstrates that CSP may deliver dependable utility-scale renewable power in areas with high DNI, particularly in western India. CSP plants can be utilised to produce high-pressure industrial process steam using solar heat in addition to producing electricity, without any CO2 emissions, also displacing the need for fossil-fuel use in similar industrial processes that require high heat. In the Indian context, PTC and LFR technologies have been the most adopted technologies given the high level of reliability, reasonable costs, and established supply chains, whereas Solar Towers and Dish systems have been further expensive but being characterized with high operating temperatures and efficiencies. Operational experience in the installations in Rajasthan, Gujarat, and Andhra Pradesh validates the technical viability of CSP but also indicates challenges, such as high initial cost, water requirement, and policy restrictions. Further progress will be based on development of receiver materials, optimization of thermal storage, increase of solar tracking accuracy, and implementation of hybrid systems. Supported by targeted legislative initiatives, limited research and development, and industry involvement, CSP could facilitate India's shift to a stable, low-carbon energy mix in the age of decarburization.

REFERENCES

[1]. Bijarniya, J. P., Sudhakar, K., & Baredar, P. (2016). A review on solar parabolic concentrators. *Renewable and Sustainable Energy Reviews, 60,* 757–770.

[2]. Purohit, I., & Purohit, P. (2017). Technical and economic potential of concentrating solar thermal power generation in India. *Renewable and Sustainable Energy Reviews, 78,* 648–667.

[3]. Kumar, A., Tiwari, A., & Khan, M. M. (2017). Performance evaluation of linear Fresnel reflector based solar thermal power plant for Indian climatic conditions. *Energy Reports, 3,* 33–41.

[4]. MNIT Bhopal. (2019). *Internal project report on pilot-scale CLFR CSP system.* Department of Energy Studies.

[5]. Prakash, O., & Kumar, A. (2017). A review on progress of concentrated solar power in India. *Renewable and Sustainable Energy Reviews, 79,* 304–307. https://doi.org/10.1016/j.rser.2017.05.086

[6]. Dabhi, M. N., Patel, M. M., & Jha, S. (2020). Performance analysis of a 1 MW parabolic trough solar thermal power plant in Gujarat, India. *Solar Energy, 195,* 17–27. https://doi.org/10.1016/j.solener.2019.11.040

[7]. Nayak, S., & Sharma, A. (2016). Techno-economic evaluation of hybrid parabolic trough collector-based systems for electricity generation in western India. *Energy Conversion and Management, 118,* 462–473. https://doi.org/10.1016/j.enconman.2016.04.012

[8]. Patel, J. H., & Patel, D. V. (2021). Modelling and simulation of parabolic trough solar thermal system using TRNSYS and MATLAB for Indian climate. *International Journal of Renewable Energy Research (IJRER), 11*(1), 305–312.

[9]. International Research Journal of Engineering and Technology (IRJET). (2020). Status of concentrated solar power in India. *IRJET, 7*(10), 1381. Retrieved from https://www.irjet.net

[10]. Alekhya, S., Aarti, D., & Kulkarni, R. (2017). Design of hybrid concentrated solar and wind power plant for the autonomy of islands. In *2017 International Conference on Intelligent Sustainable Systems (ICISC)* (pp. 806–8663). IEEE. https://doi.org/10.1109/ICISC.2017.8068663

[11]. Bijarniya, J. P., Sudhakar, K., & Baredar, P. (2016). Concentrated solar power technology in India: A review. *Renewable and Sustainable Energy Reviews, 63,* 593–603. https://doi.org/10.1016/j.rser.2016.05.064

[12]. International Research Journal of Engineering and Technology (IRJET). (2020). Status of concentrated solar power in India [MNRE demonstration projects section]. Retrieved from https://www.irjet.net

[13]. Lovegrove, K., Burgess, G., & Pye, J. (2011). A new 500 m² paraboloidal dish solar concentrator. *Solar Energy, 85*(4), 620–626.

[14]. Yan, J., Peng, Y. D., Cheng, Z. R., Liu, F. M., & Tang, X. H. (2017). Design and implementation of a 38 kW dish-Stirling concentrated solar power system. *IOP Conference Series: Earth and Environmental Science, 93*(1), 012052.

[15]. You-duo, P. E. N., & Cheng, Z. R. (2018). Design and develop for 17.70 m solar parabolic dish concentrated device. *Acta Energiae Solaris Sinica, 39*(9), 2544–2552.

[16]. Rajan, A., & Reddy, K. S. (2024). Integrated optical-thermal model and deep learning technique to estimate the performance of a conical cavity receiver coupled solar parabolic dish collector. *Energy Conversion and Management, 301,* 118052.

[17]. Ravelli, S., Franchini, G., & Perdichizzi, A. (2018). Comparison of different CSP technologies for combined power and cooling production. *Renewable Energy, 121,* 712–721.

[18]. Alam, M. I., Nuhash, M. M., Zihad, A., Nakib, T. H., & Ehsan, M. M. (2023). Conventional and emerging CSP technologies and design modifications: Research status and recent advancements. *International Journal of Thermofluids, 20,* 100406.

[19]. Brenna, M., Foiadelli, F., Roscia, M., & Zaninelli, D. (2008). IEEE evaluation of solar collector plant to contribute climate change mitigation. In *2008 International Conference on Sustainable Energy Technologies (ICSET).* IEEE. https://doi.org/10.1109/icset.2008.4747001

[20]. Yadav, A. K., Kumar, A., & Sinha, S. (2024). A review of concentrated solar power status and challenges in India. *Solar Compass, 12,* 100079.

[21]. Chen, Q., & Wang, Y. (2020). Research status and development trend of concentrating solar power. In *2020 9th International Conference on Renewable Energy Research and Application (ICRERA)* (pp. 390–393). IEEE.