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Research paper

Performance Evaluation and Site Optimization of A 5 MW Parabolic Dish CSP Plant

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Abstract

The present research investigates the design and performance capabilities of a recently developed 500 m² parabolic dish solar concentrator (PDSC), designed for clean energy production and industrial thermal applications. The research demonstrates significant progress in system architecture, optical-thermal efficiency, and component integration, grounded in both empirical data and simulation results. The proposed system employs high-reflectivity glass mirrors, a dual-axis solar tracking mechanism, and a conical cavity receiver to concentrate sunlight for effective thermal conversion. A structured, multi-criteria site selection framework outlined through a flowchart guides the evaluation process from national energy assessment to simulation of a 5 MW CSP plant for optimal location identification. A comparative analysis between two potential sites in Vadodara and Patan, Gujarat, investigates site-specific performance and identifies the optimal location for maximizing solar thermal energy yield, with validation carried out at a 5 MW CSP facility in both regions. Simulation tools, including MATLAB and SAM, were utilized to evaluate system performance under diverse solar and environmental circumstances. The findings indicate consistent energy production during peak periods and thermal energy output, facilitating industrial operations. The annual conversion efficiency varies from 25% to 30%. In contrast to traditional fossil-fuel-based thermal power plants, the PDSC system provides a cleaner and more sustainable option with significantly diminished carbon emissions. Despite ongoing economic and operational constraints, the findings emphasize the significant potential of large-scale PDSC systems in sustainable energy production, especially in areas with high solar irradiation.

Keywords: *Concentrated Solar Power System; Parabolic Disc Solar Concentrator; Clean Energy Production.*

1. Introduction

The increasing demand for sustainable and decentralized energy solutions in the worldwide market generated significant interest in solar thermal technologies, particularly concentrated solar power (CSP) systems. Parabolic Dish Solar Concentrators (PDSCs) are acknowledged as the most efficient and scalable form of Concentrated Solar Power (CSP) solutions, especially in regions with high Direct Normal Irradiance (DNI). These plants, distinguished by their modularity and superior solar-to-thermal energy conversion efficiency, possess certain advantages over alternative solar technologies, particularly parabolic dish and central receiver towers. The performance and commercial potential of PDSC improved significantly during the past 20 years. Zawadski et al. (2007) examined the Big Dish's performance at the Australian National University, demonstrating high solar/electric conversion efficiency. Their findings demonstrated the cost and performance advantages of dish systems over all other CSP technologies [1]. Accordingly, Zapata et al. (2010) examined the dynamic simulation models of steam receivers in dish systems and talked about how crucial modeling accuracy is for system optimization [2].

Technology innovation played a crucial role in advancing the PDSC systems forward. For instance, Love et al. (2011) built a 500m² dish with new design features (self-supporting mirrors) which were optically tested at an extremely high concentration ratio [3]. The DS-CSP system developed and examined by Yan et al. showed a linear relationship between DNI and produced energy with overall efficiencies of more than 25% in the best days, and peak conditions were observed [4]. Similarly, You-duo et al. (2018) measured an efficiency of 26.6% for a 17.70m dish configuration, confirming the significance of precise tracking and structural optimization [5].

Recently, several studies have been dedicated to intelligent design approaches. Li et al. (2024) employed hybrid optimization algorithms, such as PSO-GA, to enhance petal geometry and surface reflectivity and achieved optimal optical proofs as well as better manufacturability [6]. Involving AI mechanisms, Rajan et al. (2024) employed deep learning and CFD to evaluate the thermal performance of a 40m² dish system and showed that current computational tools can accurately predict multi-weather capability [7].

Concomitantly with the above, thermochemical applications have been developed. Dahler et al. (2018) presented a new dish design for redox cycle application that achieved a peak concentration of 5010 suns and increased the optical efficiency from 59.6% up to 82 % which could be achieved theoretically, based on the current Soc. [8] Similarly, Babikir et al. (2020) presented the versatility of dish systems in diverse setups, starting from a 25kW isolated application in Pakistan, where a net efficiency of 23.39% was reached together with a highly competitive LCOE, to a 200kW cogenerative plant in a hybrid configuration with thermal storage and ORC technology [9].

Empirical analysis at the regional level also confirms the promotion impacts of dish systems in electrification. Dernouni et al. [2024] examined the use of a 100kW Dish Stirling application for a remote site in the southern part of Algeria. All five sites show higher annual productivity and lower LCOE ($/kWh) when compared to similar PV systems, with Illizi as the best performer (highest annual productivity and lowest LCOE) ($0.0378/kWh) [10]. Similarly, Allouhi et al. (2022), the southern regions of Morocco are well-suited zones for SDS with low stabilized CO_2 emissions up to 13.85ktonne and the twelvemonth energy produced to 23.69GWh in the occasion of optimized applications [11].

From an industrial viewpoint, Thakkar et al. (2015), Performance evaluation method for PDSCs by thermic fluids in process-heating. Their model showed opportunities for efficiency gains in practical system enhancements such as covering the absorber with glass to minimize convective losses [12]. Another interesting work on the same topic was carried out by Pavlovic and Stefanovic et al. (2015), where the ray tracing process and the flux maps in a 10kW dish system were examined using the Sol Trace software, both demonstrating the significance of mesh density as well as the optimization of rays for more efficient thermal energy output [13].

Lastly, seminal studies such as Blanco Miller (2017) set the wider perspective of CSP technology development, Extreme energy and power densities, rechargeable CSP technologies development ppm, and LDM-based power plants [14]. These observations emphasize the significant function of PDSCs not only as independent power sources, but also as potential modules for future hybrid and multi-functional energy systems.

The reviewed literature highlights the growing potential of PDSCs as a renewable energy source. These systems prove highly effective in converting sunlight into electricity, particularly in sun-belt regions and desert areas where conventional energy production is economically unviable. Recent developments in optical-thermal engineering, simulation tools, and system integration have significantly enhanced their efficiency and cost-effectiveness. In spite of the barriers such as high initial cost and maintenance, continuous research is underway to resolve these problems, and PDSC-based systems are developing as a future preferred sustainable source of clean energy and industrial heat applications. This paper presents a detailed flowchart depicting criteria-based site evaluation for CSP deployment, along with a comparative analysis of two potential sites for a CSP plant, and discusses the various parameters influencing CSP performance.

2. Concentrated Solar Power System Component: from Collector to Power Block

CSP is a solar thermal power technology that concentrates and focuses the sun's heat on a small area to provide high-temperature heat for industrial processes and for electricity generation. CSP fits in locations with high DNI and is expected to meet the peak and mid power demands of the Sunbelt regions. A CSP plant generally has three subsystems: the solar field (SF) that harvests energy, thermal energy storage (TES) to store overflow energy, and the power block (PB) that transforms this stored heat into electricity.

2.1. Solar Parabolic Dish

The main design feature is a point focus parabolic solar concentrator, which consists of a dish-shaped structure with mirrors mounted on the surface to reflect sunlight and focus it on a receiver at its focal point.

Fig. 1: The Existing CAD Image of the New 500 m² SG4 Dish [3].

To focus sunlight and to create high temperatures that are used to harness electric power, the combination of these mirrors is used for concentrating the solar rays. Glass silvered mirrors are widely used in dish systems because of their high reflectance (93 – 95 %) and limited susceptibility to environmental degradation. Such parabolic dish systems have a high optical efficiency and are well-suited for distributed power generation.

2.2. Receiver

The receiver is an important element that intercepts the sunlight focused by mirrors and turns it into heat. Often it is positioned at the focus of the concentrator, as at the focus of a parabolic dish. Conical cavity receivers constructed of stainless steel are widely proposed for CSP systems, which could enable enhanced heat absorption due to multiple reflections of incoming rays into the cavity because of its conical shape, and stainless steel provides a high thermal resistance, high durability, and corrosion resistance under high temperature operating conditions.

2.3. Sun Tracking Unit

A sun-tracking device is one of the vital components of a CSP plant, enabling the solar collector to follow the position of the sun during the day. Also, the optimal capture of solar irradiation, resulting in enhanced thermal and power conversion efficiency, is guaranteed by varying the location of the concentrator. It is widely used in a parabolic dish for a high concentration ratio and system performance.

2.4. Thermal Energy Storage (TES) System

The main tanks of the thermal energy storage (TES) system are the hot tank and the Cold tank. CSP employs the TES system to save extra heat received in the daylight for later use. This stored heat can be tapped for power generation later, when the sun is not shining, to enable day or night-time power generation. Material such as molten salts is frequently used by TES systems because of their high thermal storage density, that is, they can store large amounts of energy for a long period of time. With the inclusion of TES, the potential to generate consistent and predictable electricity, even in the face of the intermittency of solar power.

2.5. Power block (PB) Unit

The PB is the section of a CSP plant that converts harvested thermal energy to power. It mainly consists of the heat exchanger, steam turbine, and generator assembled in an integral structure, which works as a package for efficient energy conversion. The power block performance and thermal efficiency are the decisive influences on the overall power input to electricity; the PB unit can provide continuous and stable power generation.

3. Flowchart Depicting Criteria-Based Site Evaluation for CSP Deployment

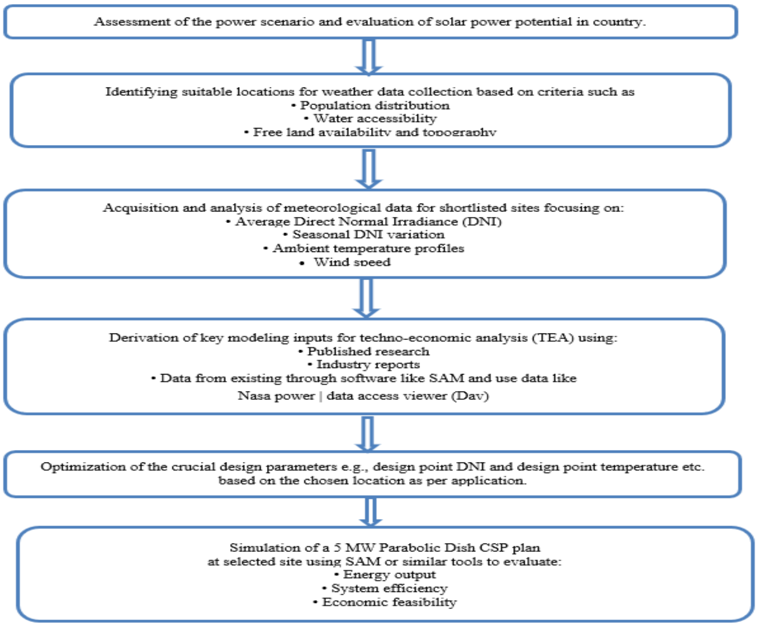

Fig. 2: Flowchart for Site Selection of CSP Plant.

Figure 2 illustrates the step-by-step procedure adopted for selecting a suitable site for a Parabolic Dish Concentrated Solar Power (CSP) plant. The process starts with an evaluation of the national energy profile and the assessment of solar energy potential. Based on specific criteria such as population distribution, land availability, and access to water, potential locations are shortlisted. Meteorological parameters, particularly DNI and temperature, are then analyzed, followed by the optimization and simulation of plant performance to ensure technical and economic feasibility.

4. Mathematical Modeling of PDSC

The PDSC technology is a novel approach for generating high-pressure steam and concentrated solar power. To assess this technology, a reference CSP plant with a capacity of 5 MW was selected. The selected plant configuration is characteristic of a standard medium-scale and small-scale concentrated solar power plant that incorporates thermal energy storage, thus making it suitable for the investigation of the performance and design of PDSC technology.

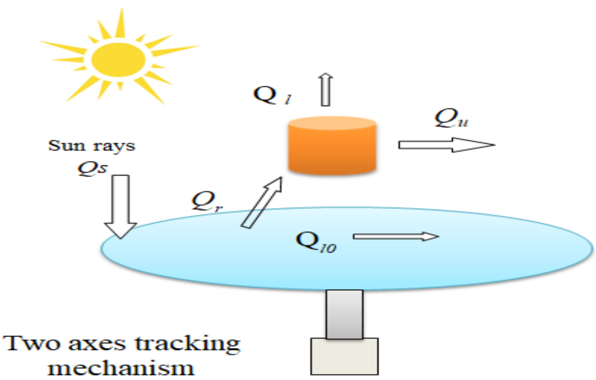

Fig. 3: PDSC Thermal Modeling.

Thermal efficiency of a solar collector, as depicted in Figure 3, is defined as the ratio between the useful energy output and the total solar energy received at the solar concentrator's aperture. The formula in Eq. 1 is employed to determine solar thermal efficiency.

$$\eta_{th} = \frac{Q_{useful}}{Q_{solar}} \quad (1)$$

Consider the irradiation (Q_{solar}) received by the PDSC, with a concentrator surface area A_{Dis} and direct normal irradiation Is, which can vary according to location and the orientation of the dish collector. In a steady-state system, the net solar heat transfer (Q_{solar}) is expressed in Equation 2.

$$Q_{solar} = I_s A_{Dis} \quad (2)$$

The amount of effective heat supplied by the collector equals the total heat gained by the heat transfer fluid inside the receiver [15]. The quantity of usable heat is determined using Equation 3.

$$Q_{useful} = Q_r - Q_l \quad (3)$$

The radiation incident on the receiver can be determined using Equation 4.

$$Q_r = I_s A_{con} \alpha_c \rho_c \tau s \quad (4)$$

The cumulative heat loss from the receiver, denoted as Q_l is expressed by Equation 5.

$$Q_l = A_{rec} h_{ad} (T_{rec} - T_{amb}) \quad (5)$$

The supplied electric power by the electric generator is calculated from equation 6.

$$P_{Electric} = Q_r \cdot \eta_{turbine} \quad (6)$$

Finally, the overall system efficiency, which expresses the Total performance of the solar to electrical conversion, is given by equation 7.

$$\eta_{Over} = Q_r \cdot \eta_{receiver} \cdot \eta_{turbine} \cdot \eta_{Generator} \quad (7)$$

The efficiency can be impacted by seasonal changes in the radiation offered at every region where the system is installed and commissioned.

5. PDSC Plant Technologies and Plant Concepts

The schematic diagram and energy flow structure of a CSP system with a PSDC are shown in Fig. In these kinds of arrangements, three basic subsystems are interconnected: the solar field (SF), which captures solar radiation, the thermal energy storage (TES), which stores the excess heat, and the power block (PB), which converts the thermal energy into electricity output [16]. Their mutually matched operation has good performance and a stable power supply.

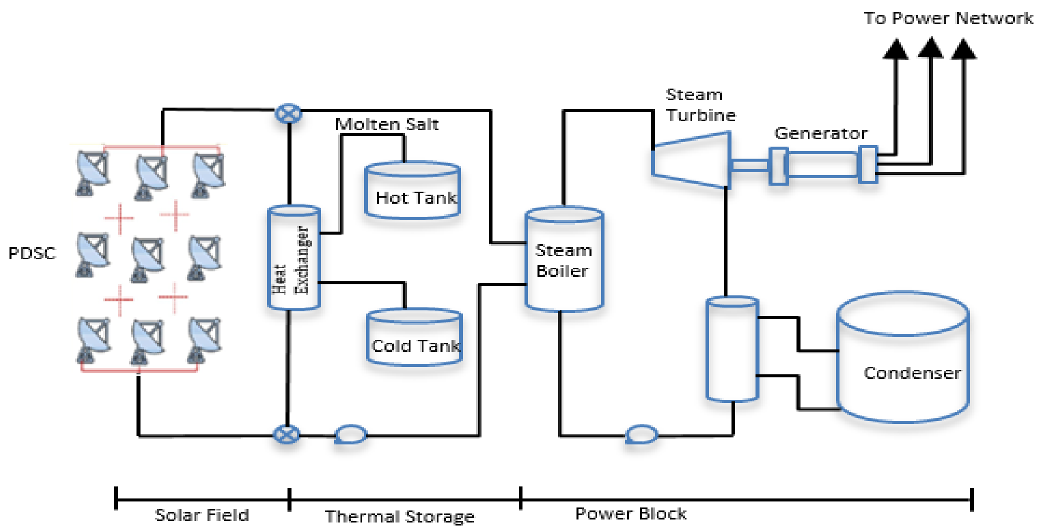

Fig. 4: Schematic Representation of Parabolic Dish Concentrated Solar Power Plant.

The solar field mainly consists of a solar parabolic dish collector with sun-tracking mirrors and a conical cavity receiver placed at the focal distance. The dish directly focuses solar radiation into a well-insulated, heat-storing receiver that allows this technology to operate at temperatures conducive to power generation. A hot tank and a cold tank store excess thermal energy during peak daylight hours. In this arrangement, the cold tank is charged with molten salt, which is pumped to the heat exchanger and then stored in the hot tank. In times of low solar radiation, the stored heat is used to enable 24/7 power production. The power block consists of a high-pressure turbine, a low-pressure turbine, and a condenser. Here, intense heat creates steam that powers the turbines, creating electricity. The steam is then condensed to water and returned to the boiler to be boiled once more.

Table 1: Core Specifications of the Solar Dish Concentrator

Parameters	Value	Units	Equation	Reference
Overall dish diameter (D con.)	25	m	----	---
Parabolic reflector's focus length (f)	13.4	m	$F_{Dis} = \frac{D_{Dis}}{4\tan\left(\frac{\varphi_{rim}}{2}\right)}$	Babikir et al. (2020)
Parabolic dish surface material	Glass/silver 2 mm	__	An optical reflectance of 90%	Hafez et al. (2016)
Dish concentrators' aperture area (A_{Dis})	500	m^2	$A_{Dis} = \frac{\pi}{4} D_{Dis}{}^2$	Harish. K et al. (2022)
Rim angle of dish (Ψrim)	45	deg.	---	Castellanos et al.(2019)
Geometric concentration ratio (C)	1000	---	$C = \frac{A_{Dis}}{A_{rec}}$	Fraser et al. (2008)

Table 1 explores the parabolic dish with a 25 m diameter and a focal length of 13.4 m, calculated using standard geometric relations. It is made of 2 mm thick glass/silver with 90% reflectivity, giving it a high-efficiency aperture area of 500 m². With a 45° rim angle, the system achieves a geometric concentration ratio of 1000, enabling intense solar energy focus.

Table 2: Key Components of the CSP System [17] [18]

Component	Type	Specification
Generator	Synchronous generator	Installed capacity: 5 MW Generator rotation rate: 1500 rpm Output power: AC three-phase Frequency: 50Hz Temperature range:260 – 550 ◦C Voltage Rating:11 kV
Turbine	steam turbine	Turbine Inlet pressure 38 – 42 bar Turbine backpressure: 0.5–2 bar Input temperature range: 260 to 550 °C Turbine rotational speed: 1500 rpm Stages: Multi-stage for higher efficiency at medium capacity
Condenser	Water-cooled surface condenser	Cooling Method: Wet cooling tower with recirculated water Steam condensing pressure: 0.5–2 bar Temperature at inlet: 110–80 °C Discharge temperature: 40 to 60 °C
Pump	Water pump	Maximum pressure capacity: 45 bar Flow rate range: 7 to 10 liters per second Rated power range: 150–300 W
Three-port valve integrated with thermal sensor	Automated three-way valve with sensing capability	Enables fluid flow once the system attains the necessary temperature and pressure for turbine use.
Pressure relief valve	Operates within a pressure range of 5 to 50 bar	Ensures system protection by limiting pressure rise beyond the safe range of 5–50 bar.
Manual flow control valve	___	Manually operated to control system flow during unexpected or abnormal conditions.

Table 2 explores the primary components utilized in the CSP system, accompanied by their respective ratings and purposes. It encompasses specifics regarding the synchronous generator, steam turbine, condenser, and pump, emphasizing their functions in the conversion process. The table describes critical control and safety components, including the three-way valve with temperature sensor, safety valve, and manual valve, which guarantee efficient regulation and secure operation of the system.

Table 3: Technical Specifications for the Simulation of Concentrated Solar Thermal Power Plant, Vadodara, Gujarat [19] [20]

Sr. No	Project	Detail
1	Project	Concentrated Solar Thermal Power Plant
2	First Location and Country	Muni seva ashram campus, Vadodara, Gujarat, India
3	Lat/Long Location	22.3354° latitude and 73.4650° longitude
4	Second Location and Country	Charanka village, Patan district. Gujarat, India
5	Lat/Long Location	23.9080° latitude and 71.2160° longitude
6	Focusing	Point focus
7	Technology	Concentrated solar thermal power
8	No. of PDSC	35
9	Turbine Capacity	5 MW
10	Steam Pressure	38 to 42 Bar
11	Heat Transfer Fluid Type	Molten salt
12	Cooling Method	Air
13	Solar Field obtains Temperature	450 to 600 ^{0} C
14	Storage Type	Thermal storage
15	Static focus concentration Ratio	1000:1
16	Tracking	Two-axis
17	Annual solar-to-electric efficiency	20-25
18	Peak solar-to-electric efficiency	25–30
19	Power Cycle	Steam rankine
20	Solar electricity generation	5 MW
21	Application	Super-critical steam for power generation and different industrial heat applications

Table 3 explores the technical features of the CSP facility located in Vadodara and Patan, Gujarat. It employs point focus technology with dual-axis tracking. It includes a 5 MW steam turbine functioning within a steam pressure range of 38 to 42 Bar. The solar field attains temperatures of 450 to 600 °C with a concentration ratio of 1000:1, resulting in an annual solar-to-electric efficiency of 20-26% and peak efficiency of 25-30%.

6. Results and Discussion

6.1. Validation and Simulations

The proposed first Concentrated Solar Power (CSP) plant is located at 22.3354° latitude and 73.4650° longitude within the Muni Seva Ashram, Goraj village, Waghodia Taluka, Vadodara, Gujarat, India. The proposed second Concentrated Solar Power (CSP) plant is located at 23.9080° latitude and 71.2160° longitude within the Charanka village, Patan district. Gujarat, India. This study focuses on evaluating the design and operational efficiency of a 5 MW Parabolic Dish Solar Concentrator (PDSC) system for thermal power generation, along with a comparative analysis of both locations to determine the most suitable site based on key selection criteria. The modeling begins with validating thermal and optical parameters using either benchmark references or experimental findings to ensure the simulation accurately reflects actual system behavior. Tools such as MATLAB and SAM are utilized to analyze the system's performance under varying solar radiation and wind conditions. The present work makes use of the System Advisor Model (SAM) to assess and select the two most appropriate locations for CSP installation. The analysis incorporated critical meteorological factors, including Direct Normal Irradiance (DNI), ambient temperature, and wind speed, to simulate plant behavior under real climatic conditions. Based on these inputs, site performance was quantified in terms of annual energy generation, overall efficiency, steam output, and net electrical power, thereby ensuring a reliable comparison of the two candidate sites.

The net power generation trends of the CSP plant at Vadodara (Fig. 6.9) and Patan (Fig. 6.10) are depicted, highlighting the site-specific performance variations.

Figures 6.1 and 6.2 show the variation in solar beam radiation (W/m²) recorded on March 6, 2025, at the Vadodara and Patan CSP plants, respectively [21]. The radiation intensity increases steadily during the morning hours, reaching its maximum between 12:00 p.m. and 1:00 p.m. Following the peak, the radiation decreases gradually, with a slower rate of decline compared to the rate of increase observed earlier in the day. From the results, it is observed that Vadodara consistently receives higher solar beam radiation compared to Patan. This higher radiation intensity directly translates into greater potential for thermal energy generation, which in turn enhances the opportunity for higher power output from the CSP plant. Accordingly, the discussion expanded to emphasize that Vadodara demonstrates more favorable site characteristics for CSP deployment compared to Patan.

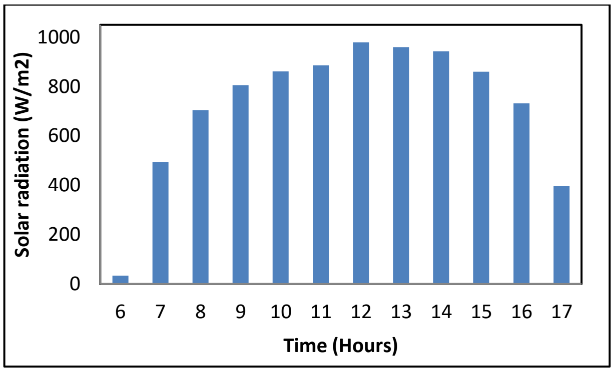

Fig. 6.1: Variation of Solar Beam Radiation with Time at Vadodara CSP Plant.

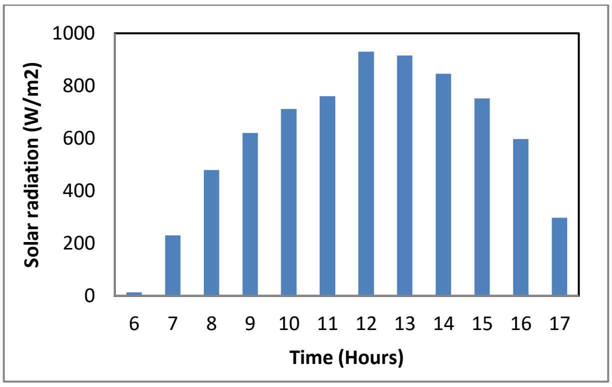

Fig. 6.2: Variation of Solar Beam Radiation with Time at Patan CSP Plant.

Figure 6.3 illustrates the variation of ambient temperature with time at the Vadodara CSP plant, while Figure 6.4 presents the same data for the Patan site. The results indicate that the Vadodara site experiences relatively higher ambient temperatures compared to Patan. This aspect is significant because elevated ambient temperatures influence the overall thermal performance of CSP systems by affecting thermal efficiency. Seasonal conditions and altitude substantially affect ambient temperature levels. The highest temperatures are observed between 12:00 p.m. and 1:00 p.m. This data was obtained from the system advisory model (SAM) software, which was used to analyze the variation of ambient temperature over time.

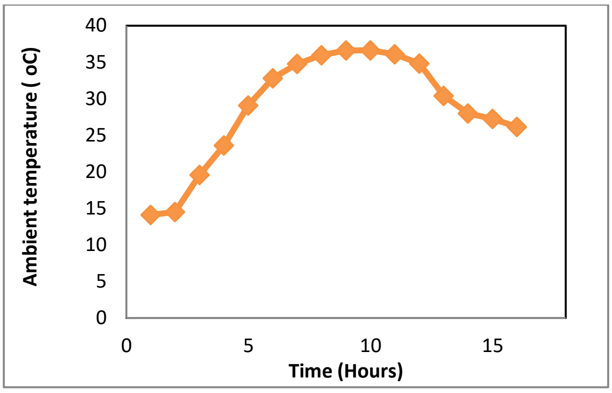

Fig. 6.3: Variation of Ambient Temperature with Time at Vadodara CSP Plant.

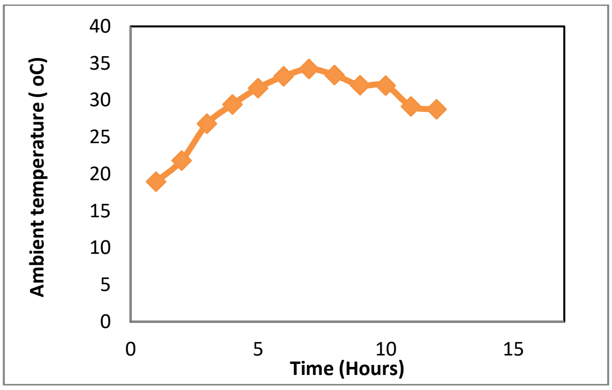

Fig. 6.4: Variation of Ambient Temperature with Time at Patan CSP Plant.

The changes in temperature with respect to time for the two CSP locations are shown in Figures 6.5 (Vadodara) and 6.6 (Patan). In the CSP system, the receiver temperature often peaks around midday, when solar irradiation is highest, allowing the heat transfer fluid to receive and retain a significant amount of thermal energy. The period of high temperature is critical for successful power generation since the system operates most efficiently under these conditions. However, as the afternoon progresses and sunlight diminishes, the temperature of the HTF gradually decreases, leading to a reduction in energy production. This decline continues into the evening, where the system may rely on thermal energy storage to sustain output for a while, but ultimately, the cooling process signifies the end of effective energy generation until the next day. The Vadodara CSP site records higher receiver temperatures compared to Patan. This condition enhances the potential for improved thermal energy conversion efficiency at Vadodara.

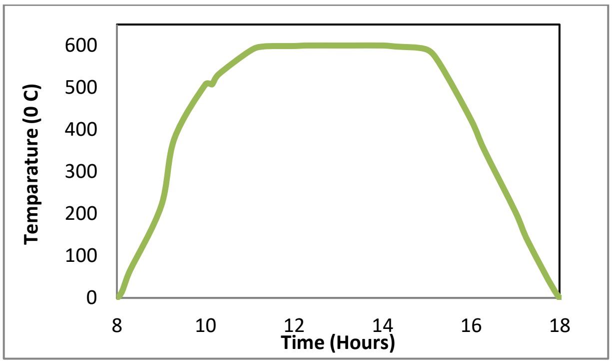

Fig. 6.5: Variation of Temperature with Time at Vadodara CSP Plant.

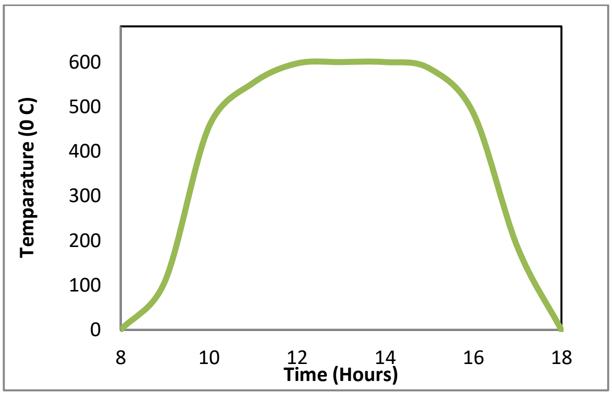

Fig. 6.6: Variation of Temperature with Time at Patan CSP Plant.

Figures 6.7 and 6.8 show the hourly steam production profiles of Vadodara and Patan CSP plants, with average outputs of 16,496 kg and 15,136 kg, respectively. The higher steam yield at Vadodara indicates stronger site suitability for power generation. This steam can be used for power generation as well as high-temperature industrial applications in industries such as paper, textiles, food processing, chemicals, and the pharmaceutical industry.

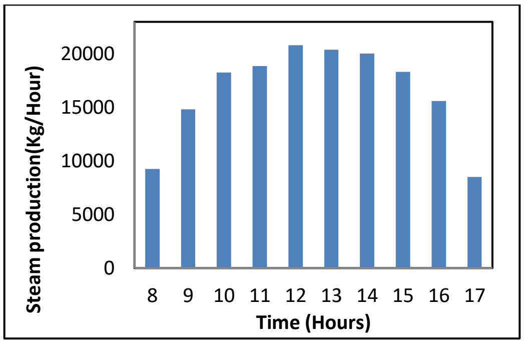

Fig. 6.7: Steam Production (Kg/Hour) at Vadodara CSP Plant.

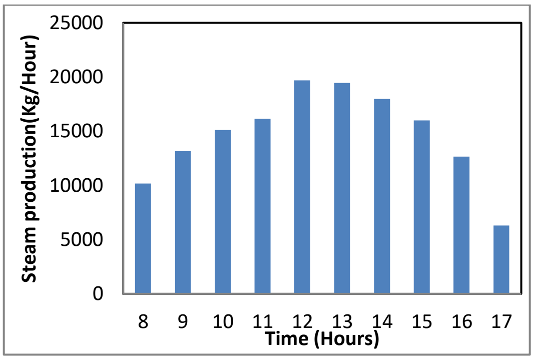

Fig. 6.8: Steam Production (Kg/Hour) at Patan CSP Plant.

The net power output obtained from the parabolic dish solar collectors at the Vadodara and Patan CSP plants is depicted in Figures 6.9 and 6.10, respectively. The typical net power output profile of a CSP system with a maximum thermal power of 5 MW features a low start-up in the morning, a peak around midday at or near maximum capacity, a gradual decline in the afternoon, and a significant drop in the evening. Effective thermal energy storage can help extend energy production beyond daylight hours. The results indicate that the Vadodara site achieves slightly higher net power output compared to Patan, reflecting its stronger solar resource availability and greater suitability for efficient CSP operation.

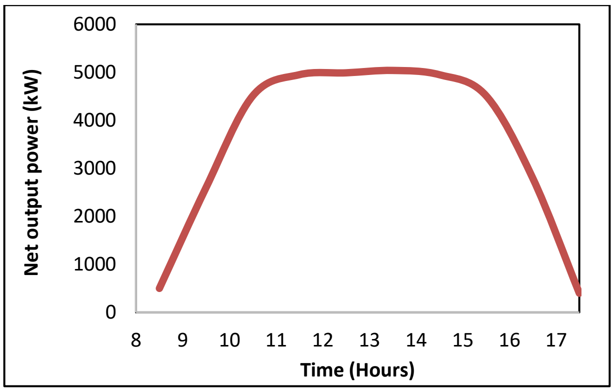

Fig. 6.9: Typical Net Power Output Profile of CSP at Vadodara CSP Plant.

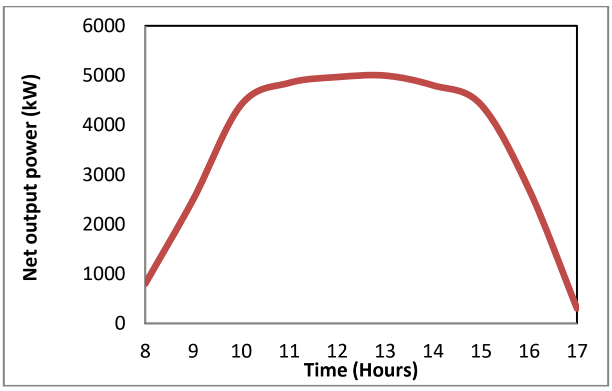

Fig. 6.10: Typical Net Power Output Profile of CSP at Patan CSP Plant.

Table 4: Evaluation of Efficiency, Cost, and Emissions: 5 MW Thermal and Solar Thermal (CSP) Plant. [22 - 24]

Parameter	5 MW Conventional Thermal Plant	5 MW Solar Thermal (CSP) Plant
Capital Cost	Lower (approx. 5–6 crore/MW)	Moderate (approx. 8-10 crore/MW)
Running/Operating Cost	High (due to fuel, maintenance, pollution control)	Low (mainly maintenance; no fuel cost)
Efficiency	30–40% (depends on fuel and cycle used)	20–30% (solar-to-electric conversion efficiency)
Fuel Cost	Continuous expense (coal, gas, oil)	Free (solar energy)
Environmental Emissions	High (CO_2, NO_x, SO_2, particulates)	Minimal (almost zero direct emissions)
Water Requirement	High (for cooling, steam generation)	Moderate to low (depending on cooling method)
Carbon Footprint	High (fossil fuel-based)	Very low (clean energy)
Maintenance Cost	Moderate to high (due to mechanical wear, emissions)	Moderate (cleaning mirrors, mechanical tracking systems)
Plant Lifespan	25–30 years	25–30 years
Energy Source Reliability	High (fuel-controlled, can operate 24/7)	Variable (depends on sunlight availability; needs storage)
Storage Requirement	Not needed (fuel-based operation)	Thermal storage is needed for continuous output
Grid Dependence	Independent (dispatchable)	Needs hybridization or storage for grid stability

Table 4 presents a comparative assessment of a 5 MW conventional thermal power plant and a 5 MW solar thermal (CSP) plant, focusing on critical performance metrics including efficiency, cost, and environmental effect. Conventional thermal plants provide enhanced reliability and reduced capital expenditures, although they entail substantial operational costs, fuel dependency, and considerable emissions. CSP plants are more environmentally friendly and sustainable, with reduced operating costs and no fuel expenses; yet, they necessitate a moderate initial investment and effective thermal storage for reliable output. The two plant varieties exhibit comparable lifespans, although they markedly differ in their carbon emissions and reliance on energy sources.

7. Conclusion

This study highlights the viability and potential of a 500 m² Parabolic Dish Solar Concentrator (PDSC) system for clean energy production and industrial thermal applications in areas with high solar irradiation. With steam output averaging more than 16,000 kg/day and an annual thermal conversion efficiency of up to 30%, the proposed 5 MW solar thermal power plant in Vadodara demonstrates dependable energy performance through a combination of experimental validation and simulation utilizing programs like MATLAB and SAM. The architecture of the system, which includes thermal energy storage and dual-axis tracking, guarantees reliable operation and raises total efficiency. The comparative assessment clearly identifies Vadodara as the more suitable site for a solar thermal power plant, since its higher Direct Normal Irradiance (DNI) and favorable ambient temperature conditions lead to improved thermal performance, greater steam generation, higher net power output, and better long-term sustainability when compared with Patan.

In contrast to traditional thermal power plants, the PDSC system presents a markedly diminished carbon footprint, minimum ecological impact, and reduced operational expenses, rendering it a sustainable and economically feasible option for decentralized power generation. Despite moderate initial investment and the need for storage optimization, the technology proves highly promising for further renewable energy infrastructure.

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