

Direct Steam Production in Focus: Solar Energy Stations

Noor Al-Bandar^{1, *}  and Ahmed Hamza Osman² 



¹ Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, UKM, Bangi 43600, Selangor, Malaysia; p117813@siswa.ukm.edu.my

² Department of Information Systems, Faculty of Computing and Information Technology in Rabigh, King Abdulaziz University, 21911, Saudi Arabia; ahoahmad@kau.edu.sa

* Correspondence: p117813@siswa.ukm.edu.my

Abstract: A modeling method was created to forecast the efficiency of a focusing solar energy facility using direct steam production (DSP) method. We developed a comprehensive DSP solar field model for parabolic troughs (PTC) and linear Fourier collector in MATLAB. The predictions of the model had been assessed against operational information from the first precommercial 10 MW DSP solar power station, intended for a government initiative. The station efficiency was examined in dual ways: “fixed” and “sliding” steam turbine intake flow.

Keywords: Focused solar energy; Straight Combustion Production; Capacity analysis; Modeling

1. Introduction

Results from government-funded studies indicate that DSP is a compelling technical alternative for focusing solar power generation [1]. Utilizing water and steam for both the solar field and the power block has various advantages over the existing CSP method that use parabolic trough collectors with synthetic oil as the heat transfer fluid. The steam heat threshold of around 399°C for contemporary artificial oils can be surpassed. An efficient temperature of 450°C appears to be viable for next-generation receiving containers, hence enhancing the potential for overall efficacy.

In addition, the elimination of oil and water radiators is feasible if water is immediately drained and heated in the solar field [2], leading to a more straightforward plant architecture and reduced capital expenditures. The utilization of demineralized water is considered environmentally benign: in contrast to oil, water is more economical, environmentally friendly, and non-flammable.

In comparison to liquid salt, water is both more economical and less caustic. Among DSP that related interest issues, the adhering to essential challenges are the the majority pertinent [3-5]:

Firstly, the equilibrium of the circular liquid within each tube is essential to enable interior chilling of the exterior walls, hence eliminating areas of heat. The skeletal strength of absorbers tubes and the links between enthusiasts and absorption tubes at extreme pressure and high temperatures. Subsequently, implement station management systems, especially during transitional phases of irradiation. Ultimately, connection with storage facilities tailored to the unique properties of the dual-phase fluid water and steam occurs in the evaporating portion, while the initial heating and overheating components can be managed by traditional two tank hot salt storage methods.

The expertise and knowledge gained from the work were utilized in the Iraqi government's initiative to develop the inaugural precommercial DSP station. The system consists of a parabolic trough solar sector linked to a heated steam The actress cycle operating at 399°C and 70 bar, with a nominal output of electricity of 10 MW. This research proposes the use of modeling for modeling a DSG plant that generates steam from superheated air.

Citation: Al-Bandar, N. and Osman, A. H., Direct Steam Production in Focus: Solar Energy Stations. 2026. 4. p. 2-8

Academic Editor: Asst. Prof. Wurod Qasim Mohamed

Received: 5/1/2026

Revised: 10/2/2026

Accepted: 8/3/2026

Published: 12/3/2026



Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

The data collected from the government program has been utilized as a guide because to the scarcity of details on current DSP deployments. Attention has been directed on producing electricity via the steam turbine, with variations in inlet pressure management over a 24-month duration.

2. Materials and Methods

2.1 Installation of DSP Station

Figure 1 illustrates the configuration utilized in the current investigation. This pertains to the government DSP solar energy station with an authorized capacity of 10 MW, for which conceptual viability was evaluated in [6-8]. The PTC solar area has 8 parallel-connected loops, each containing 9 solar arrays. A single loop of readers has 10 readers designated for getting ready and evaporated, while the final two readers are allocated for overheating. A separation device with an exit water rating of 0.9 is positioned between the evaporator unit and the superheater in order to ensure adequate cooling of the absorber's tubes in continuous operation. Recirculating and injecting valves are employed to enhance management of the solar field exit heat. Table 1 delineates the design aspects of the PTC [9]. Regarding the power block as illustrated in Table 2, the steam pressure and temperature at the turbine inlet are established at 70 bar and 350°C, correspondingly. Due to the plant's limited dimensions, a solitary steam obtaining range, with a pressure limit of 3.1 bar to 6.1 bar, was included to supply a deaerator. The air-cooled condenser was evaluated with a design maximum pressure for operation of 0.2 bar.

Table 1. Photovoltaic radiation characteristics

A particular collector's total length (m)	99
Each receiver's gross collectors' size (m ²)	623
Iron isolator tube's outside perimeter (m)	0.082
Iron absorbers tube with inner diameter (m)	0.061
The quantity of 90° angles	4
The degree of roughness of the isolator tube	8.59*10 ⁻⁴
Maximum refractive effectiveness	0.901
Tension decreases in the sun radiation (bar)	15

Table 2. Specifications for the energy unit.

Pressure and temperature at turbine inlet	78bar-380°C
Pressure and temperature at solar field inlet	93bar-170°C
Deaerator pressure (bar)	7.2
Condenser pressure (bar)	0.192
HP/LP Turbine isentropic efficiency (%)	82/91
Gross power (MW)	6.3
Net power (MW)	6
Net electric efficiency (%)	24.1

Two distinct ways to operate for a steam turbine were evaluated: the first, termed “sliding pressure,” entails an inverse variation of the turbine inlet pressure with the steam flow rate, while the second, referred to as “throttle mode,” maintains an unchanged turbine entry pressure equal to 70 bar, despite a steam flow rate entering the turbine that is below the design specification. Additionally, steam from exhaust parameters were meticulously computed, considering kinetic expenses as an effect of the emission volumetric flow Figure 2. The emission waste graph is a causal relationship for an entropy differential known as combustion waste (CW). When applied to the entropy at the expanding path conclusion (EPC), it enables the accurate calculation of turbine power per mass unit (W) as follows [10]:

$$W = h_1 - (h_{EPC} + CW) \quad (1)$$

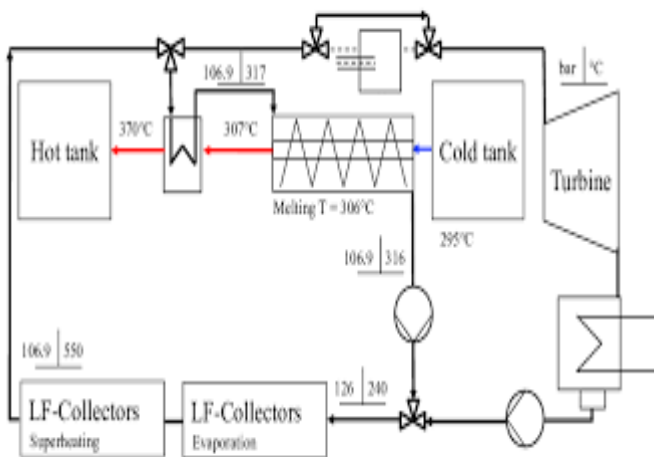


Figure 1. Diagram of the simulated DSP station

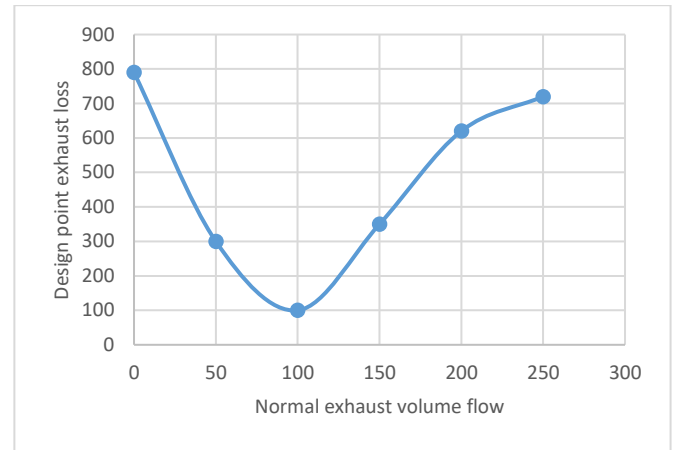


Figure 2. Its standard daily brightness

Based on climate information from the Meteonorm database structure, a second gas-fired engine is activated when the steam flow rate is less than one-third of the design value to prevent power station closure throughout the evening. Because of reduced sinusoidal expenses, Figure 3 exhibits a rise in solar irradiation throughout the summer, when PTC may capture a sizable portion [11].

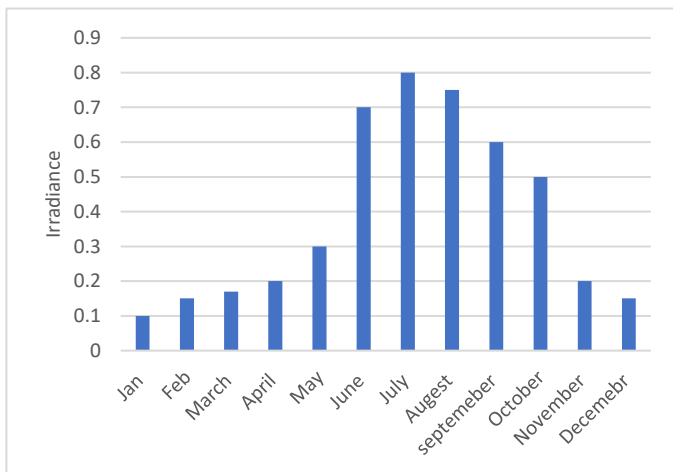


Figure 3. Mean monthly sunlight in Iraq

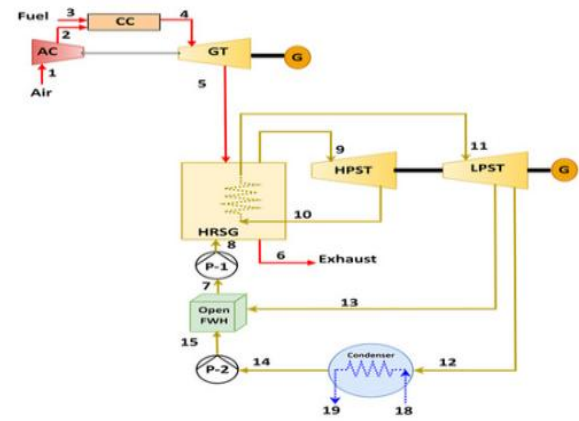


Figure 4. Illustration of the DSP station's hourly modeling process in Iraq [12]

2.2 Technique and parameters of the experiment

In the context of Iraq, a thorough modeling of the DSP solar field was developed for both linear Fourier collections and parabola dips. The first method uses a custom algorithm that calculates both the pressure drop and solar field steam generation based on the required quality of steam and solar radiation. The latter makes it possible to incorporate sophisticated control techniques like narrowing and turning on the second boiler at evening. Using an iterative method, the two programs collaborate to offer an initial estimate of the solar field performance Figure 4.

To prevent a power station, collapse at nighttime, an auxiliary gas-fired boiler activates when the velocity of steam falls below one third of the intended level (8.5 kg/s), therefore maintaining a minimum steam flow rate of 2.8 kg/s.

The referred to location is Madrid. The annual DNI for the location is 1625 kWh/m², based on meteorological data from the Meteonorm dataset. Figure 3 demonstrates a rise

in solar radiation during the summer months, when PTC may capture a substantial portion of the DNI, owing to reduced sinusoidal costs.

3. Results

A comprehensive model of the DSP solar field was developed for both parabolic troughs and linear Diffraction collectors inside a combined Octave setting. In the previous instance, a custom algorithm calculates the steam output as well as the drop of the solar surface, contingent upon the solar rays and the required vapor grade. The last feature permits the incorporation of complex control schemes, involving the activation of the auxiliary boiler at nighttime and refocus. Both projects cooperate to provide a preliminary assessment of the sun's radiation efficiency via an iterative procedure Figure 4.

Temperature input and velocity equilibria were verified at each dx . The controlling parameters are the liquid speed in the heater and the energy value in the evaporator/superheater. The X-Steam utility facilitated the calculation of thermal characteristics of water and steam under all conditions of heat, pressure, and steaming condition.

Furthermore, concentrated and dispersed pressure losses were calculated for both one-phase and two-phase modules independently, as recommended by [13]. Concentrated losses consider four conventional 89° elbows, while dispersed effects are computed at each differential segment, because they involve shearing loss across the whole length of the module. In two-phase circulation, pressure losses are amplified by an amount dependent upon steam reliability, as shown by [13, 14]. The Matlab code produces results for pressure and temperature at the solar field exit, which are displayed alongside the steam rate of flow provided. The last parameter undergoes additional modification: if pressure and temperature surpass the maximum flow rate thresholds, focusing is initiated; conversely, if pressure and temperature fall below the lowest possible flow rate, the second boiler turns on and use of fossil fuels is considered (refer to Figure 4). The reader is directed to [15] for a comprehensive account of the formulas used in the solar field model. This research excludes thermal power storing. Focusing has been disabled.

Yearly numerical simulations have been conducted to assess the efficiency of the DSP plant during various turbine operational conditions. Outcomes are given by concentrating on a representative both summer and winter workday to examine the intricacies of part-load performance. Subsequently, data from one-year models are juxtaposed to assess the influence of turbine operational modes on power production and solar-to-electric performance.

3.1. Hourly Modeling Outcomes

Climatic circumstances regarding the outside temperature and DNI patterns are shown in Figures 5a and 5b for the chosen days: one in winter, on November 15th, and one in summer, June 15th. The minimum outside temperature is around 5°C in winter, while the maximum temperature reaches 51°C during summer afternoons, coinciding with a peak Direct Normal Irradiance (DNI) of 750 W/m^2 . In November, the peak sun radiation is restricted to 640 W/m^2 . Figures 6a and 6b illustrates the total electrical power and total electric performance of the DSP, calculated as the proportion of total power production to solar heat input. Four patterns are shown throughout time to accommodate winter and summer climates as well as throttle and sliding turbine settings.

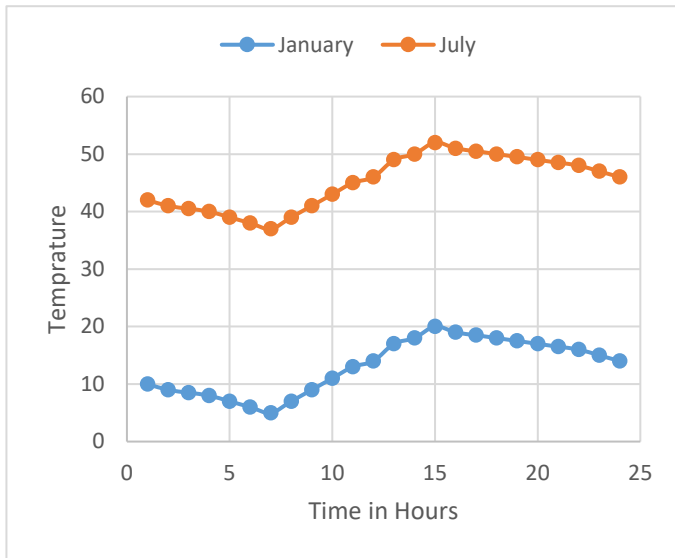


Figure 5a. Temperature of the day

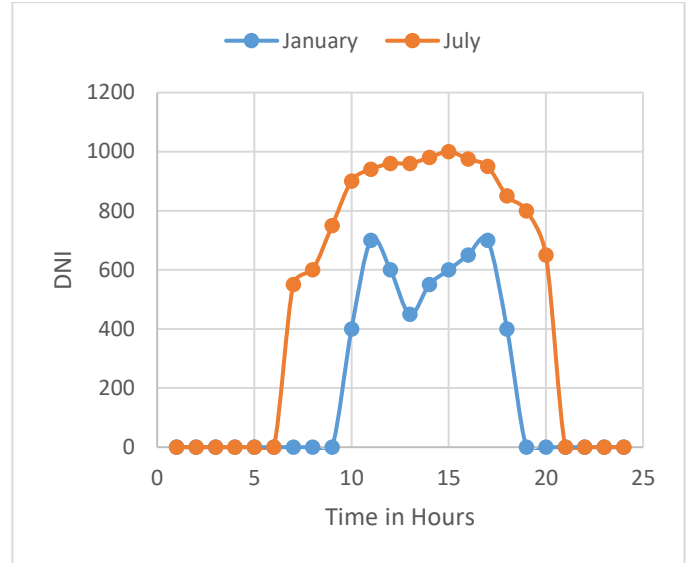


Figure 5b. Sunlight exposure per day

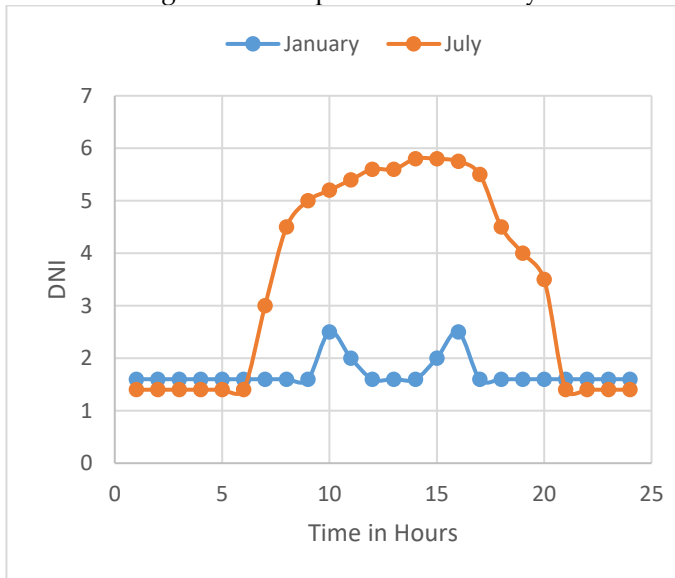


Figure 6a. Gross energy usage per day

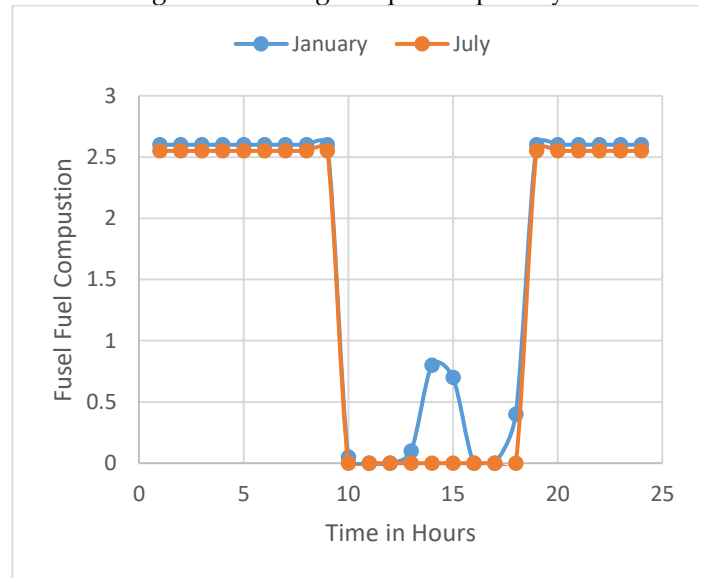


Figure 6b. Use of fossil fuels

Beginning from left to right, the total energy curves indicate that the intended power point of 6 MWe was surpassed for 10 hours on June 15th. In November, the power production is consistently below fifty percent of the rated amount throughout the day.

The causes for this are associated with the elevated sunlight and high visibility during summer, contrasted with the diminished solar energy and suboptimal performance during winter. The proportion of solar radiation captured decreases in winter due to its cosine impact and reduced temperature outside.

The beneficial impact of the sliding setting on total energy performance, compared to the accelerator setting, during midnight at minimal load usage results in a productivity increase of up to 2%; during daytime hours, the enhancement in performance is below 2%. The decreased effectiveness of the accelerator state under partial load is attributable to choking losses in the high-pressure turbine phase. The restriction diminishes the general effectiveness of the HP turbine when the steam flow rate falls below the intended threshold. In contrast, the sliding operation maintains a nearly constant total turbine output at the design value, regardless of the steam flow rate Figure 7.

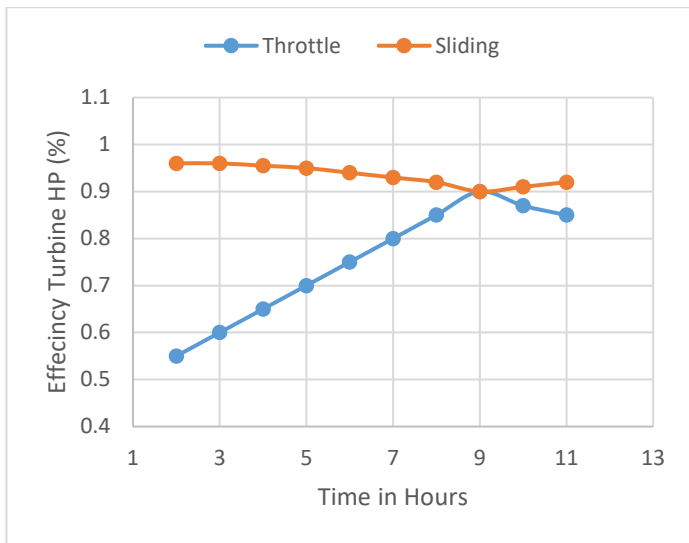


Figure 7. The total efficiency of an HP rotor

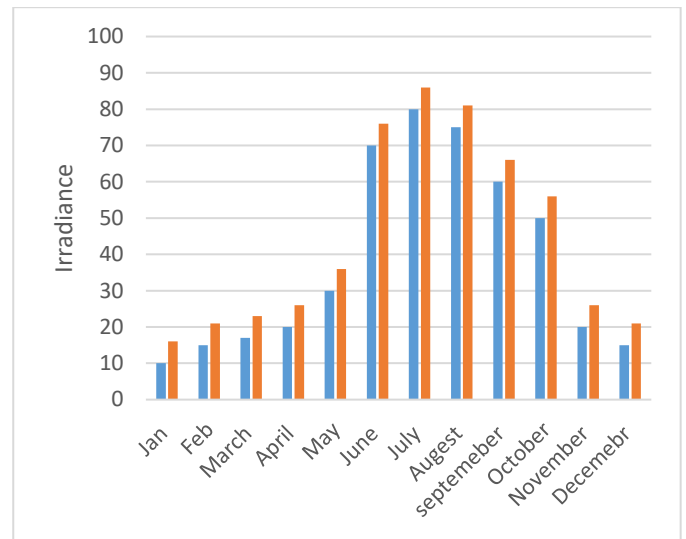


Figure 8. Median total energy production per month.

Concentrating on the sliding mode, it is noteworthy that on the chosen days, the percentage consistently remains below the design threshold (24%) during periods of intense solar radiation and moderate temperatures. A greater quantity of solar energy is accessible at elevated ambient temperatures, hence diminishing the effectiveness of the ranked cycle to around 24%. It is well recognized that heat dissipation to air in a dry cooling system is crucial during hot weather. During winter, low temperatures combined with weak steam output result in 24% at 12 hours. During nightfall, the plant's performance at minimal load is only influenced by the outside temperature, which is three percent greater on winter days.

3.2. Yearly Modeling Outcomes

Figure 8 illustrates the typical monthly total power generation for both turbine settings. The sliding phase guarantees increased total energy production consistently during every season, particularly during winter months when the plant works at partial load continuously. Figure 8 illustrates the total energy effectiveness of the DSP performances for each hour of the entire year, correlated with DNI. Values of DNI below 360 W/m² were excluded owing to severe off-design situations. A second-degree quadratic was determined to be the optimal estimate for both blade speeds. A limit of 24.1% is attained for accelerator setting.

Table 3. DSP operations on an annual basis.

	Throttle mode	Sliding mode
Electricity Gross energy (MWh/day)	53.1	53.6
Gross energy performance on average (%)	18.2	19.1
Mean level at the turbine's intake (bar)	73.8	74
Annual usage of fossil fuels (kg/h)	501	504

The outcomes of the yearly experiments are encapsulated in Table 3. In comparison to the accelerator setting, the sliding selection yields about 6% more total electrical power annually, accompanied by an enhanced average total efficacy (19.7% against 21.3%). The mean turbine intake pressure is around fifty percent of the intended amount, so indicating that the DSP generator works at partial capacity for the majority of every year.

The sole drawback of sliding operation is a marginal increase in the use of fossil fuels (+3.3%), attributed to the elevated entropy of the hot steam reaching the high-pressure

turbine; the heated steam maintains the same temperature as in accelerator function but operates at reduced pressure ranges. This disadvantage mostly manifests at nighttime.

5. Conclusions

A modeling approach using three distinct simulation platforms, including MATLAB, has been employed to predict the performance of a 6MWe DSP solar power plant, developed under the INDITEP program. The coexistence of different codes allowed the user to take the best from each programming language. Specifically, it is the most appropriate platform for addressing transient irradiation intervals; it additionally excels in forecasting energy unit performance under partial load while adeptly handling the specifics necessary for DSP solar environment modeling. Annual models with a one-hour time increment were conducted for two distinct operational modes of the HP steam turbine, namely "sliding" and "acceleration" inlet temperature. The sliding mode yielded a 6% increase in net power generation and a 10% enhancement in net power performance annually, as comparison to the throttle mode. The only disadvantage is a 3.1% increase in energy use.

References

1. Ravelli, S., et al., *Modeling of direct steam generation in concentrating solar power plants*. Energy Procedia, 2016. **101**: p. 464-471.
2. Montes, M., A. Abánades, and J. Martínez-Val, *Thermofluidynamic model and comparative analysis of parabolic trough collectors using oil, water/steam, or molten salt as heat transfer fluids*. 2010.
3. Martínez, I., et al., *Annular Two-Phase Flow Regimen in Direct Steam Generation for a Low-Power Solar System*, in *Experimental and Computational Fluid Mechanics*. 2013, Springer. p. 157-174.
4. Chiarappa, T., *Performance of direct steam generator solar receiver: laboratory vs real plant*. Energy Procedia, 2015. **69**: p. 328-339.
5. Seitz, M., P. Cetin, and M. Eck, *Thermal storage concept for solar thermal power plants with direct steam generation*. Energy Procedia, 2014. **49**: p. 993-1002.
6. Pal, R.K. and R. Kumar, *Investigations of thermo-hydrodynamics, structural stability, and thermal energy storage for direct steam generation in parabolic trough solar collector: a comprehensive review*. Journal of Cleaner Production, 2021. **311**: p. 127550.
7. Bandaru, S.H., et al., *A general framework for multi-criteria based feasibility studies for solar energy projects: Application to a real-world solar farm*. Energies, 2021. **14**(8): p. 2204.
8. Wu, J., et al., *Operation strategy and capacity configuration of digital renewable energy power station with energy storage*. Heliyon, 2024. **10**(15).
9. Zarza, E., et al., *INDITEP: The first pre-commercial DSG solar power plant*. Solar energy, 2006. **80**(10): p. 1270-1276.
10. Graciano, D., et al., *Damage evaluation and life assessment of steam turbine blades*. Theoretical and Applied Fracture Mechanics, 2023. **124**: p. 103782.
11. Escandón, R., et al., *How do different methods for generating future weather data affect building performance simulations? A comparative analysis of Southern Europe*. Buildings, 2023. **13**(9): p. 2385.
12. Talal, W. and A. Akroot *Exergoeconomic Analysis of an Integrated Solar Combined Cycle in the Al-Qayara Power Plant in Iraq*. Processes, 2023. **11**, 656 DOI: 10.3390/pr11030656.
13. Akba, T., D. Baker, and A.G. Yazıcıoğlu, *Modeling, transient simulations and parametric studies of parabolic trough collectors with thermal energy storage*. Solar Energy, 2020. **199**: p. 497-509.
14. Khoshrou, I., M.J. Nasr, and K. Bakhtari, *New opportunities in mass and energy consumption of the Multi-Stage Flash Distillation type of brackish water desalination process*. Solar Energy, 2017. **153**: p. 115-125.
15. Ramde, E.W., et al., *Pilot low-cost concentrating solar power systems deployment in Sub-Saharan Africa: a case study of implementation challenges*. Sustainability, 2020. **12**(15): p. 6223.