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Modelling and simulation of a 1 MWe parabolic trough concentrator solar thermal power plant in different locations in Egypt

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Abstract

The aim of this article is to create a simulation of the thermal performance of a solar power plant that generates electricity using a steam Rankine Cycle, with a solar parabolic trough concentrator as the primary heat source. The TRNSYS simulation Software and the TESS Library were used to carry out the simulation. The simulation software was utilized to analyse the impact of the meteorological conditions on the annual thermal and electrical energy gained for a solar power plant of 1 MWe. The solar power plant is consisting of various components, including parabolic trough concentrators (PTC), a thermal storage tank, a steam generator, an auxiliary boiler, a condenser, variable speed pumps, a steam turbine and an electric generator. The investigation focused on analysing the temperature and energy values of the PTC, steam generator, and electric generator. This theoretical analysis was applied to three locations in Egypt, where each location has different metrological conditions. The annual DNI values are between 1800 kWh/m^2 to 2500 kWh/m^2, so the energy production and plant performance have been evaluated with different solar radiations on those sites. The excellent thermodynamic properties of synthetic oil make it a preferred choice as a HTF. The designed plant can generate annual thermal energy 7.50, 6.18, 5.14 GWh of with plant efficiency of 46%, 52%, and 58% for Aswan, Asyut, and Sidi-Barrani respectively. The outcomes of the PTC solar thermal power plant's performance suggest that there is scope for more progress and advancement in the development of CSP plants in Egypt.

***Keywords**:* Solar power plant; Parabolic trough concentrator; Rankine cycle; Steam generator; TRNSYS software

Introduction

Solar thermal power plants are an environmentally friendly of electricity generation. However, their effectiveness depends on seasonal variations in solar radiation levels, which are location-dependent. Furthermore, factors such as cloud cover, precise siting, and reliable operation of the plant can lead to uncertainties, making it a challenging matter to address [1, 2]. In recent times, parabolic trough solar concentrators have gained popularity as a cost-effective solution for meeting future electricity requirements. The economic targets can be achieved under suitable climate conditions, utilizing medium or high levels of direct solar radiation, even in partially cloudy conditions in certain locations [3, 4]. The demand for energy has grown considerably in recent times, leading to a critical situation. Consequently, there is a shift towards renewable and sustainable energy sources, with solar energy being the most plentiful among them [5].

Compared to photovoltaic (PV) plants, Concentrated Solar Power (CSP) plants have higher efficiency and longer lifespan, which makes them a more promising option [6]. Given Egypt's substantial solar potential, particularly due to the abundance of vast desert land, it is crucial to investigate design of concentrated solar thermal power plants [7]. The parabolic trough solar collector (PTC) is currently the most appropriate technology for industrial purposes since it has the ability to function within temperature ranges of 100 to 400 °C [8, 9]. Parabolic troughs are utilized in 90% of all CSP systems due to their maturity in comparison to other concentrating collectors' types. These systems are regarded as lightweight and have been in use for many years [10, 11].

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Modelling and simulation studies play an effective role in the design and execution phases besides providing a clear vision for optimizing the performance of critical energy processes [12]. In the near future, they should also help in the operation and maintenance of power plants and also will be a great tool for decision-makers to evaluate the energy and economic impact [13, 14]. A detailed assessment of the energy and economic performance of a 100MW parabolic trough CSP plant in central Saudi Arabia was carried out by Asiri and AL-Yahya. By utilizing SAM software, they found that the plant's thermal performance yielded an annual energy production of 324,781 MWh and a capacity utilization factor of 37.1% with a direct normal irradiance (DNI) of approximately 6.38 kWh/m^2.day. The plant generated a total of 7,927,623 MWh of electrical energy during its 25-year lifespan. The proposed CSP plant was economically feasible at the intended location because its payback period was shorter than its lifespan [15]. Nada Y. Ahmed et al. conducted a study that examined a single solar collector LS-2 type with a width of 5 m and a length of 50 m. They used Therminol Vp-1 as the HTF fluid due to its good thermal properties and temperature range. The study involved calculating the absorbed solar energy for the four seasons, given direct solar radiation varying from 1950 kWh/m^2 to 2600 kWh/m^2 throughout the year. The results showed that the number of sunny hours per day ranged from 8 to 10 hours, and the absorbed energy ranged from 4.2 kW/m^2 in winter to 5 kW/m^2 in summer [16]. Gary Ampuno et al. developed a model for a solar thermal energy generation plant, which took into consideration variables such as output temperature and oil flowrate. They simulated the plant using TRNSYS software, and validated the models with a solar concentrator with an area of 2,635.2 m^2 using MATLAB software. The electric generator output power obtained was 0.5 MW. The simulation results showed that the total annual solar thermal energies obtained at the selected sites were 2450 GJ, 1080 GJ, and 1700 GJ, respectively. The corresponding electricity generation was about 680 MWh, 497 MWh, and 411 MWh, and the total amount of CO_2 emissions avoided was about 526 tons, 85 tons, and 70 tons, respectively. The results indicates that the solar thermal energy generation plant has significant potential to generate renewable energy while reducing carbon emissions at the selected sites [17]. Desai et al. carried out a simulation of a Solar Thermal Power Plant in India, which had a capacity of 1MWe and was not reliant on fossil fuels. The plant comprised two solar fields: parabolic trough collectors and linear Fresnel reflectors. The first HTF was Therminol VP1 oil, which flowed through the parabolic trough collectors, while the second HTF was saturated steam that moved through the linear Fresnel reflectors. The two HTFs were combined to produce superheated steam at a pressure of 42 bar and a temperature of 350°C, which powered a turbine and generator to generate electricity. The parabolic trough collectors provided approximately 60% of the required heat, while the linear Fresnel reflectors supplied the remaining 40%. The plant produced an annual energy output of about 1365 MWh, with a capacity factor of 15.6%, based on an annual DNI of 1273 kWh/m^2 at the location. In April, the plant delivered a maximum output power of around 232.2 MWh, while the minimum output power of approximately 122.5 MWh was noticed in June [18]. Kumar et al. designed and analysed a 1 MWe PTC plant based on the direct steam generation (DSG) method. The investigated numbers of collectors are based on standard collector Euro trough-100 m, LS-3 data. Four collectors were used in preheating, seven collectors were used in the evaporation zone, and three collectors were used in the superheated zone. While the input solar radiation energy was 4.257 MW, the collector thermal efficiency was 71.05%, the overall plant/solar field efficiency was 23.48%, and about 76.52% of the heat was lost from the PTSC plant [19]. A dynamic simulation model was introduced by Al-Maliki et al. for an operational parabolic trough solar thermal power plant located in Spain. The simulation model they created characterized the path of the heat transfer fluid, steam/water paths, and sophisticated control systems, which includes controllers for steam bypass, economizer water bypass, and drum level. The model of the parabolic trough power plant was developed using Advanced Process Simulation Software (APROS). By comparing the simulation outcomes with the actual measurements, they were able to demonstrate that their model can accurately predict the plant's real behavior. The validation of their simulation model made it possible to accurately simulate future operation processes of the real plant [20]. Jignasha Bhutka et al. made modifications to the design of a 1 MW power plant that was using Parabolic Trough Collector (PTC) technology in Gurgaon. To validate their modified design, they tested it using data from 18 solar power plants of different capacities located in different parts of the world. They adjusted the model parameters to match the plant capacity, without significantly altering the overall plant design. Their study revealed that the amount of energy that can be generated annually by a solar thermal power plant with a 1 MWe capacity is not fixed, but rather ranges from 900 to 2700 MWh [21]. In 2022, Benhadji Serradj et al. carried out a study to evaluate and simulate a 100 MW solar thermal power plant that uses parabolic trough technology, and investigated two cooling systems: dry and evaporative condensers. The solar power plant was designed with a solar multiple of two, which produced excess energy that was stored using molten salt in an indirect two-tank (cold/hot) thermal storage system, a widely used technology globally. The researchers performed a cost analysis of the power plant, and found that the levelized cost of electricity (LOCE) was approximately 0.062 USD$/kWh, with 8.78 years period of payback and a benefit-cost ratio of 1.73, indicating that the project was economically feasible. Moreover, a thorough assessment of the power plant's environmental impact was carried out, revealing that the solar power plant has the capability to mitigate carbon dioxide gas emissions by up to 2 million tons of CO_2 annually when compared to a traditional generation system [22]. A study conducted by Jebreel, A. A. A. and Hamad, H. M. A. aimed to design and simulate a 1 MW concentrated solar power plant with thermal energy storage that would operate in Sudan. The researchers utilized TRNSYS software to achieve this objective. The study evaluated two power generation scenarios, one without a storage system where the plant would only function during daylight hours, resulting in power generation fluctuating between 0.6 and 1 MW throughout the year. The other scenario involved thermal energy storage which would provide around 0.9 MW throughout the year. Overall, this model could serve as a valuable tool for analysing PTC power plant components' performance and predicting power generation under varying scenarios and conditions [23].

The main aim of this research is to develop and simulate a parabolic trough solar thermal power plant that consist of a solar field, thermal energy storage (TES) tank, a steam generator, a power Rankine cycle, and a fuel boiler as an auxiliary heater. The study will be carried out in three different locations in Egypt, which have different solar irradiance levels, to determine the impact of metrological parameters on the power plant's functionality. The annual thermal energy generated by the solar concentrator for each location will be assessed, along with the annual auxiliary energy used to produce 1 MWe of electricity. The study will also evaluate the monthly solar fraction and the efficiency of the solar power plant for each location. Moreover, the simulation program will be an essential resource for investigating the thermal performance of such solar power plants.

Description of the system

The solar power plant consists of a parabolic trough concentrator, a stratified storage tank, a steam generator, an auxiliary boiler, and an energy conversion system (the power block). The solar collector field has a total area of 10,000 m^2. The storage tank has a cylindrical shape with a volume of 40 m^3. A steam generator was connected to the storage tank to generate steam using the hot oil from the storage tank. The HTF is a synthetic oil with a specific heat of 1.9 kJ/kg K. The generated steam output from the steam generator passes through a fuel boiler with 2 MW power, which acts as an auxiliary heater source, to maintain the steam state at the required condition for the steam turbine. A steam turbine of 1.5 MW with 0.7 efficiency was used to transfer steam energy into mechanical energy. An electric generator of 1.5 MW with 0.95 efficiency was connected to the steam turbine to transfer the mechanical work into electric work. Water cooled condenser was connected to the outlet of the steam turbine to condense the outlet steam. A variable-speed pressure pump was used to circulate the water through the steam cycle. The schematic diagram of the plant is presented as shown in Fig. 1.

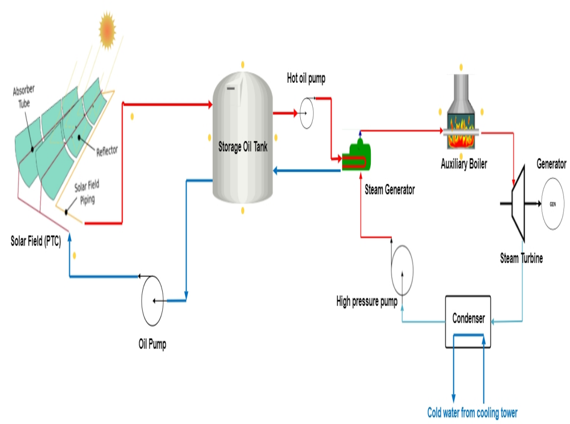


Figure 1: Schematic diagram of the solar thermal power plant

The initial stage of establishing a CSP power plant is choosing a suitable location. A CSP power plant can only be set up in areas where the Direct Normal Irradiance (DNI) is greater than or equal to 5.5 kWh/m^2.day (equivalent to over 1800 kWh/m^2.year). Various factors, such as water and land availability, are taken into account when selecting a site. There are additional requirements for installing a solar thermal power plant, including a reliable water supply, access to transportation, connection to the power grid, soil quality, land costs, initial funding, environmental impact, etc. Preferably, solar energy facilities should be located in areas with high DNI levels, which are represented by the orange and red zones on Figure 2. These zones are located in the Western Desert and along the Red Sea coast.

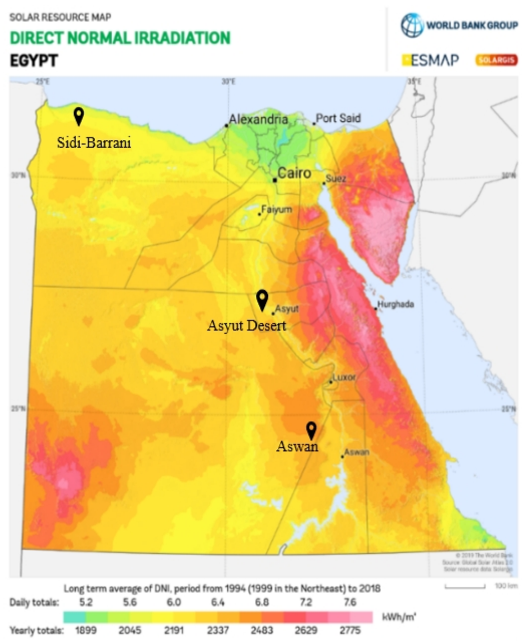


Figure 2: The Solar Atlas of Egypt contains data of direct normal radiation [24]

Based on the climatological data availability and the potential sites indicated in figure 2, the locations that have the highest annual DNI values have been chosen. The coordinates of the selected regions, Sidi-Barrani, Asyut and Aswan, and the annual Direct Normal Irradiance intensity for those cities are presented in table 1.

Table 1
The coordinates and annual radiation for the selected sites

Name of the Site	Location Coordinates	Annual DNI (kWh/m^2)
Sidi-Barrani	N 31° 38°, E 25° 24° 27°	1745 – 2000
Asyut Desert	N 27° 03°, E 31° 01° 69°	1940 – 2460
Aswan	N 23° 58°, E 32° 47° 192°	2885 – 3270

The assessment of total electrical energy production, efficiency, capacity factor, and thermal energy output for a concentrated solar power plant requires multiple input parameters. Considering a 1 MW electricity generation, the components' efficiencies, and the plant operation availability during the sunset period, some design parameters of main plant components are presented in table 2.

Table 2
The PTC solar thermal power plant design parameters for the simulation

Item/Component	Value	Unit
Solar Field		
Collector type	PTC	-
No. of collectors per loop	5	-
No. of loops	65	-
Aperture area	10000	m^2
HTF (Synthetic Oil) specific heat at (25°-400°)	(1.5 – 2.6)	kJ/kg K
Stratified Storage Tank		
Type	Cylindrical	-
Volume	30	m^2
Hight	2.4	m^2
Loss coefficient	3	kJ/h m^2 K
Oil pump flowrate	10.5	kg/sec
Power Cycle		
Boiler Capacity	2	MW
Boiler efficiency	0.76	-
Condensate pump flowrate	1.9	kg/sec
Turbine capacity	1.5	MW
Electric generator output	1	MWe

Modelling and Simulation procedures:

TRNSYS is simulation software designed mainly for the simulation of renewable energy engineering fields. It can be used for designing active systems, and also, it can be used for solar power plants simulation to get the plant performance and efficiency based on model results [25]. Figure 3 shows the component that represents the modelling system, including the variable speed pump, parabolic trough concentrator, auxiliary gas boiler, stratified storage tank, steam generator, steam turbine, electric generator, and water condenser. The annual weather data from the TRNSYS library was used for the three selected locations in Egypt. During the daytime, the flow rate of the heat transfer oil through the PTC was adjusted to 10.5 kg/s and the circulation stops through the night when the temperature drops down.

The Mathematical model of main components.

1. **Solar concentrator**

The model of Parabolic trough concentrator (PTC) components relies on theoretical equations that have been described by Duffie, J.A. and Beckman, W.A

[26]. The amount of heat that the PTC gains as a rate $\dot{Q}_u$ is presented as shown:

$$\dot{Q}_u = R_1 R_2 A_{ap} N_{pa} \left[F_R (\tau\alpha)_n IAM \cdot I_b \frac{F_R U_L}{conRat} (T_{in} - T_{amb}) \right] \quad (1)$$

Where A_{ap}, F_R, I_b, U_L refer to the following parameters, respectively: the concentrator aperture area, heat removal factor, incident direct solar radiation, and overall heat transfer coefficient. The following equation provides the value of T_{out}, which represents the temperature of the fluid at the outlet of the collector:

$$T_{out} = T_{in} + \frac{\dot{Q}_u}{\dot{m} \cdot C_{p,f}} \quad (2)$$

2. Storage tank

This component models the thermal performance of a sensible energy storage tank that contains fluid with thermal stratification. It assumes that the tank is divided into six fully mixed segments of equal volume, and the energy balance equation for each segment i^{th} is expressed as shown:

$$M_i C_{p,f} \frac{dT_i}{dt} = \& \alpha_i \dot{m}_h C_{p,f} (T_h - T_i) + \beta_i \dot{m}_L C_{p,f} (T_L - T_i) + UA_i (T_{amb} - T_i) + \dot{Q} + \gamma_i (T_{i-1} - T_i) C_{p,f} + \gamma_i (T_{i-1} - T_i) C_{p,f} \quad (3)$$

Where $\dot{m}_h$ is the fluid mass flow rate coming from the heat source while the mass flow rate to the load and the fluid specific heat are represented by $\dot{m}_L$, $C_{p,f}$, respectively.

3. Steam Generator

The component is designed to simulate the functionality of a heat recovery steam generator, which uses a high-temperature heat source to heat a flow of steam. Additionally, this component can model a steam superheater. It can be set up to operate in either a counter-flow or parallel-flow configuration.

4. Back-up Gas Boiler

That component is used to increase the temperature of the steam to the required level for superheating. The model determines the amount of heat $\dot{Q}$ necessary to raise the steam's temperature to the desired value T_{set} using the equation below:

$$T_{set} = \frac{\dot{Q}}{\dot{m}_{p,f}} + T_{in} \quad (4)$$

Where T_{in} represents the temperature of the fluid at the inlet, while $\dot{m}$ refers to the flow rate of the fluid.

5. Steam Turbine

The component models the operation of a non-condensing steam turbine. The equation for the work done during the expansion process $\dot{W}$ is expressed as follows:

$$\dot{W} = \dot{m}_{st} (h_{in} - h_{out,act}) \quad (5)$$

The enthalpy $h_{out,act}$ of the steam after expansion process is determined by assuming that the process is isentropic. The subroutine for steam properties is then called using the inlet entropy and outlet pressure values which returns the ideal enthalpy $h_{out,ideal}$ for the expansion process. To obtain the actual enthalpy of the steam following expansion, the following equation is used:

$$h_{out,act} = h_{in} \quad \eta_{isen} (h_{in} \quad h_{out,ideal}) \quad (6)$$

Where h_{in} refers to the inlet steam enthalpy, while η_{isen} represents the isentropic efficiency of the turbine.

6. Generator

To create electric power using an electric generator, the spinning motion of an input shaft is converted into electricity. The model is considering the generator efficiency η and the power of the input shaft $\dot{P}_{in}$ to calculate the amount of electricity produced as power $\dot{P}_{out}$ using the following formula:

$$\dot{P}_{out} = \eta \dot{P}_{in} \quad (7)$$

The simulated components are connected to model the desired system that provides flexibility in changing various operating conditions, configurations, and weather data locations as shown in Figure 3. The calculations were carried out for an entire year and the simulation time interval was set to 60 minutes. The integration of incident DNI, auxiliary boiler required power, and an electric power value was performed using a quantity integrator component.

Results and discussion

1. Solar potential assessment.

Sidi-Barrani, Asyut, and Aswan weather data have been analysed for the plant solar field as shown in figure 3 and on average, throughout the year, the three sites are exposed to a sufficient amount of radiation for around 10 to 12 hours per day. The performance of the parabolic trough concentrator of the power plant at the selected sites has been evaluated using data from a standard meteorological year (TMY), obtained from NREL.

Figure 4 presents the daily direct normal radiation that each location receives for one week in June to illustrate the DNI profile of each site. Aswan and Asyut receive close maximum daily values of DNI with about 920 W/m^2 and Sidi-Barrani gets lower DNI values with about 860 W/m^2 per day. The three sites have a long daily solar radiation period in summer about 14-15 hrs. As shown in Fig. 4. The difference in DNI values for the three selected sites can be noticed in figure 5 as it is slightly different through the summer season while there is a considerable difference in the winter months.

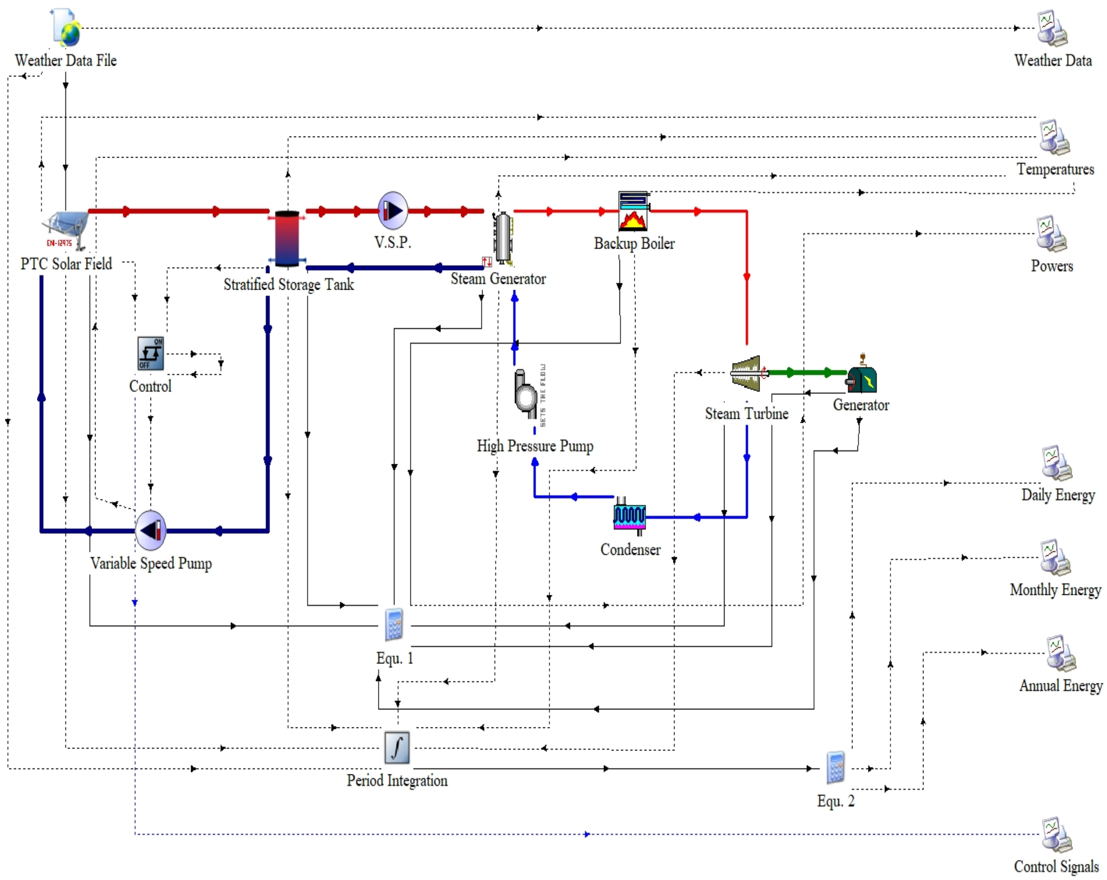


Figure 3: TRNSYS simulation model of the plant

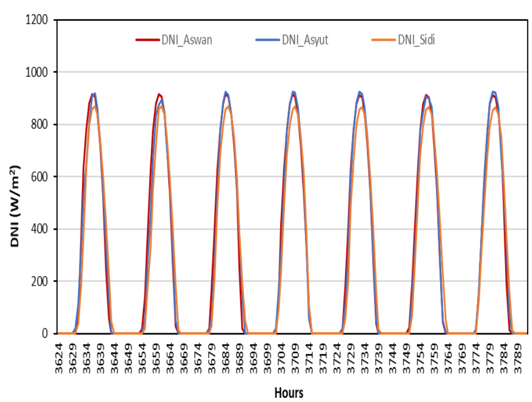


Figure 4: Direct normal radiation for the first week in June for the three sites

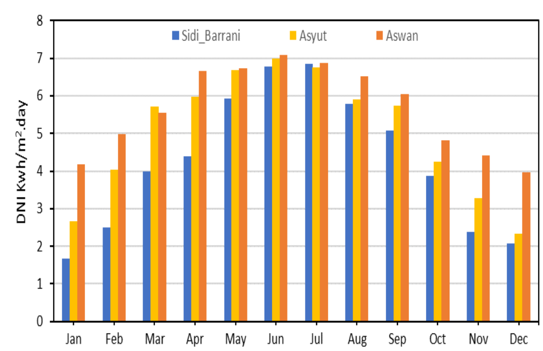


Figure 5: Average of daily solar incident irradiation energy for each month

It’s obvious that the highest daily DNI value was recorded for the Aswan region, which was about 7 kWh/m^2 in June, and the minimum value was recorded for sidi barani, which was about 1.8 kWh/m^2 in January.

Figure 6 illustrates the changes in wind speed and dry bulb temperature, based on the recorded data. The highest dry bulb temperature of 45°C was observed in Aswan on June 19th, while the lowest temperature of 2°C was recorded in Asyut on January 15th. In terms of wind speed, the maximum of 13.70 m/s was noted in Aswan on January 21st, and the minimum of 0.05 m/s was observed in Sidi-Barrani on April 4th.

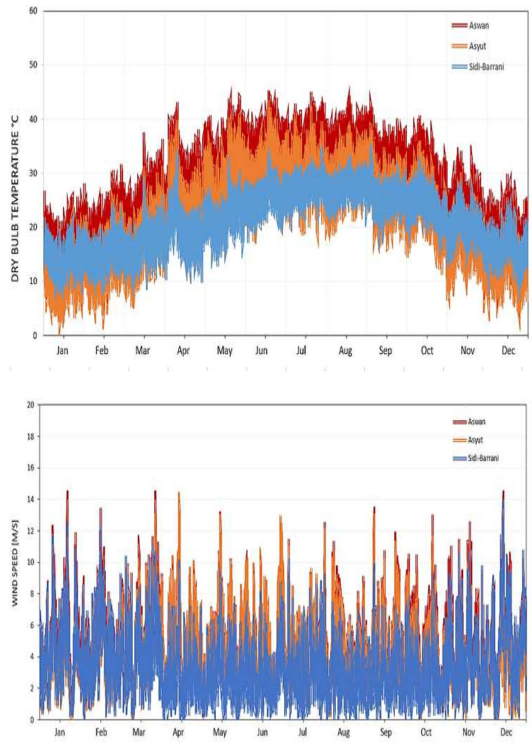


Figure 6: Dry bulb Temp and wind speed for the three selected site

2. Plant performance evaluation.

The amount of thermal energy gained from the PTC each month is shown in Figure 7. It can be noticed that Aswan city is achieving the highest energy gained with about 820 MWh_{th} in June. The difference is significant among the three locations in all seasons except the summer season as the amount of energy gained is high and close to each other. The least amount of energy is gained in December in Sidi-Barrani on the North Coast of Egypt.

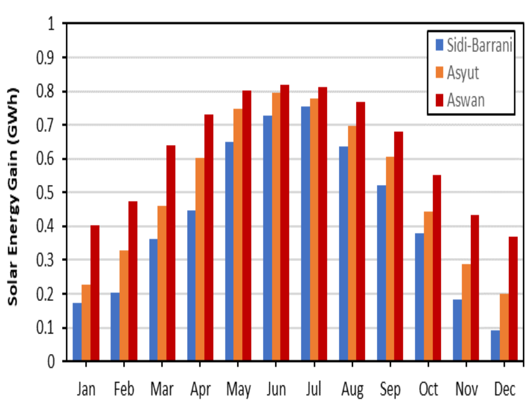


Figure 7: Energy gained from the solar field each month

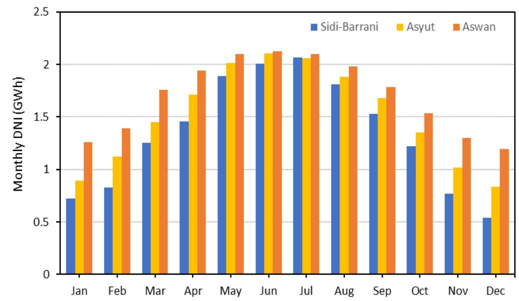


Figure 8: Monthly DNI gained from the solar field

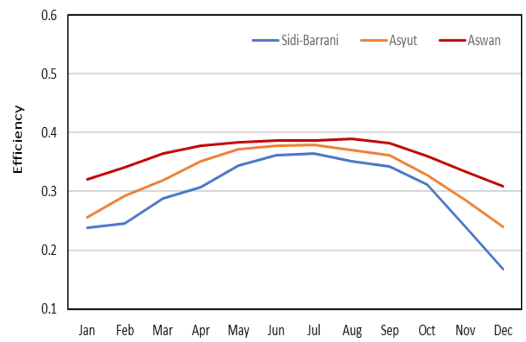


Figure 9: Solar field efficiency for the three select regions through one year

The outlet and inlet temperatures and temperature rise of HTF gained by the solar field through a complete day in winter (15 January) and a complete day in summer (15 June) for the three sites are presented in figure 10 and figure 11. The energy transfer rates between the PTC and HTF, and Auxiliary boiler and steam, are presented in figure 12 for one week in summer (10-17 June) in Aswan. The Monthly Solar Fraction (SF) for a whole year is calculated for the three selected sites and presented in figure 13. The Maximum SF was in Aswan in June and July with a value of 0.42 and 0.41 respectively while the least SF value is 0.06 in December at Sidi-Barrani city. Figure 14 shows the amount of thermal energy obtained annually from the solar parabolic trough concentrator, the annual electric energy generated, and the annual input energy required from the steam boiler for the selected sites. The figure demonstrates that Aswan has the highest annual energy gain from the solar concentrator where it records 7.5 GWh while the electric energy generated is 9.38 GWh and the annual input fuel energy required by the steam boiler is 18.60 GWh. The lowest annual energy gained by the solar concentrator is achieved in Sidi-Barrani, where it records a value of 5.14 GWh with the same amount of electrical energy generated while the annual fuel energy required by the steam boiler is 19.50 GWh.

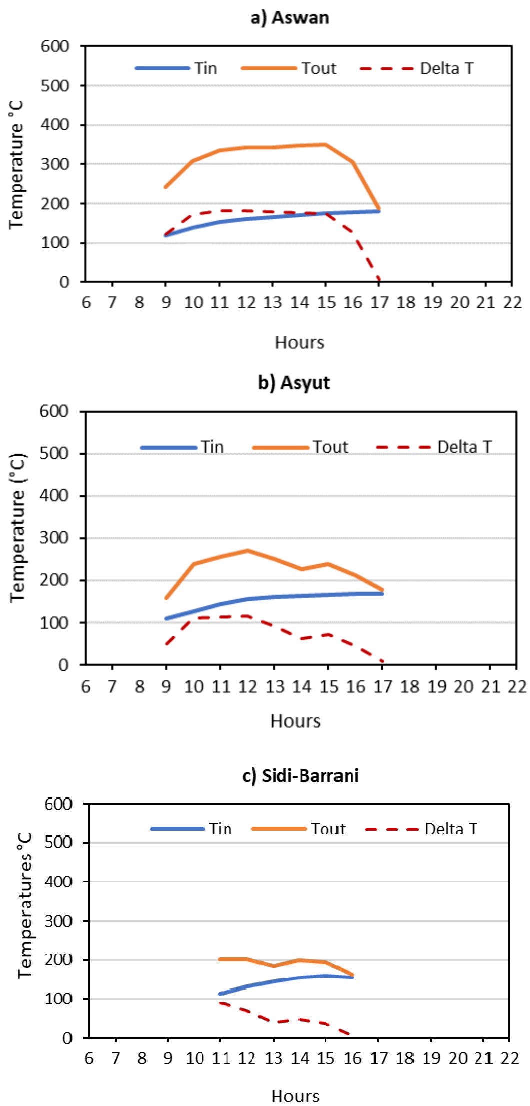
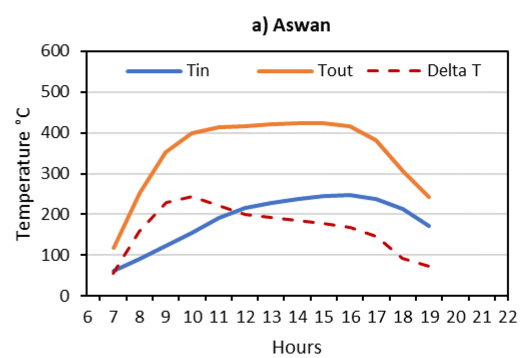


Figure 10: The inlet, outlet, and temperature raised of HTF through the solar concentrator on a day in Winter (15 January) for a) Aswan b) Asyut c) Sidi-Barani



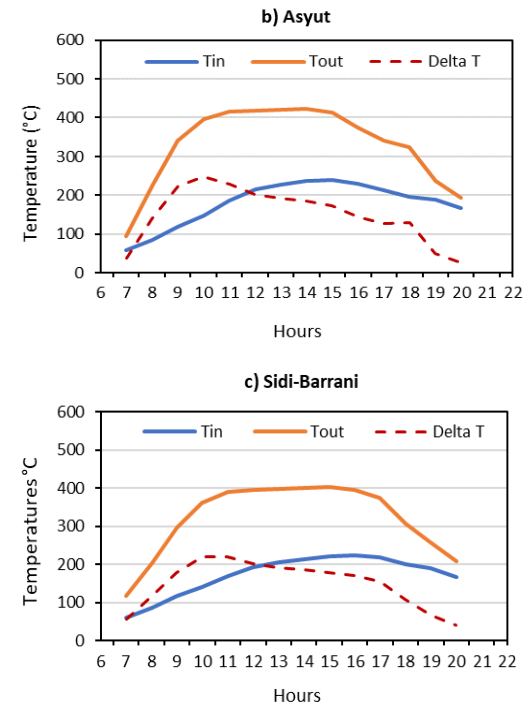


Figure 11: The inlet, outlet, and temperature raised of HTF through the solar concentrator on a day in Summer (15 June) for a) Aswan b) Asyut c) Sidi-Barani

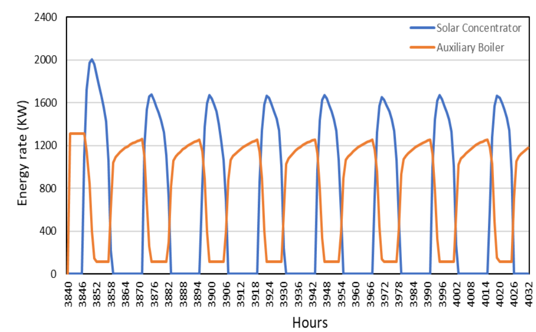


Figure 12: Energy rate delivered from Collector and Auxiliary Boiler from 10-17 June

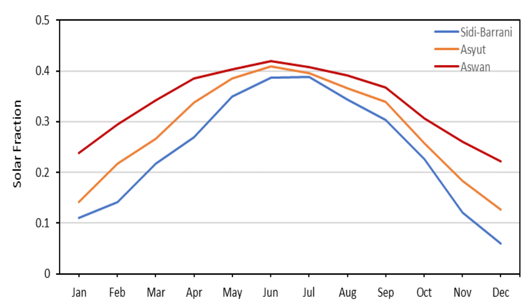


Figure 13: Solar Fraction of June in the three selected sites

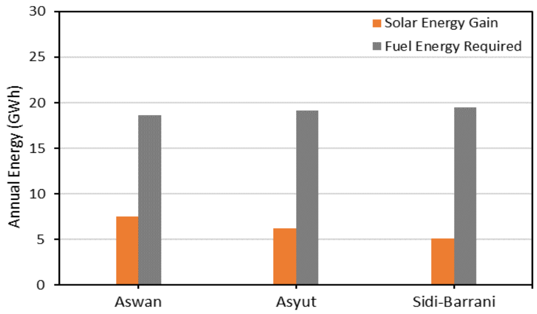


Figure 14: The Collector Energy Gained and Boiler Energy Required Annually for the Selected Sites

Figure 15 represents the thermal energy which indicates the amount of fuel needed for the boiler to maintain a constant steam condition at different solar collector areas for the three selected locations. The collector surface area varied in the simulation from 8000 to 14000 m^2. The save in the annual energy required by the boiler is under investigation while changing the collector aperture area in the simulation for each location.

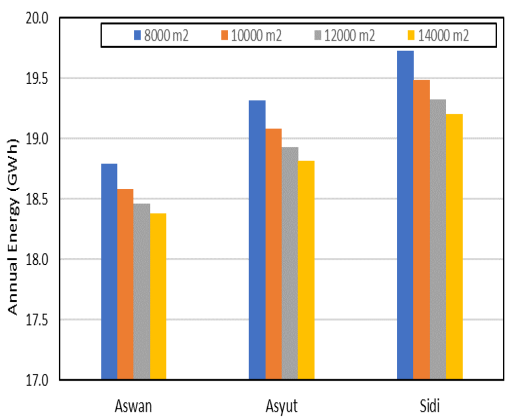


Figure 15: The annual energy required by the boiler at the three selected Sites with different PTC aperture areas

At 10000 m^2, it is noticed that, Aswan is the lowest consumption of thermal energy required annually as it needs about 18.5 GWh of thermal energy for the boiler while Sidi-Barrani needs 19.84 GWh as the highest amount of annual energy required by the boiler. As figure 15 shows that increasing the solar concentrators areas by 2000m^2 from 8000m^2 to 10000 m^2 for each location will save energy by about 207.9, 234.7 and 240.5 MWh for Aswan, Asyut and sidi-Barrani, respectively. To get the same output electricity with the same amount of fuel the locations with less DNI will need more land area and cost.

Conclusion

This paper simulates a solar thermal power plant at three different locations in Egypt. According to the results, Aswan and Assiut locations receive the highest rates of solar thermal gain monthly with an average of 0.6 GWh and 0.5 GWh respectively. In summer, the output temperature of synthetic oil (HTF) recorded a value of 380ºC to 420ºC for Aswan and Assiut, respectively. Asyut also has the highest temperature-raised values of the HTF of approximately 250°. The amount of solar thermal energy obtained from the selected sites on an annual basis is 7.50, 6.18, and 5.14 GWh for Aswan, Asyut, and Sidi-Barrani, respectively. The annual thermal energy required by the boiler in Aswan is 18.5 GWh, which is the lowest value compared to other cities taking into consideration that the boiler work with full power when there is no solar radiation. The fuel energy required by the boiler in Sidi-Barrani has a maximum value of 20 GJ. The power plant needs 30 GWh of fuel energy consumption by the steam boiler to generate the same amount of annual electricity of 9.4 GWh without a solar thermal source so the solar field in Aswan with high DNI will save fuel consumption for the boiler by 38%. Previous results agreed with the current results that Aswan and Asyut are promising locations in Egypt to install solar power plants. The proposed model has demonstrated its ability to conduct dynamic simulations that effectively estimate the performance of all components in the plant under various conditions. Further studies in the direction of sensitivity analysis are needed to determine the optimal conditions for the technical and economic feasibility of PTC solar thermal power plants. The simulation program can be considered a valuable tool for studying the thermal performance of solar power plants using the parabolic trough concentrator as a heat source.

Nomenclature

A_{ap}	The aperture concentrator area, m^2
Con_{Rat}	Concentration ration
$C_{p,f}$	Specific heat of fluid, J/kg K
F_R	Heat removal factor
h	Enthalpy, kJ/kg
IAM	Incident angle modifier
I_t	Total solar radiation, W/m^2
M	Mass, kg
$\dot{m}$	Mass flow rate, kg/s
N_{Pa}	Number of the collector in parallel
N_G	Natural gas
$\dot{P}$	Power, W
$\dot{Q}$	Rate of heat energy gained, W

R_1, R_2	Modifier correlations
T	Temperature, ºC
t	Time, s
U_L	Overall heat transfer coefficient
α	Receiver tube absorptivity
η	Efficiency
α_i, β_i, γ_i	Control functions
τ	Transmissivity
Subscripts	
amb.	Ambient
c	Collector
f_g	Evaporation enthalpy
g	Saturated vapor enthalpy
h	Heat source
in	Inlet
isen.	Isentropic
L	Load
out	Outlet
st	Steam
V	Vapor

References

1- Sims, R.E.H. (2004) Renewable energy: A response to climate change. Sol. Energy, 76, 9–17.

2- Brinsfield, R.; Yaramanoglu, M.; Wheaton, F. (1984) Ground level solar radiation prediction model including cloud cover effects. Sol. Energy, 33, 493–499.

3- Taggart, S. (2008) Parabolic troughs: CSP's quiet achiever, Renewable Energy Focus, Volume 9, Issue 2, Pages 46-50, ISSN 1755-0084, https://doi.org/10.1016/S1471-0846(08)70064-7 .

4- Achkari Begdouri, O., El Fadar, A. (2022) Impact of parabolic trough collector model on the CSP plants' performance, Thermal Science and Engineering Progress. 34, 101434, https://doi.org/10.1016/J.TSEP.2022.101434 .

5- Hannan, M. A., Al-Shetwi, A. Q., Ker, P. J., Begum, R. A., Mansor, M., Rahman, S. A., Dong, Z. Y., Tiong, S. K., Mahlia, T. M. I., Muttaqi, K. M. (2021) Impact of renewable energy utilization and artificial intelligence in achieving sustainable development goals, Energy Reports. 7, 5359–5373, https://doi.org/10.1016/J.EGYR.2021.08.172.

6- Ahmadi, MH, Ghazvini, M, Sadeghzadeh, M, et al. Solar power technology for electricity generation: A critical review. Energy Sci Eng. 2018; 6: 340– 361. https://doi.org/10.1002/ese3.239.

7- IRENA (2018), Renewable Energy Outlook: Egypt, International Renewable Energy Agency, Abu Dhabi.

8- Price, H., Carpenter, S. (1999). The potential for low-cost concentrating solar power systems. NREL/CP-550-46649, National Renewable Energy Laboratory, U.S.A.

9- Price, H., Lupfert. E., Kearney, D., Zarza, E., Cohen, G., Gee R, Mahoney, R., (2002), "Advances in parabolic trough solar power technology," Journal of Solar Energy Engineering, Vol. 124, pp. 109–125.

10- Binotti, M., Zhu, G., Gray, A., Manzolini, G., Silva, P., (2013), "Geometric analysis of three-dimensional effects of parabolic trough collectors," Solar Energy, Vol. 88, pp. 88–96.

11- Clark, J.A., (1982), "An analysis of the technical and economic performance of a parabolic trough concentrator for solar industrial process heat application," Int. J. Heat Mass Transfer, Vol. 25, pp. 1427–1438.

12- Subramanian, A.S.R.; Gundersen, T.; Adams, T.A., (2018) Modeling and Simulation of Energy Systems: A Review. Processes 2018, 6, 238. https://doi.org/10.3390/pr6120238.

13- Qudrat-Ullah, H.; (2015) Modelling and Simulation in Service of Energy Policy, Energy Procedia, Volume 75, Pages 2819-2825, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2015.07.558.

14- Ringkjøb, H.; Haugan, P. M.; Solbrekke, I. M.;(2018) A review of modelling tools for energy and electricity systems with large shares of variable renewables, Renewable and Sustainable Energy Reviews, Volume 96, Pages 440-459, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2018.08.002.

15- Asiri, I. M., AL-Yahya, S. (2021). Design and Analysis of Parabolic Trough Collector Power Plant in Saudi Arabia. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 12(2), 12A2F, 1-13. DOI:10.14456/ITJEMAST.2021.27.

16- Ahmed, N. Y., Abdel-Aziz, A. M., El-Maghalany, W. M., Rezeka, S. F. (2017) Absorbed Solar Energy in Parabolic trough Collector in Alexandria, Egypt. International Journal of Engineering Research & Technology (IJERT) http://www.ijert.org ISSN: 2278-0181 IJERTV6IS110199 Vol. 6 Issue 11, November – 2017.

17- Ampuno, G., Lata-García, J. & Jurado, F. (2021) Modeling of a solar thermal power generation plant for the coastal zones through the TRNSYS program. Electr. Eng. 103, 125–137. https://doi.org/10.1007/s00202-020-01037-z.

18- Desai, N., Bandyopadhyay, S., Nayak, J., Banerjee, R., & Kedare, S. (2014). Simulation of 1MWe Solar Thermal Power Plant. Energy Procedia, 57, 507–516. https://doi.org/10.1016/j.egypro.2014.10.204.

19- Kumar, A., Chand, S., Umrao, O.P. (2013) Design and Analysis for 1MWe Parabolic Trough Solar Collector plant based on DSG method. International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 6, ISSN: 2278-0181.

20- Al-Maliki, W.; Alobaid, F.; Kez, V.; Epple, B., (2016). Modelling and dynamic simulation of a parabolic trough power plant. Journal of Process

Control. 39. 123-138. 10.1016/j.jprocont.2016.01.002.

21- Bhutka, J., Gajjar, J. and Harinarayana, T., (2016) Modelling of Solar Thermal Power Plant Using Parabolic Trough Collector. Journal of Power and Energy Engineering, 4, 9-25. doi: 10.4236/jpee.2016.48002.

22- Benhadji Serradj, D.E.; Sebitosi, A.B. and Fadlallah, S.O., (2022) Design and performance analysis of a parabolic trough power plant under the climatological conditions of Tamanrasset, Algeria. Int. J. Environ. Sci. Technol. 19, 3359–3376. https://doi.org/10.1007/s13762-021-03350-x.

23- Jebreel, A. A. A.; Hamad, H. M. A., (2022) The design of a model for a 1 MW parabolic trough concentrated solar power plant in Sudan using TRNSYS software. Polityka Energetyczna – Energy Policy Journal, 25(3), 67-90. https://doi.org/10.33223/epj/153589.

24- Energy-Data. Global solar atlas. https://globalsolaratlas.info/download/egypt.

25- TRNSYS 18. A transient system simulation program, Solar Energy Laboratory, University of Wisconsin-Madison.

26- Duffie, J.A. and Beckman, W.A., 1991. "Solar Engineering of Thermal Processes – Second Edition," Wiley-Intercience, New York.