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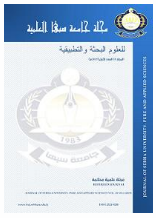

Simulation and optimization of a Concentrating Solar Power Plant with Thermal Energy Storage in Sebha city by using system advisor model (SAM)

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ABSTRACT

Concentrated solar power (CSP) is viewed as one of the most promising alternatives in the field of solar energy utilization; parabolic trough collector (PTC) solar power plants are the most commercially established among the power plants operating with CSP technology. In this paper, a parabolic trough solar thermal power plant with thermal energy storage was evaluated in terms of design and thermal performance, using the SAM program of NREL (System Advisor Model). This program is used to evaluate the active and economic performance of a plant such as monthly energy production, annual energy production, and level cost of energy (LCOE).one representative site in south Libya, Sebha city, which offers an annual average direct normal radiation (DNI) of more than 6.0 kWh/m2/day, has been chosen for the analysis and optimization of the proposed 100 MWe PTC Solar power plant. The optimization is carried out with solar multiple (SM) and full load hours of thermal energy storage TES as the parameters, to minimize the Levelized cost of electricity and maximize the annual energy yield. Based on the findings of the study, the proposed 100 MW PTC solar power plant with thermal energy storage can contribute to the sustainable energy future of Libya with reduced dependency on fossil fuels. This design and performance analysis of the plant encourages further development and innovation of solar thermal power plants in all regions of Libya.

محاكاة وتحسين محطة توليد طاقة شمسية تركيزية مع تخزين للطاقة الحرارية، في مدينة سبها، باستخدام نموذج (SAM)

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الكلمات المفتاحية:
المجمعات الشمسية التركيزية
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التكلفة المستوية للطاقة.

الملخص

تعتبر الطاقة الشمسية المركزة (CSP) من أكثر البدائل الواعدة في مجال استخدام الطاقة الشمسية، حيث تعد محطات الطاقة الشمسية ذات مجمعات الأحواض المكافئة (PTC) من أكثر محطات الطاقة التي تعمل بتكنولوجيا الطاقة الشمسية المركزة من الناحية التجارية. في هذا البحث، تم تقييم محطة للطاقة الحرارية الشمسية ذات حوض مكافئ مع تخزين للطاقة الحرارية من حيث التصميم والأداء الحراري، باستخدام برنامج SAM الخاص بـ NREL. يستخدم هذا البرنامج لتقييم الأداء النشط والاقتصادي لمحطة، مثل إنتاج الطاقة الشهري، والإنتاج السنوي للطاقة، ومستوى تكلفة الطاقة (LCOE). تم اختيار مدينة سبها، في جنوب ليبيا، والتي سجلت بها قيمة للإشعاع المباشر (DNI) يزيد عن 6.0 كيلو واط ساعة / متر مربع / يوم ، لتحليل وتحسين محطة الطاقة الشمسية. يتم إجراء التحسين باستخدام الطاقة الشمسية المتعددة (SM) وساعات الحمل الكاملة لتخزين الطاقة الحرارية TES كمعطيات لتقليل التكلفة المستوية للكهرباء وزيادة إنتاجية الطاقة السنوية إلى الحد الأقصى. استنادًا إلى نتائج الدراسة، يمكن لمحطة الطاقة الشمسية PTC المقترحة بقدرة 100 ميجاوات مع تخزين الطاقة الحرارية أن تساهم في مستقبل الطاقة المستدامة في ليبيا مع تقليل الاعتماد

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على الوقود الأحفوري. يشجع هذا التصميم وتحليل الأداء للمحطة على مزيد من التطوير والابتكار لمحطات الطاقة الحرارية الشمسية في جميع مناطق ليبيا.

1. Introduction

Solar thermal technology means that the energy from the incident solar rays is converted to heat. This technology can be effectively used where a high amount of direct solar radiation is available. Libya is in the heart of these areas because it receives direct high-intensity solar radiation. Even though most of the Libyan regions are ideal for the installation of solar thermal plants [1], there is an increase in the average annual DNI values when moving from northern to southern regions. Thus, most of the Libya regions are highly suitable for the installation of concentrating solar power (CSP) plants. The amount of thermal energy storage and the size of the solar multiple are important factors in the design of CSP plants. Various combinations of these two parameters give different Levelized cost of electricity (LCOE) results. Thermal storage permits CSP to reach higher capacity factors and dispatch generation when the sun is not shining. This can make CSP a good competitor for conventional base- or intermediate-load power plants. The 280 MW Solana 1 is a large-scale example of this kind of technology. It is a power plant under construction by Abengoa for the Arizona Public Service Co, United States [2]. Moreover, in the field of research Kumaresan Govindaraj et al. [3] experimentally investigated the performance of a solar parabolic trough collector (PTC), integrated with thermal energy storage (TES), this study concluded that the PTC should be located very close to the storage system and different components of the storage system have to be insulated properly for reducing heat losses. Abbes et al. [4] carried out a performance assessment of a 100 MWe PTC solar power plant for feasible locations in Algeria, economically, classified this project in the large-scale projects yielding long term return favored by the Algerian state. Martin et al. optimized the performance of a CSP plant using the renewable Rankine cycle for a site in Spain using the Mathematical Modelling Programming Technique [5], the results obtained from this model were compared with the experimental data of the power plant operating in Spain, where the results showed that the cost of production was halved. Boutella et al. [6] presented a comparative study on the performance of different configurations of PTC plants operating with two different HTF fluids, the configurations with integrated thermal energy storage and fossil fuel backup system are found to be techno-economical, but on the in the same time non-environment friendly. Shouman et al. [7] described a strategic road map for the introduction of CSP technology in Egypt. A parabolic trough solar heating system has been designed and simulated using meteorological data of Ipoh, Malaysia by Rizwan Masood et al [8], this study was carried out for a solar-only system without thermal energy storage which produced a low annual capacity factor. Deepak et al. [9] analysed the performance of a 100 MWe PTC plant for the location of Udaipur in India. Kamran Mahboob et al [10] presented the design, analysis, and optimization of a 50MWe solar thermal power plant in Multan using CSP Parabolic Trough technology. SENER, ACCIONA, and TSK make up the construction consortium with the turnkey contract, or EPC, for Noor I, a high-efficiency modern power station. With 160 MWe of power and 3.5 hours of thermal storage, it gives 500 GWh of solar power per year, enough to feed 115,000 homes. China’s task in the next stage of the energy shift is presented in [12]: it includes the contributions to global niche configuration in the Concentrated Solar Power sector. Wael Al-Kouz et al [13] is investigated the performances of a smaller scale Solana power plant, with half the solar field, and 1 of 2 turbines in the power cycle, that possible built-in Amman or Ma’an in Jordan. The same authors [14] suggested justification of the latest System Advisor Model (SAM) vs. the experimental information for CSP energy facilities. Parabolic troughs, and solar towers, are considered, with and without thermal energy storage. From this literature, there are very few research works available that focus on design, performance analysis, and optimization of the CSP for feasible locations in North Africa. The research on this field is extremely important since there is a high demand to tap the abundant renewable energy sources in the area to meet growing energy demand. Furthermore, this is critical for the future development of Libya as it reduces the reliance on fossil fuels and solves the problems connected with air pollution and greenhouse gases. Thus, the objectives of this research are to design, analyse and optimize the performance of a commercial 100 MWe parabolic trough collector solar power plant with TES for feasible locations in Libya.

2. Mathematical background

The solar field is the area where, various solar radiation collecting devices like a collector, absorber, etc. have to be installed. It is the first and most important deciding parameter for the design of any CSP plant. The solar multiple (SM) is defined as the ratio between thermal power obtained by the solar field at the design point and thermal power required by the power block at nominal conditions [15,16], and expressed as follow:

$$SM_{design-point} = \frac{Q_{th,solar-field}}{Q_{th,power-block}} \quad (1)$$

The full load hours of the TES indicates the number of hour’s thermal storage can supply energy for the operation of the power block at the designed input level, and is given as [16,17]

$$H_{tes} = \frac{P_{des} h_{tes}}{\eta_{des,cycle}} \quad (2)$$

P_{des} is the design cycle power (kW), h_{tes} is the total number of desired storage hours (h), $\eta_{des,cycle}$ is the design point cycle efficiency,

The total incident solar energy received by sola field aperture area is given as:

$$Q_i = DNI \cdot A \cdot cos\,\theta \quad (3)$$

Where: A is the collector's aperture area (m^2), θ is the angle of incidence (degree).

While the total useful energy delivered by the solar field is presented as:

$$Q_u = \dot{m_{sf}}\left(h_{SF_o} - h_{SF_i}\right) \quad (4)$$

Where: m_{sf} is the mass flow rate of heat thermal fluid (kg/s), h_{SF_o}, h_{SF_i} is enthalpy at the outlet and inlet of the solar field respectively (kJ/kg). The energy efficiency of the solar field is given as:

$$\eta_{E_{SF}} = \frac{Q_u}{Q_i} \quad (5)$$

The energy efficiency of the power block is,

$$\eta_{E_{PB}} = \frac{P_{net}}{Q_{in}} \quad (6)$$

Where: P_{net} net energy generated (kWh), Q_{in} is the total thermal energy received by the power block (kWh). The Overall Energy efficiency of the plant is given as:

$$\eta_{E_o} = \eta_{E_{SF}}.\eta_{E_{PB}} \quad (7)$$

The net capacity factor of the designed 100MWe concentrated solar power plant is given by:

$$CF = \frac{P_{net}}{Number\ of\ Day \times (24\ h/day) \times\ 100MW} \quad (8)$$

The economic assessment of the plants is assessed in the software System Advisor Model (SAM), where the LCOE, gives an average price of annual energy, in cents/kWh [16,17], is calculated as given below,

$$LCOE = \frac{crf.C_{inv} + C_{o\&M} - C_{env}}{Q_{el,net}} \quad (9)$$

Where: C_{inv} is the total investment cost, $C_{o\&M}$ is the annual operating and maintenance costs ($/year), C_{env} is the environmental cost according to CO_2 rejected (US$), $Q_{el,net}$ is the annual net electricity MWh/year, crf is the capital recovery factor, given by:

$$crf = \frac{k_d.(k_d+1)^N}{[(k_d+1)^N - 1]} \quad (10)$$

Where: k_d is the annual discount rate, *n* is the depreciation period in years. It considers yearly operating costs and initial investment, including site development, components, system costs, assembly, grid connection, and financing costs. It is also including the plant's capacity factor and efficiency; the local DNI at the plant site; the O&M costs (including insurance) costs; and the cost of capital, an economic lifetime… etc. Therefore, can be used as a decision criterion of investment [18].

3. Simulation

In this study System Advisor Model (SAM) (version 2020.11.29) software has been used for thermal analysis of a designed parabolic collector system [19]. The physical Trough Model is used for the ease and flexibility present in it to some extent [20, 21]. The main parts of this system are the solar field, power block, and thermal energy storage optional, and backup systems for fossil fuels, and shows a diagram of the station parabolic trough of the SAM in Figure 1.

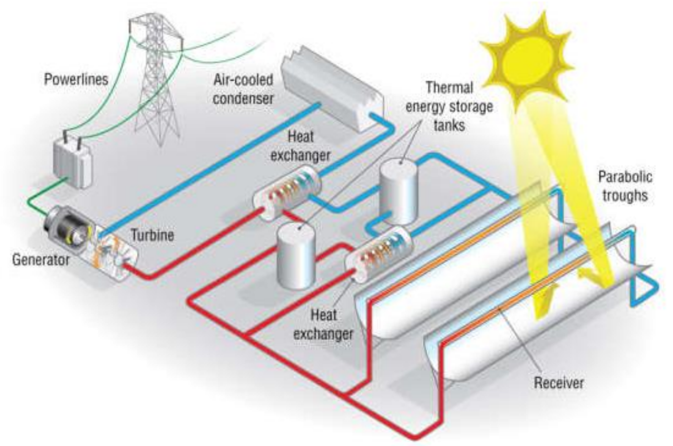

Fig.1: System Advisor Model (SAM) sketch of a parabolic trough plant. Credit NREL/SAM [19].

3.1 Characteristics of the shortlisted location

Determining a suitable location for installing a CSP station is one of the important factors to realize the maximum benefit of the power station. It is found that concentrated solar power plants are economically feasible for locations with DNI greater than 5.5 kWh/m^2.day. In this research work, the city of Sebha, located in southern Libya, was selected for analysis. The hourly DNI is presented in Fig. 2.

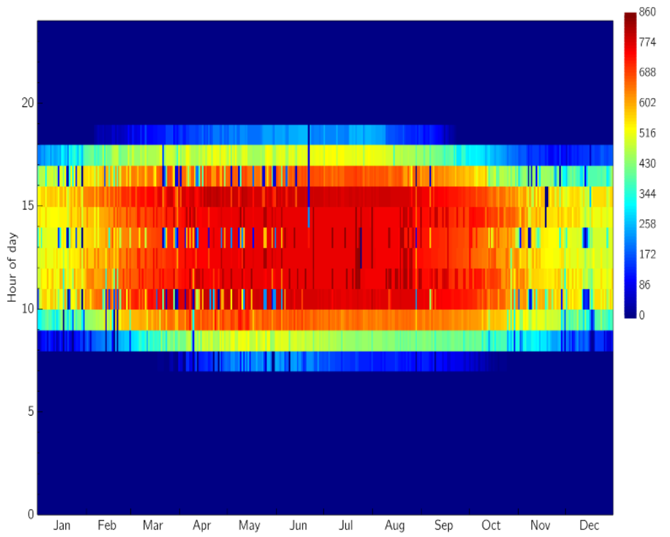

Fig2: Hourly DNI-Cosine Product Irradiance for Parabolic Trough Collector at Sebha city [19].

It can be seen in Fig. 2 that the DNI irradiance peaks at just 860 W/m^2 during hours of maximum direct sunlight. Using the solar irradiance data for Sebha city, a parabolic trough solar field was designed in SAM.

Table 1 also shows the characteristics of the selected installation site [19].

Tab.1: Characteristics of Sebha city

Characteristics of Sebha city	
Latitude	26.987
Longitude	14.473
Elevation	434.9m
Annual DNI	6.68 kWh/m^2/day
Annual average temperature	23.2°C
Annual (standard) wind speed	5.2m/s
Data Source	ISD-TMY

3.2 Design Characteristics of the proposed CSP

For the preliminary analysis, the solar multiple was chosen to be 2 to simulate this hypothetical PTC-based solar thermal power plant design to increase the capacity factor and power generation during the night and cloudy days. To generate electricity after sunset, HTF fluid should be stored in a storage tank with a storage capacity of 6 hours. Assume that the full load time of TES is 6 hours. The optimization of TES's solar power and full load hour value will be carried out after the initial performance evaluation of the plant.

Table 2 summarizes the design features of the proposed 100 MW PTC solar power plant.

Tab.2: Design Characteristics of the proposed 100 MW PTC Solar Power Plant.

Collector geometry	
Type	SkyFuel SkyTrough
Reflective aperture area per SCA	656 m^2
Aperture width, total structure	6 m
Length of the collector assembly	115 m
Number of modules per assembly	8
Average surface to focus path length	2.15 m
Piping distance between assembly	1 m
Mirror reflectance	0.93
Dirt on mirror	0.97
Optical efficiency at design	0.848494

Heat transfer fluid	
Field HTF	Therminol VP-1
Field HTF min operating temp	12 °C
Field HTF max operating temp	400 °C
Freeze protection temp	100 °C
Min single loop flow rate	1
Max single loop flow rate	12
Min field flow velocity	0.3 m/s
Max field flow velocity	3.7 m/s

Receiver Geometry	
Type	Schott PTR80
Absorber tube inner diameter	0.076 m
Absorber tube outer diameter	0.08 m
Glass envelope inner diameter	0.115 m
Glass envelope outer diameter	0.12 m
Boiler operating pressure	100 bar

Thermal energy storage (TES)	
Hours of storage at the design point	6.0 hours
Storage HTF	Therminol VP-1
Storage tank volume	39896.4m^3
Storage tank heater efficiency	0.98
Tank diameter	65.0626m

4. performance analysis of the CSP plant design

As can be seen from Figure 3, Sebha's proposed CSP plant can generate 406.26 GWhe per year. The maximum monthly power generation from March to September ranges from 38.36 GWhe to 38.7 GWhe. Due to the higher direct normal irradiation in these months, the energy output in July was significantly higher. From October to February, the minimum energy output received from PTC plants ranged from 32.71 GWhe to 27.5 GWhe. This makes sense because CSP solar is best operated during summer when solar irradiance peaks and the sky is clear. The important point is that when there is more radiation, (especially at noon) more energy consumption is being performed, so there is no need to store energy.

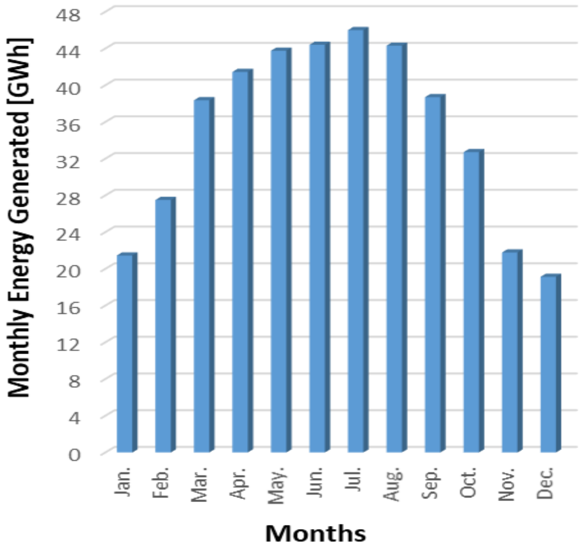

Fig.3: Monthly energy generation from PTC in Sebha.

Figure 4 shows the hourly data of on-site thermal power accidents, total power output, and total grid power for the proposed power plant in Sebha.

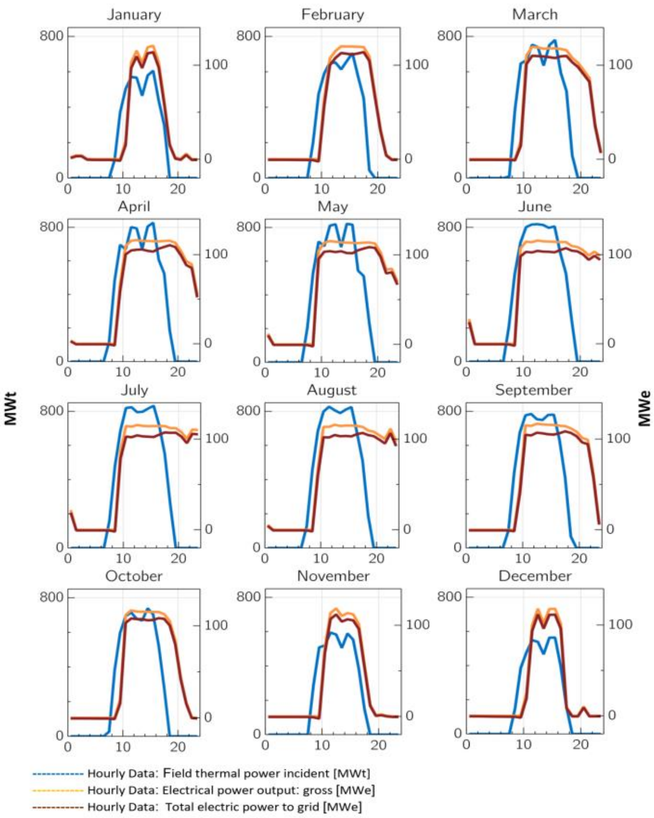

Fig.4: Hourly data of field thermal power incident, gross electrical power output, and total electrical power to grid for the proposed plant in Sebha.

The value of these cycles depends on the intensity of solar radiation in the area selected for the proposed PTC plant. The figure also shows the possible schedulability of a typical year (a typical day of each month). During the peak summer period, the solar energy collected from the solar farm is sufficient to operate the facility at peak power and store the energy in storage to provide electricity at almost midnight from June to September. It is noted that the solar energy collected from the solar field during the winter days is not sufficient to operate the plant at maximum power, and this reduces energy production during the day and will not obtain stored energy for operation during the night. The excess thermal energy stored during the day can be used for the power cycle when the supply from the solar field is reduced, meaning that there is an opportunity to produce electricity until around midnight during the summer.

Figure 5 shows the cycle efficiency of the designed PTC solar power plant in Sebha and the mean efficiency (Gross) 0.1993 and maximum efficiency 0.39 are recorded for the proposed PTC plant.

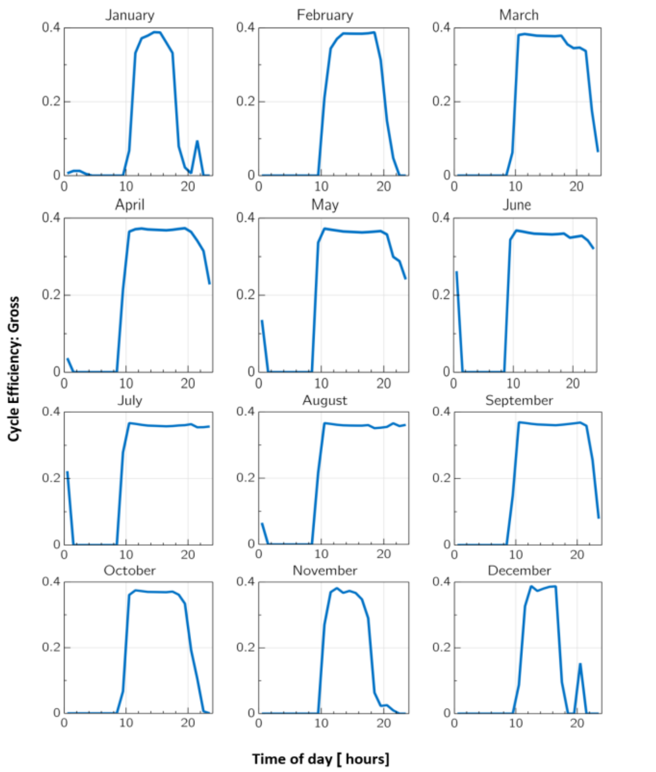

Fig.5: Cycle Efficiency of the proposed plant in Sebha.

The average cycle efficiency is high in the summer period, the reason for this is an increase in DNI and a decrease in humidity, and there are also some other problems related to some dirt and dust, which can be overcome by using the cleaning system., while it decreases in the winter period in which the intensity of radiation is low.
The Levelized energy cost at the beginning of the design is 13.48 cents/kWh.

5. Optimization of the Initial CSP Plant Design

The optimization of the initial design of the Parabolic Trough Plant is performed by changing the values of solar multiple and thermal energy storage.
From Figure 6 by increasing solar multiple and load hours of thermal energy storage, the annual energy production will increase.

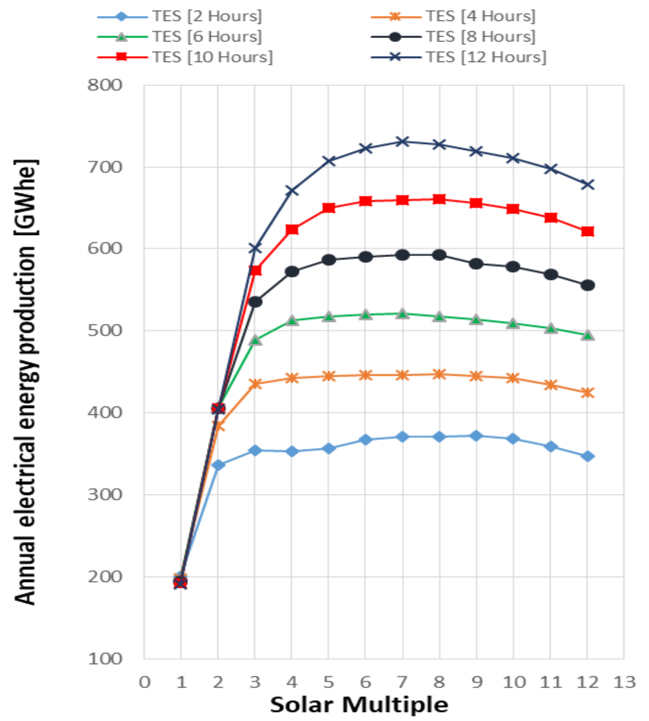

Fig.6: Variation of solar multiple and hours of storage with annual energy production for PTC plant in Sebha.

This can be attributed to the fact that an increase in solar multiple results in a corresponding increase in solar field aperture area and header pipe length, and hence a greater steam outlet temperature from the solar field. The solar multiple and the hours of storage selected for the initial designing of the proposed PTC plant with a corresponding energy generation is 406.26GWh are 2 and 6 hours respectively. If we increase the value from 2 of solar multiple, a substantial change will occur the optimum value of solar multiple for the PTC plant is from 6 to 8 for better energy generation. Fig 6 illustrates the optimum value of hours of storage, which is 12 hours.
The minimum range of LCOE can be achieved by varying the thermal energy storage and solar multiple values (Figure 7).

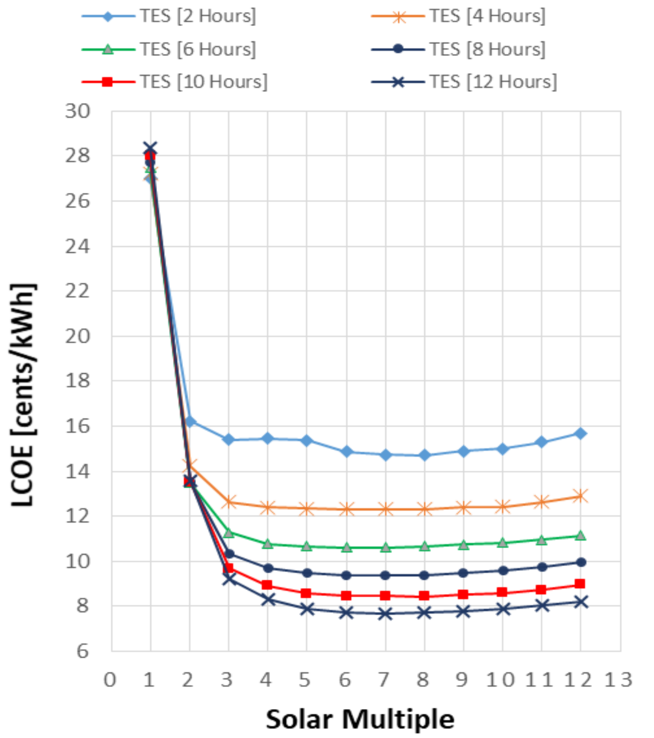

Fig.7: Levelized Cost of Energy for 100 MW Parabolic Trough Plant

as a function of the size of the solar field and Thermal Storage

This analysis suggests that the minimum LCOE is achieved with a solar multiple of, from 6 to 9, and 10, 12 hours energy storage. However, there is relatively little difference between plants with the same solar multiple of from 6 to 9 and 10, 12 hours thermal energy storage. Whereas the objective of the optimization is to determine the optimal configurations and components size that gives the lowest LCOE; therefore, choosing the optimal plant design will depend on the minimum range of LCOE.

Table 3 summarizes the results obtained for the proposed CSP project improvement objective. The optimized configuration is selected based on the tradeoff between annual power generated, LCOE, and the mean efficiency of the plant. From the table, there is a significant improvement in the annual energy generation, capacity factor, and LCOE values for the optimized configuration when compared to that of the initial design.

Table 3: Summarizes the results obtained for the proposed CSP project improvement objective.

SM	TES=2 hours			TES=4 hours			TES=6 hours		
	Annual Net Electrical Energy Production [GWh]	Capacity Factor %	LCOE ¢/kWh	Annual Net Electrical Energy Production [GWh]	Capacity Factor %	LCOE ¢/kWh	Annual Net Electrical Energy Production [GWh]	Capacity Factor %	LCOE ¢/kWh
1	199.66	22.80	27.01	197.92	22.6	27.24	196.20	22.4	27.48
2	336.07	40.30	16.21	384.20	45.5	14.23	406.26	47.9	13.48
3	354.30	43	15.39	434.69	51.8	12.62	488.66	58.1	11.27
4	353.25	42.9	15.44	442.66	52.9	12.40	512.80	61	10.76
5	355.03	43	15.36	444.56	53.3	12.35	517.66	61.7	10.66
6	367.42	44.2	14.86	445.81	53.4	12.32	520.46	61.9	10.61
7	370.54	44.2	14.74	445.86	53.3	12.32	520.65	61.8	10.60
8	370.76	43.8	14.70	446.61	53.2	12.3	517.67	61.4	10.66
9	371.94	42.10	14.90	444.82	52.8	12.39	514.67	60.9	10.74
10	368.05	44.03	15	441.81	52.3	12.42	509.18	60.3	10.83
11	358.87	42	15.30	434.21	51.1	12.63	503.08	59.5	10.96
12	347.01	41.7	15.70	424.86	49.7	12.90	494.44	58.4	11.14
	TES=8 hours			TES=10 hours			TES=12 hours		
1	194.31	22.2	27.74	192.31	22	28.02	190.15	21.7	28.34
2	405.66	47.8	13.50	404.89	47.7	13.52	404.12	74.6	13.55
3	534.90	63.6	10.33	573.03	68.1	9.67	601.18	71.5	9.24
4	572.80	68.3	9.67	624.06	74.6	8.91	671.06	80.4	8.32
5	586.54	70	9.46	650.16	77.8	8.57	707.28	84.8	7.91
6	590.27	70.20	9.4	658.16	78.5	8.47	723.02	86.7	7.75
7	593.13	70.40	9.36	660.09	78.5	8.45	730.63	87.3	7.67
8	592.40	70	9.37	660.41	78.1	8.44	727.94	86.5	7.70
9	582.54	69.2	9.46	655.54	77.4	8.50	719.71	85.3	7.78
10	578.22	68.3	9.59	648.34	76.3	8.59	711.18	84	7.87
11	568.39	67.1	9.75	637.79	75	8.73	697.55	82.1	8.02
12	556.28	65.7	9.95	621.51	73.1	8.95	679.06	79.8	8.22

6. Conclusion

The design, performance analysis, and optimization of a 100 MWe parabolic trough collector Solar Power Plant with thermal energy storage have been carried out for one location in south Libya, Sebha city. The SAM software has been used to assess the performance of the designed CSP plant in this location whose annual average DNI is greater than 6 kWh/m^2/day. The initial analysis of the proposed design revealed that the CSP plant has an annual energy yield of 406.26 GWh, and a Levelized cost of the energy yield of 13.48 ¢/kWh; with an annual Capacity Factor equal 47.9 %. The performance of the proposed CSP plant is further optimized by varying the initial design parameters such as solar multiple and full load hours of TES. The optimum values for solar multiple and full load hours of TES are found to be 7 and 12 h respectively. The analysis of this optimum configuration revealed that annual energy generation can be increased to 727.94 GWhe with a corresponding decrease in LCOE value 7.67 ¢/ kWh. Based on the findings of the study, the proposed 100 MW parabolic trough-based CSP plant with a TES system is found to be ideally suited for Sebha city and can contribute to the sustainable energy future of southern Libya. Finally, additional research investigations are required for analysing the system design parameters such as collector loop, solar field configuration, heat transfer fluid, thermal capacity, efficiency, and storage system, etc., to determine the conditions which, make this technology profitable and more economically feasible. Moreover, the combination of (PTC) solar with conventional fuel systems can significantly contribute to the reduction of conventional fuel usage and the addition of thermal energy storage can add to its value even more.

7. Reference

[1]- International Renewable Energy Agency (IRENA), " Estimating the Renewable Energy Potential in Africa", A GIS-based approach, Copyright © IRENA 2014.

[2]- National Renewable Energy Laboratory, "Concentrating Solar Power: Projects, Solana Generating Station", February 22, 2013

[3]- Kumaresan, G.; Sridhar, R.; Velraj, R. Performance studies of a solar parabolic trough collector with a thermal energy storage system. Energy **2012**, 47, 395–402.

[4]- Abbas, M.; Belgroun, Z.; Aburidah, H.; Merzouk, N.K. Assessment of a solar parabolic trough power plant for electricity generation under Mediterranean and arid climate conditions in Algeria. Energy Procedia **2013**, 42, 93–102.

[5]- Martin, L.; Mariano, M. Optimal year-round operation of a concentrated solar energy plant in the south of Europe. Appl. Therm. Eng. **2013**, 59, 627–633.

[6]- Boukelia, T.E.; Mecibah, M.S.; Kumar, B.N.; Reddy, K.S. Investigation of solar parabolic trough power plants with and without integrated TES (thermal energy storage) and FBS (fuel backup system) using thermic oil and solar salt. Energy **2015**, 88, 292–303.

[7]- Shouman, E.R.; Khattab, N.M. Future economic of concentrating solar power (CSP) for electricity generation in Egypt. Renew. Sustain. Energy Rev. **2015**, 41, 1119–1127.

[8]- Rizwan Masood, Syed Ihtsham Ul Haq Gilani, and Hussain H. Al-Kayiem,' A simplified design procedure of parabolic trough

solar field for industrial heating application', ARPN Journal of Engineering and Applied Sciences, vol.11, No. 22, November **2016**.

[9]- Bishoyi, D.; Sudhakar, K. Modeling and performance simulation of 100 MW PTC based solar thermal power plant in Udaipur India. Case Stud. Therm. Eng. **2017**, 10, 216–226.

[10]-K. Mahboob, F. Ali, Hassan M., Irfan M., S. Tanveer, A. khan, "Design, analysis and optimization of 50MWe solar thermal power plant in Multan using CSP Parabolic Trough technology", CRANET-2018, November 2018

[11]-SENER, ACCIONA, and TSK, "Parabolic trough plant Noor Ouarzazate I, Morocco", dep.energia@sener.es - © SENER 2018, http://www.poweroilandgas.sener.

[12]-Jorrit Gosens, Christian Binz, Rasmus Lema, " China's role in the next phase of the energy transition: Contributions to global niche formation in the Concentrated Solar Power sector", Environmental Innovation and Societal Transitions 34 (2020) 61–75

[13]-Wael Al-Kouz, Ahmad Almuhtady, Nidal Abu-Libdeh, Jamal Nayfeh, Alberto Boretti, " A 140 MW Solar Thermal Plant in Jordan", MDPI journals, June 2020

[14]-Alberto Boretti, Jamal Nayfeh and Wael Al-Kouz, "Validation of SAM Modeling of Concentrated Solar Power Plants", MDPI journals, April 2020

[15]-Matthias Günther, Michael Joemann, Simon Csambor, " Advanced CSP Teaching Materials. Chapter 5. Parabolic Trough Technology", DLR.

[16]- Boukelia, T.E.; Mecibah, M.S.; Kumar, B.N.; Reddy, K.S. Optimization, selection, and feasibility study of solar parabolic trough power plants for Algerian conditions. Energy Convers. Manag. **2015**, 101, 450–459.

[17]-Praveen R. P., Mohammad A. Baseer, A. B. Awan and M. Zubair, " Performance Analysis and Optimization of a Parabolic Trough Solar Power Plant in the Middle East Region", MDPI journals, March 2018

[18]-International Renewable Energy Agency IRENA, Renewable Energy Technologies: Cost Analysis Series, Concentrating Solar Power, *Volume 1: Power Sector* Issue 2/5, June 2012.

[19]-National Renewable Energy Laboratory, "System Advisor Model (SAM) Reference Manual for CSP Trough Systems", Version 2020.11.29.

[20]-Michael J. Wagner, Nate Blair, and Aron Dobos, " A Detailed Physical Trough Model for NREL'S Solar Advisor Model", SolarPACES 2010 Perpignan, France September 2010.

[21]-Michael J., Wagner and Paul Gilman, " Technical Manual for the SAM Physical Trough Model", NREL/TP-5500-51825, June 2011.