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Development, Construction, Operation and Maintenance of Shouhang Dunhuang 100 MW Molten Salt Solar Power Tower Plant

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Abstract. The Shouhang Dunhuang 100 MW molten salt solar power tower plant is the first 100 MW-scale commercial demonstration project in China. The plant started to break ground in October 2016, was completed and connected to the grid for power generation in December 2018, and achieved full-load operation in June 2019. This paper comprehensively introduces the development, design, and construction process of the project as well as its operation and maintenance over the past five years, and shares experiences and lessons learned from the project.

Keywords: Concentrated Solar Power, Commercial Project, Tower Plant, Lessons Learned

1. Introduction

With the advancement of global carbon emission reduction, concentrated solar power (CSP) has received widespread attention as a clean renewable energy source that can be dispatched by the electric grids [1]. The Chinese government has proposed its so-called “dual carbon” goals, which aims to peak carbon dioxide emissions by 2030 and achieve carbon neutrality before 2060 [2], [3]. Given this background, CSP has shown a trend toward large-scale development in China. According to statistics from the China Solar Thermal Alliance (CSTA) [4], as of 2022, China has 29 CSP projects in the construction or planned development phase, with a total installed capacity of approximately 3.3GW. These projects are expected to be commissioned in 2023 or 2024.

Shouhang Dunhuang 100 MW molten salt solar power tower plant was constructed in 2016 and is one of the first batches of China’s national CSP commercial demonstration projects [4]. The power station was independently designed, invested in, and constructed by Shouhang High-Tech Energy Co., Ltd. (Shouhang). It is located in the photoelectric industrial park of Qili Town in Dunhuang City, Gansu Province. The total effective reflection area of the solar field is approximately 1.38 million m^2. It consists of 11,935 heliostats, each with a reflection area of 115.72 m^2, and is equipped with an 11-hour heat storage system. The plant was completed and connected to the grid for power generation in December 2018, and achieved full-load operation in June 2019. A photograph of the power station is shown in *Figure 1*.

The remainder of this paper is organized as follows. First, we comprehensively introduce the development conditions, design parameters, and construction process of this solar power tower plant. Subsequently, the operation and maintenance of the power station over the past five years, particularly the power generation data, are described in detail. Third, some experiences and lessons learned are shared. Finally, the conclusions and an outlook for this project are presented.

Figure 1. *Shouhang Dunhuang 100 MW molten salt solar power tower plant*

2. Development, design, and construction process of the project

2.1 Site and climate conditions

The project site is approximately 15 km from Dunhuang City. The center coordinates of the site are 94.66° east longitude and 40.14° north latitude. It is 1240 m above sea level (SL). During the project preparation stage, the owner conducted meteorological observations at the site over two full years. The total solar direct normal irradiance (DNI) in a typical meteorological year (TMY) at the site was determined to be 1883 kWh/m²/y by correcting the satellite data based on the measured data. The climate of the site is dry and has low rainfall with a large temperature difference between day and night, typical of a continental arid climate. The annual average temperature of a TMY is 10.6°C. The highest temperature is 37°C and the lowest temperature is -16.6°C. The average annual rainfall is 43.6 mm. The annual average wind speed of a TMY is 3.4 m/s, with a maximum wind speed of 12.9 m/s. The project site lies within the Gobi landform, characterized by barren terrain devoid of vegetation. The landscape is predominantly flat, with a natural slope is 0.8%, making it suitable for the construction of a solar power tower plant.

2.2 Development and design

The solar concentration and heat collection system for the project was independently developed, designed, constructed, installed, and commissioned by Shouhang. This project adopts a 115 m^2 heliostat, which consisting of 35 facets. The area of each facet is approximately 3.3 m^2. The facet has a metallic backplate. The thickness of the mirror glass is 3 mm. The metallic backplate and the mirror are glued by silicone. *Figure 2* shows a 3D (three dimensional) model and an actual picture of the heliostat.

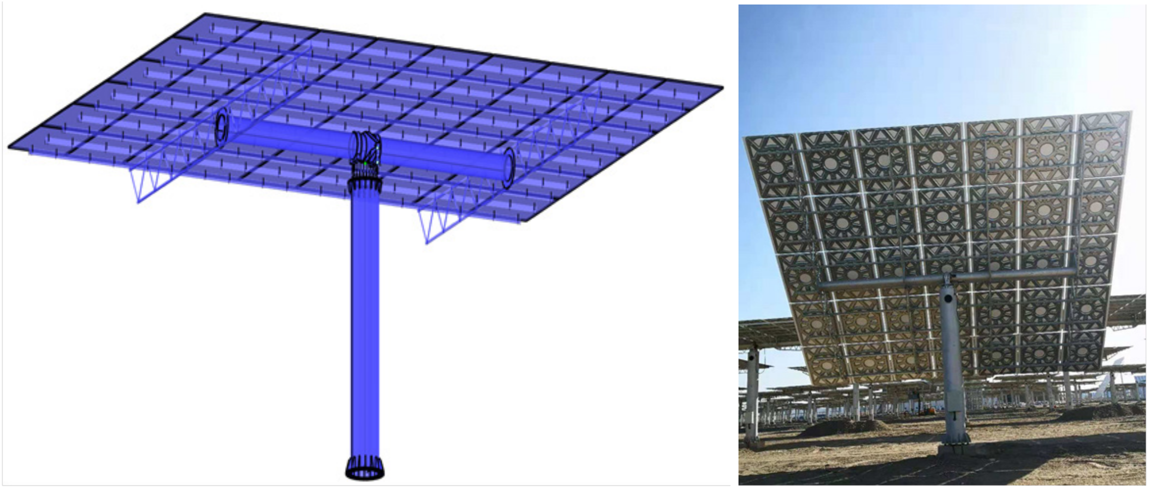

Figure 2. *A 3D model (left) and an actual picture (right) of the heliostat*

The solar field consists of 11,935 heliostats, and its layout is shown in *Figure 3*. The designed annual power-generation capacity of this plant is 351.6 million kWh, with a total investment of approximately 2.8 billion yuan. The designed annual power generation was calculated from the hourly solar field efficiency combined with the hourly data of a typical meteorological year. The designed capacity factor of the plant was 40.13% and the solar multiple was 2.57.

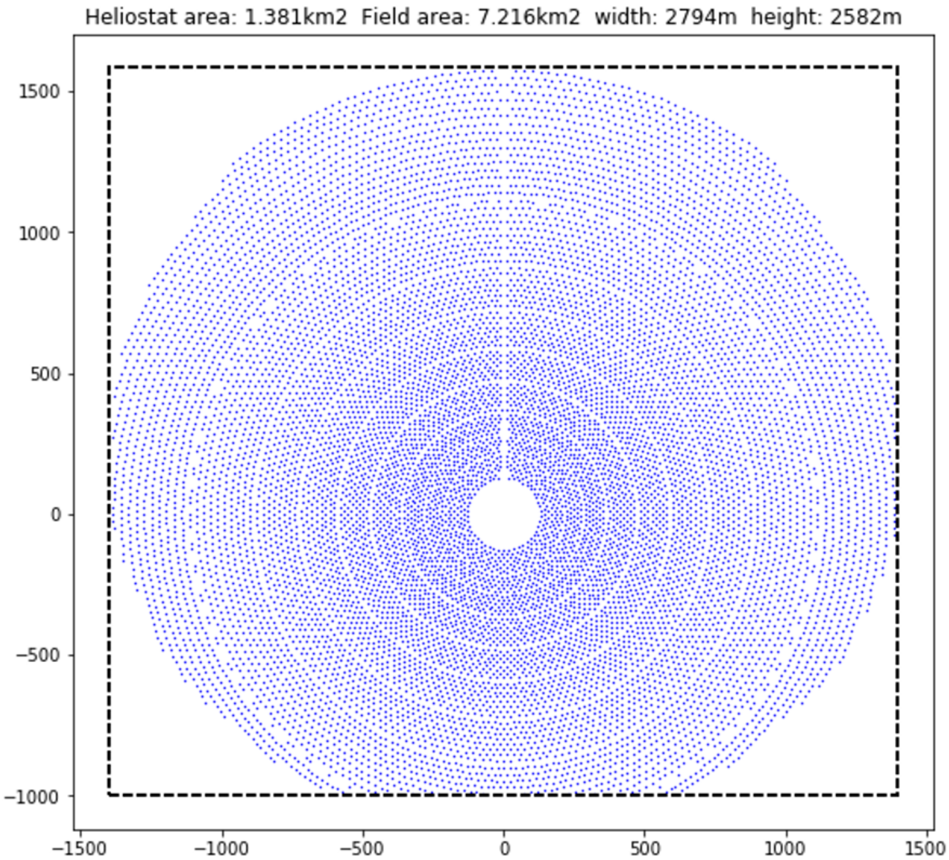

Figure 3. *The layout of the solar field*

The main design parameters of this 100 MW molten salt solar power tower plant, including heliostats, solar field, receiver, heat storage and exchange system, conventional power generation system, and the main technical and economic indicators, are shown in *Table 1.*

Table 1. *Main design parameters of the Shouhang Dunhuang 100 MW molten salt solar power tower plant*

Items		Unit	Value
Solar field	Total reflective area	m^2	1381118
	Number of heliostats	--	11935
	Total land area	km^2	7.2
	The farthest heliostat from the tower	km	1.57
	Average annual solar field efficiency (DNI weighted)	--	53.3%
	Solar multiple	--	2.57
Heliostat	Single heliostat reflective area	m^2	115.72
	Number of heliostat facets	--	35
	Mirror thickness	mm	3±0.2
	Dimensions of the heliostat (width×height)	m	11.42×10.42
	Height of pedestal	m	5.5
	Reflectivity (new and clean)	--	94%
	Tracking Accuracy	mrad	≤2.0
	Maximum operational wind speed	m/s	≥13 (10 min average)
	Survival wind speed	m/s	≥40 (gust)
Receiver	Rated input heat power	MW	630
	Rated efficiency	--	90%
	Tower optical height (center of the receiver)	m	229.3
	Tower total height (top of the receiver)	m	260
	Diameter	m	15.13
	Height	m	18.6
	Number of panels	--	14
Thermal storage	Hours of storage	h	11
	Molten salt type	--	Solar salt (60% NaNO3 + 40% KNO3)
	Molten salt dosage	ton	30000
	Dimensions of cold tank (Diameter × Height)	m	37.4×15
	Dimensions of hot tank (Diameter × Height)	m	39.3×14.8
Power cycle	The unit nameplate power	MW	100
	Inlet pressure	MPa	12.6
	Inlet temperature	℃	550
	Rated back pressure	kPa	8
Main technical and economic indicators	Designed annual power generation	kWh	351.6 million
	Annual utilization hours	h	3516
	Designed annual optical-to-electrical efficiency	--	13.52%
	Electricity purchase price	yuan/kWh	1.15
	Total project investment (financial final accounts)	yuan (RMB)	2.8 billion
	Levelized cost of electricity (LCOE)	yuan/kWh	0.83

In the design process of a CSP plant, the selection of heat storage time is an iterative optimization process. Increasing the heat storage time reduces the amount of energy that the power station throws away because of the storage tank is full. The capacity factor and annual power generation will increase accordingly, but the growth rate will become increasingly slow until it reaches a certain value and will no longer increase. However, as heat storage increases, the costs of the molten salt and storage tanks increase proportionally. Therefore, the economics of the entire power station first increase and then decrease as the heat storage time increases, and there is an optimal heat storage time. Considering the price of electricity sales and the price of molten salt, the designed heat storage time for the Dunhuang project was set at 11 h.

2.3 Construction

The investor in this power plant was Dunhuang Shouhang Energy Saving New Energy Co., Ltd., a wholly owned subsidiary of Shouhang. The construction of the project was undertaken by 11 contracting units. The project broke ground on October 25, 2016, and was connected to the grid for power generation on December 28, 2018, with a total construction period of 26 months. The important nodes and milestones of the project are listed in *Table 2*.

Table 2. *The important nodes and milestones of the project*

Date	Important nodes and milestones
2016.10.25	Groundbreaking
2016.10.27	Excavation of tower foundation
2017.03.22	The tower went out to zero meters
2017.05.29	Excavation of main building foundation
2017.06.09	Excavation of heliostats foundation
2017.06.19	The first tank of concrete in the main building
2017.10.31	Sealed the roof atop of the main building
2017.12.27	Started lifting and installing the heliostat pedestals
2018.05.19	Molten salt tank foundation completed
2018.09.05	Steam turbine cylinder locked
2018.09.12	The first receiver panel was lifted and installed
2018.10.15	Solar field commissioning and the first concentrating was carried out
2018.12.26	The steam turbine turned on successfully
2018.12.28	Grid-connected and put into operation

The project can produce, assemble, and install 80 heliostats daily, and the production and installation of heliostats for the entire solar field took approximately five to six months. The civil construction period of the tower was approximately 10 months. On-site photos taken during project construction are shown in *Figure 4*.

3. Operation and maintenance

The power generated by this project is fully purchased by the power grid and the electricity price is 1.15 yuan/kWh. Under the dispatch of the State Grid Corporation of China, the power station attempts to operate at peak levels as much as possible. The power station achieved full-load operation in June 2019. In its operation for the past five years, there have been no major safety production accidents that have caused the plant to shut down for a long time. The annual electricity output of the project is illustrated in *Figure 5*. As can be seen from the figure, the power generation in the years 2019, 2020, 2021 and 2022 are 86.7 million kWh, 136.9 million kWh, 200.2 million kWh and 197.4 million kWh respectively. In 2023, from January to August, the power generation exceeds 140 million kWh. From 2019 to 2021, through learning and systematic optimization, the solar field efficiency and other system performances of the generating unit significantly improved, and the electricity output increased annually. However, by 2022, owing to steam turbine issues, the electricity production did not continue to increase. To date, the maximum electricity output of the power station in a single month exceeded 33.79 million kWh, and in a single day, it reached 2.12 million kWh. The longest uninterrupted power generation time is approximately 263 h. The annual auxiliary power consumption of the plant is approximately 8.5% to 10%. Currently, the actual monthly optical-to-electrical efficiency of the power station is approximately 6% to 12%.

Figure 4. *On-site photos taken during the construction period*

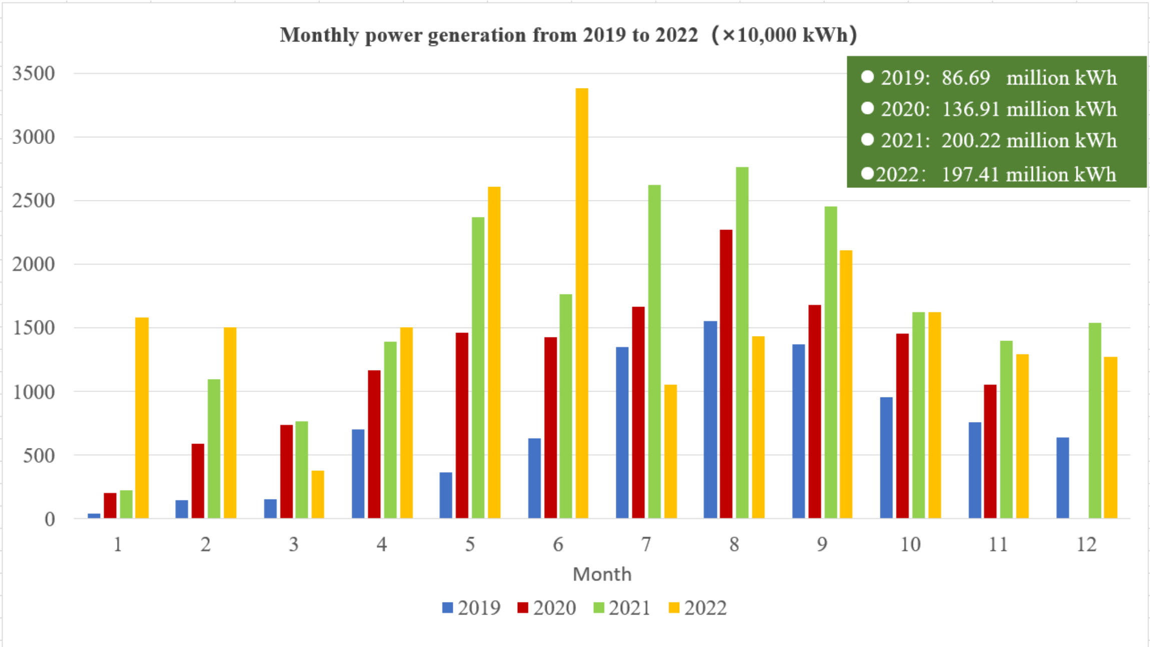

Figure 5. *The annual and monthly electricity output of the project*

Currently, the electricity output of the power station reaches approximately 60% of the design value. The main reasons for this are as follows:

First, the power station underwent a long period of defect elimination and optimization in the early stages, especially the change to the technical scheme of heliostat tracking error correction, which took a long time, making the learning time of the power station relatively long. At the beginning, the heliostat error correction scheme adopted by this project was the conventional "camera + white target" method. However, this solution was less efficient for a large-area solar field. Furthermore, it was difficult to distinguish the beam spot on the target when the heliostat was further from the tower. Subsequently, the correction scheme was changed to use a camera installed on the tower directly to capture the heliostats. The correction efficiency was greatly improved, and the power generation of the plant also increased annually.

Second, in 2022, an abrasion issue emerged in the main shaft of the high-pressure cylinder of the steam turbine. To ensure safety, the generating unit can only run continuously at 50% load all the time, which leads to very low efficiency of the unit. At the same time, a large amount of sunlight in the solar field is dumped because the unit cannot consume the molten salt in the hot tank in time, which seriously affects the production of the plant. This problem still exists, and according to the maintenance plan, it will not be resolved until the end of 2023.

Third, when designing the power station, certain input parameters were given more aggressively for a large-area solar field of 1.38 million m^2, such as atmospheric attenuation, spillage loss, plant availability (considering maintenance), and cleanliness. In summary, the plant design parameters are somewhat optimistic.

4. Lessons learned

Reviewing the process of the development, design, construction, operation and maintenance of the entire project, the lessons learned are summarized as follows:

1) Solar field cleaning is the most important task in operation and maintenance and significantly affects the electricity output of the power station. Therefore, some automated and efficient cleaning methods are required. From this perspective, relatively large-area heliostats would have advantages because the number of heliostats is smaller and the distance between adjacent heliostats is larger. Therefore, large-scale mechanized cleaning equipment can be deployed.
2) Changes in temperature and gravity deformation have a significant influence on the surface shape of a heliostat with a stamped metal backplate, which in turn affects the solar field output. Special attention should be paid to these factors in the subsequent optimization of the heliostats, particularly when used in an area with large temperature variations throughout the year.
3) The conventional "BCS camera + white target" solution is not suitable for heliostat tracking error calibration of a large-area solar field. The method of installing cameras on top of the tower to directly capture the heliostats works better, although some accuracy is sacrificed.
4) When the solar field is out of operation, it is better not to put the heliostats in the conventional “stow” mode. Instead, heliostats should be placed in an upright, dust-proof mode, and in “stow” mode only when strong winds come. This has an evident effect on preventing dust falling on the heliostats in desert areas.
5) The operating angle ranges of the heliostat azimuth and elevation axes should be as large as possible to adapt to certain special working conditions of the solar field. For example, in the “defrost” mode in winter in cold areas requires that the normal direction of the front or back of the heliostat points exactly toward the sun.
6) If an uninterrupted power supply (UPS) system is used as the backup power supply, the solar field can be defocused within a few seconds, depending on the maximum rotational speed of the heliostat. Thus, the capacity of the inlet vessel and emergency compressed air system on the tower can be made very small to save investment. The

inlet vessel and compressed air system can be even eliminated if the defocusing strategy is reasonable.

7) In the foundation construction of hot and cold tanks, a stainless-steel wire mesh can be filled into the ceramsite to increase reliability and prevent the separation of ceramsite particles of different sizes during 30 years of operation.
8) To ensure the quality of the tanks, a perfect manufacturing process is required, as well as detailed instructions, documentation, and control procedures for the entire process. Welding-quality inspection is one of the most important factors to consider. The welding seams of the tanks require 100% non-destructive inspection.
9) It is necessary to continuously improve the automation level of the solar field control system. For example, Shouhang adopts a "one-click preheating and salt filling" system, which uses sensors and infrared cameras to monitor the temperature changes of each receiver panel in real time. Therefore, the number and aiming point positions of the preheating heliostats can be adjusted automatically and accurately, ensuring that the temperature of the entire receiver panel increases evenly to the salt-filling temperature. Then, according to the height of the salt level in the riser pipe, the pump speed and valve opening of the downcomer pipe are adjusted in time to automatically complete the salt filling and normal operation process of the receiver. Thus, the speed of the entire process is significantly improved. The preheating time is reduced by 60%.
10) The Power generation system is not conventional in the CSP field. The rapid response and frequent start and stop characteristics of the solar power steam turbine make its design concept different from that of coal-fired power-generating units. Therefore, attentions should be paid to the reliability of CSP steam turbines.
11) For the main equipment in the system, such as the pumps and valves, it is best to choose manufacturers whose after-sales services can respond in time.

5. Conclusions and outlook

The Shouhang Dunhuang 100 MW molten salt solar power tower plant is one of the first batches of China's national CSP commercial demonstration projects and has been operating smoothly for nearly five years. During the development, design, construction, operation, and maintenance of the project, we navigated numerous challenges, overcame the majority, and accumulated valuable project experience. The successful implementation of the project not only drives the development of the relevant industrial chains, but also verifies the feasibility of the commercial operation of molten salt solar power tower technology in China and achieves a demonstration effect. The current operating conditions of the project are far from perfect. The annual electricity output reached approximately 60% of the designed value. There is still a lot of room for improvement. As problems such as the steam turbine issues are resolved, the power generation of this project will further increase. With the large-scale development of CSP projects in China, the levelized cost of electricity (LCOE) is expected to continue to fall in the long run.

Data availability statement

This paper is an introduction to a commercial CSP project and is not based on experimental or simulated data. The authors confirm that the operation data (electricity output) are already available within the article. Other detailed information about the project is available from the corresponding author, Dr. Xiao, upon reasonable request.

Underlying and related material

None.

Author contributions

According to the CreDIT guidelines, the contributions of the authors are summarized as follows:

Wenbo Huang: Supervision.

Jun Xiao: Writing – original draft.

Fuguo Liu: Investigation.

Zhipeng Qi: Writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

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References

[1] A. H. Alami, A. G. Olabi, A. Mdallal, A. Rezk, A. Radwan, S. M. A. Rahman, M. A. Abdelkareem, “Concentrating solar power (CSP) technologies: Status and analysis,” International Journal of Thermofluids, vol.18, pp.100340, 2023, doi: https://doi.org/10.1016/j.ijft.2023.100340.

[2] X. Jia, Y. Zhang, R. R. Tan, Z. Li, S. Wang, F. Wang, K. Fang, “Multi-objective energy planning for China's dual carbon goals,” Sustainable Production and Consumption, vol.34, pp. 552-564, 2022, doi: https://doi.org/10.1016/j.spc.2022.10.009.

[3] X. Huo, D. Jiang, Z. Qiu, S. Yang, “The impacts of dual carbon goals on asset prices in China,” Journal of Asian Economics, vol. 83, pp. 101546, 2022, doi: https://doi.org/10.1016/j.asieco.2022.101546.

[4] F. Du, “Blue book of China's concentrating solar power industry 2022,” 1th ed. Beijing, China: China Solar Thermal Alliance, 2023. pp. 8–15.