Experimental Study on Performance of Trough Solar Thermal Power Station

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Abstract. With the large number of construction and commercial operation of trough solar thermal power station, the performance test standard and test method of trough solar power station are still missing and imperfect. For the heat storage heat exchange system of trough type solar thermal power station, the index system of heat exchange efficiency, heat storage time and heat collection efficiency are constructed, and the work contents of performance test and technical index are improved. Learn from the idea and concept of performance acceptance test of thermal power generation equipment system in power industry, combined with many years of relevant work experience. It is expected to bring reference and guidance to relevant technical personnel and peers.

1. Preface

The utilization of solar energy is to collect the solar radiation energy and turn the solar energy into usable heat energy through the solar heat collecting device. Solar thermal power station is a clean way of power generation. Compared with thermal power generation, it can effectively avoid the pollution caused by burning fossil energy. Compared with photo-electricity power generation, it can effectively replace the expensive silicon materials in photo-electricity technology and reduce the cost of power generation. The solar thermal power station obtains excellent quality heat energy through the light and heat conversion of the heat collecting device, and then generates electricity. It is deeply coupled with other renewable energy power generation or traditional coal-fired power generation, which effectively solves the continuous continuity of solar thermal power generation, and promotes the standardized utilization of solar thermal power.

Due to its simple structure, mature technology, medium temperature heat storage and good for joint operation, trough solar power generation system has become the first solar thermal power generation technology to enter commercial production. According to different heat transfer media, trough solar power generation has heat transfer oil type, molten salt type, super-critical CO2 and so on. With the large number of construction and commercial operation of trough type solar thermal power station, the performance acceptance of power station will be gradually implemented. At present, the performance test standard for trough solar solar thermal power station is not perfect, especially for the performance assessment and acceptance of heat collection and storage and heat exchange system (hereinafter referred to as the collection and storage heat exchange Island) is still blank. In this paper, referring to the power generation equipment system performance assessment and acceptance ideas, combined with many years of relevant work experience, describes the performance test work content and technical indicators of the trough type solar solar thermal power station, in order to bring reference and
guidance to relevant technical personnel and peers [1-3].

2. Trough solar thermal power generation system

Trough solar thermal power generation is a mature and low-cost solar thermal power generation technology. The typical trough solar thermal power generation system is mainly divided into several parts, such as concentrating heat collection system (sunglasses field), heat storage system, heat exchange system, conventional power generation system and auxiliary energy system. The concentrating heat collecting system is the core of the trough type solar thermal power generation system. It is composed of several concentrating heat collection units. The solar radiation energy is focused on the concentrator, and the solar energy is transformed into heat transfer medium such as heat transfer oil, water or molten salt. The heat storage system is to store the surplus heat when the solar radiation is strong and the power generation load is low, so as to release the heat for the heat exchange system when the solar radiation is insufficient or at night. The heat exchange system consists of Re-heater, steam generator, super-heater and Re-heater [4]. Conventional power generation system is similar to traditional thermal power generation equipment, including steam turbine and generator. In order to facilitate the work division, the concentrating heat collection system, heat storage system and heat exchange system are often referred to as the heat collection and storage Island, and other equipment systems are collectively referred to as conventional power generation island. A typical solar thermal power generation process with heat transfer oil tank is shown in Figure 1.

![Diagram](image)

**Figure 1.** Schematic diagram of typical trough solar thermal power generation process

3. Test requirements of heat exchange island system

The original purpose of equipment system performance test in traditional power industry is to check whether the performance of equipment system reaches the design value of the manufacturer or the specified value in the contract. With the guidance of national energy conservation and emission reduction policy, especially for thermal energy conversion equipment, the performance test requirements of power generation equipment are more reflected in energy-saving performance, such as conversion efficiency of thermal equipment, working medium parameters, auxiliary power consumption Rate, etc. The performance test of trough type solar thermal power station is a kind of test work implemented in the field of power station equipment operation by using test instruments and test environment after the solar thermal power station is put into commercial operation.

For the performance test of heat transfer oil tank type solar thermal power station, especially for the
collection and storage heat exchange island system, first of all, according to the performance guarantee
value, thermal calculation description, heat balance diagram, meteorological environment and other
data provided by the equipment manufacturer and the Design Institute, relevant technical indicators
shall be detected through performance test to check whether the performance index of the heat
exchange island system is full Meet the design requirements and the performance guarantee value
provided by the supplier.

Table 1 shows the performance evaluation indexes of the heat collection and storage heat exchange
island system of the solar thermal power station with heat transfer oil tank.

| Equipment and system | Test name | index |
|----------------------|-----------|-------|
| Heat collecting system | Efficiency test of heat collecting system | Total efficiency of heat collecting system |
| Heat storage system | Continuous heat storage performance test of heat storage system | Effective heat storage time |
| Heat exchange system | Heat exchange efficiency test of heat exchanger | Heat exchange efficiency |
| Auxiliary system | Output test of auxiliary equipment | Output of auxiliary equipment |

4. Content of performance test

4.1. Heat exchange efficiency of heat exchanger

The typical heat exchange system of solar thermal power station with heat transfer oil tank has typical
equipment such as Pre-heater, Super-heater, Re-heater and steam generator. These equipments belong
to heat ex-changer. The heat exchange performance of heat ex-changer is characterized, and the heat
exchange capacity can be measured by heat exchange efficiency index. The heat transfer efficiency is
based on the ratio of the effective heat absorbed by the steam water side of the heat ex-changer to the
heat released from the heat transfer oil side. Taking the Super-heater as an example, the calculation
formula 1 is as follows:

\[ \eta_{SH} = \frac{\sum_{t=1}^{n} Q_{SH,t}(h_{SH,\text{out}}^t - h_{SH,\text{in}}^t)}{\sum_{t=1}^{m} Q_{\text{oil},SH}(h_{\text{oil},\text{SH,\text{out}}^t}^t - h_{\text{oil},\text{SH,\text{in}}^t}^t)} \times 100\% \]  

Where, \( \eta_{SH} \) is the heat exchange efficiency, \( \% \); \( Q_{SH,t} \), \( Q_{\text{oil},SH} \) are the measured flow values of steam
water and heat transfer oil in the heat ex-changer at time \( t \), kg/s; \( h_{SH,\text{out}}^t \), \( h_{SH,\text{in}}^t \) are the enthalpy
values of the outlet and inlet of the steam water working medium of the heat ex-changer at time \( t \),
kJ/kg; \( h_{\text{oil},\text{SH,\text{out}}^t}^t \), \( h_{\text{oil},\text{SH,\text{in}}^t}^t \) are the enthalpy values of the heat ex-changer heat transfer oil at time \( t \),
kJ/kg; \( n \) and \( m \) is the number of measurements.

4.2. Heat storage and heat storage time

The effective heat storage time of the heat storage system can be converted by the effective heat
storage of the heat storage system, and can also be obtained through field test. Before the test, the
molten salt hot tank of the heat storage system should be stored at full load, and the molten salt level
should reach the full energy design level. The inlet oil temperature at the cold end of the heat transfer
oil of the molten salt storage system should be adjusted to the design temperature. The hot salt transfer heat should be returned to the cold salt tank to maintain the cold salt temperature within the design temperature range. The heat transfer oil will transfer heat to the working medium for power generation until the molten salt tank is reduced to the minimum level Effective thermal storage time of thermal storage system.

The thermal storage performance of the thermal storage system directly determines whether the solar thermal power station can continuously generate electricity. The heat storage system of solar thermal power station with heat transfer oil tank has its unique characteristics because of the heat transfer medium of heat transfer oil. In order to evaluate the thermal storage performance of heat storage system, it is necessary to consider the full load storage capacity of molten salt and the power generation capacity of feed water steam with heat transfer oil. It can be characterized by two indicators: one is the maximum effective heat storage energy of the heat storage system, which represents the maximum effective energy storage capacity of the heat storage system [5]; the other index is the effective heat storage time, which indicates that the heat storage system can generate power through heat transfer of heat transfer oil under the premise of maximum effective heat storage, which can meet the continuous operation of steam turbine under the minimum operating load condition Time.

The maximum effective heat storage heat of the heat storage system can be calculated according to formula 2 or formula 3 through the effective operation of the hot salt salt tank, the maximum and minimum salt liquid level, hot salt transport flow, hot salt and cold salt temperature and other physical parameters.

\[
M = \sum_{i=1}^{j} Q_{sa,t} \cdot (h_{sa, out}^i - h_{sa, in}^i) \quad (2)
\]

\[
M = V_{sa} \cdot (h_{sa, out}^i - h_{sa, in}^i) \cdot \sum_{i=1}^{j} \rho_{sa}^i \quad (3)
\]

Where, \( M \) is the maximum effective heat storage capacity of heat storage system, kJ; \( Q_{sa,t} \) is flow measurement value at time \( t \) of molten salt, kg/s; \( h_{sa, out}^i, h_{sa, in}^i \) is the enthalpy value of outlet and inlet of hot melt salt time \( t \), kJ/kg; \( V_{sa} \) the effective heat storage volume of hot melt salt tank, m3; \( \rho_{sa}^i \) is the density of hot salt tank at hot salt time \( t \), kg/m3; \( i \) and \( j \) is the number of measurements.

4.3. Efficiency of heat collecting system

The total efficiency of the heat collecting system is the ratio of the total heat absorbed by the heat conducting oil per unit time to the direct solar radiation energy that can be obtained by the effective area Sunglasses per unit time. The total efficiency of the heat collecting system is used to characterize the maximum heat absorption capacity of the heat transfer oil after the direct solar radiation energy per unit time and the reflection focusing heating of the sunglasses. The total efficiency of the heat collection system is affected by many factors such as the characteristics of the sunglasses, the surface cleanliness of the sunglasses, the reflection loss, the refraction loss, the heat collection and heat transfer characteristics of the collector tube [6-7].

The direct solar radiation energy can be measured by the solar radiation instrument; the heat absorption of heat transfer oil can be obtained through the physical parameters at the inlet and outlet of the heat transfer oil and the flow measurement calculation. The total efficiency of the heat collecting system can be calculated according to Formula 4.

\[
\eta = \frac{\int_{t=1}^{j} Q_{oil,t} \cdot (h_{oil, out,t}^i - h_{oil, in,t}^i)\, dt \times 100\%}{\int_{t=1}^{j} AQ_{oil,t}\, dt} \quad (4)
\]
Where, \( \eta_C \) is the total efficiency of the heat collection system, \%; \( Q_{oil} \) is the flow measurement value of the heat transfer oil at time \( t \), kg/s; \( h_{oil,i}^{out} \), \( h_{oil,i}^{in} \) is the enthalpy of the heat transfer oil at the outlet and inlet at time \( t \), kJ/kg; \( Q_{sc}^{i} \) is the direct solar radiation energy flow density recorded at time \( t \) measured at the position of the sunglasses, w/m²; \( A \) is the effective mirror area of the sunglasses corresponding to the heat transfer oil measuring circuit, m². \( x \) and \( y \) is the number of measurements.

In the measurement process, the local solar illumination is stable and continuous sunny weather conditions, the ground wind speed is less than 1.5 m/s. The measurement interval can be 10-30 min.

4.4. Maximum Continuous Output
The maximum continuous output of the heat collecting system is to check the maximum working capacity of all the sunglasses collecting heat and continuously outputting the rated parameter heat transfer oil, which indicates the maximum continuous working capacity of the full-scale sunglasses of the sunglasses field to output the rated parameter heat transfer oil under the optimal and maximum conversion efficiency working conditions during the period with the strongest sunshine radiation throughout the year. The maximum continuous output of the heat collecting system can be characterized by the maximum heat transfer oil flow or the maximum thermal power.

Taking the characteristic index of the maximum heat transfer oil flow as an example, the time period with the strongest sunshine radiation in the whole year should be selected for measurement. It is appropriate to adjust the heat transfer oil flow of each heat transfer oil circuit to maintain the same pressure and temperature at the inlet and outlet of each heat transfer oil circuit.

\[
Q_c = \frac{\int \int Q_{oil,i}^{i} dt i}{N}
\]

Where, \( Q_c \) is the maximum flow rate of heat transfer oil, kg/s; \( Q_{oil,i}^{i} \) is the flow measurement value at time \( t \) of the I circuit heat transfer oil, kg/s; \( N \) is the number of times for the same measurement interval.

4.5. Flow deviation of heat transfer oil circuit
For large-scale trough type heat transfer oil solar thermal power station, there are usually hundreds of heat transfer oil circuits, each circuit runs through several Sunglasses heat collection groups. For different heat transfer oil circuits, the operating conditions of solar collector group, pipeline resistance, mirror cleanliness and reflection loss of heat transfer oil circuit are different, and the physical parameters of heat transfer oil at the outlet of heat transfer oil circuit are different. In order to improve the heat collection efficiency of each heat transfer oil circuit and make the outlet oil temperature of hundreds of heat transfer oil circuits consistent to meet the rated parameters, it is necessary to dynamically adjust the flow rate of heat transfer oil circuit in the heat collection system, and calculate the flow deviation rate between each circuit.

5. Test instrument
According to the test content and method, the test instrument is selected. For the generator set test instruments of conventional power island, such as thermometer, flow-meter, electric energy meter, power meter and so on, several important measuring instruments are needed in the test. One is a high-temperature ultrasonic flow-meter installed at the inlet and outlet of the thermal oil pipeline of the solar collector, which is used to measure the temperature and mass flow rate of the heat-conducting oil medium; the other is the solar radiation intensity meter, which is used to measure the radiation flux density and DNI value of direct solar radiation [8].

Other test parameters use equipment to run their own installed instruments, such as liquid level gauge, field meteorological test instrument, etc., which need to be calibrated and indicated accurately
before the test.

6. Conclusion

Trough solar thermal technology, with its advantages of mature technology, low cost, convenient operation and maintenance, has been paid more and more attention in the field of renewable energy power generation technology, and has a broad development prospect. In recent years, the major scientific research institutes, electric power research institutions, industry groups are actively building the relevant technical standards of photo thermal power stations, among which the standards related to the performance acceptance of power stations are still under research and exploration. Based on the ideas and methods of performance assessment and acceptance of thermal power generation equipment system in power industry, this paper explores the technical indicators, working methods and contents of performance test for typical equipment and system of heat collection and storage heat exchange island of heat transfer oil tank type solar thermal power station, so as to expect the performance test development of heat transfer oil tank type photo thermal power station, as well as relevant technical personnel and peers The technical work brings reference.

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Reference

[1] Huang S Y and Huang S H 2012 Principle and technology of solar thermal power generation China Electric Power Press 2012 100-211
[2] Luo K, Xu T and Liu H M 2016 The performance test of tower-type solar thermal power plant Hubei Electric Power 40 40-42
[3] L Zhang, Wang C H and Li B J 2016 Test method for the thermal performance of medium temperature solar collector J. Sustainable Energy 6 112-121
[4] Li H B, Zheng Q R and Cui N 2015 Performance analysis of parabolic trough solar collector Applied Energy Technology 213 32-37
[5] Xin H 2015 Trough solar thermal power steam parameters Applied Energy Technology 213 38-42
[6] Mao K A 2019 method of testing the efficiency of parabolic trough solar trough solar thermal power collection system Energy AND Energy Conservation 166 68-69
[7] Jin S, Li Y X and Zang P W 2018 The whole layout study of molten slat steam generation system in solar thermal power generation project Dongfang electric review 32 80-83
[8] Wu M L 2019 Research on characteristics and economics of solar photo-thermal power generation technology Qingai Electric Power 38 18-21