INTERNET OF THINGS TEMPERATURE CONTROL OF INDIRECT DUAL TANK HEAT STORAGE SYSTEM IN SOLAR PHOTO-THERMAL POWER PLANT

by

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In order to study the temperature control of the IoT for indirect dual tank heat storage systems in solar thermal power plants, the author proposes a refined design method for heat storage systems. Through CFD software FLUENT analysis, the author proposes a temperature control scheme for storage tanks in solar thermal power plants and applies this method to the temperature control and salt injection processes of actual commercial power plants. The refined design of a systematic heat storage system mainly involves precise calculation of molten salt content and refined analysis of overall and local stresses in the storage tank. For molten salt storage tanks with a diameter of about 30 m, every 1 cm of liquid level design error will result in economic losses of tens of thousands of Yuan. In addition, the design process of storage tanks should fully consider temperature control, salt injection, and some special operating conditions during operation. By numerically simulating the flow process of flue gas and molten salt in the storage tank and the real-time wall temperature of the storage tank, a temperature control scheme that does not exceed the maximum allowable wall temperature difference of the storage tank is obtained to reduce thermal stress during the temperature control process of the storage tank, reduce the risk and failure rate of the storage tank. The temperature control scheme has achieved good results in practical projects.

Key words: *solar energy, photo-thermal power plant, temperature control dual tank heat storage system*

Introduction

With the commercial operation of multiple trough solar thermal power plants, the reliability of this power generation technology has been confirmed, and it has broad commercial prospects in areas with good solar resources such as western and northern China. The slot solar thermal power generation technology consists of multiple parabolic concentrator arrays forming a solar energy collection field, focusing direct solar radiation on the collector tube heats the heat transfer fluid, which then exchanges heat with water to generate steam, driving the steam turbine unit to generate electricity. Although solar energy is a huge energy treasure trove, the energy density of solar radiation reaching the Earth's surface is very low, and is influenced by geographical, day night, and seasonal changes, as well as random factors such as overcast, sunny, cloudy, and rainy conditions, its radiation intensity is also constantly changing, with significant sparsity, discontinuity, and instability [1]. In order to better become a high quality alternative energy source, improve the efficiency of system power generation, improve the sta-

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bility and reliability of system power generation, and reduce power generation costs, thermal energy storage devices need to be installed in solar thermal power generation, when the solar energy is insufficient, the stored heat energy is released to meet the power generation demand.

As a component of solar thermal power plants, thermal storage systems play an important role in the continuous and stable power generation of power plants. The heat storage system of a solar thermal power station can store heat during normal solar radiation, and release heat to supply steam turbines for power generation during insufficient radiation, playing a power buffering role. On the other hand, during the day, the sunlight is strong at noon and weak in the morning and evening. At night, solar energy cannot be used for power generation, and the heat storage system can store the energy radiated by the sun during the day in the form of thermal energy, which is released at night for thermal power generation, which can play a role in peak shaving and valley filling [2].

Heat storage technology is an important technology for rational and effective utilization of existing energy, optimizing the use of renewable energy, and improving energy efficiency. Thermal storage technology is mainly applied in the following three aspects: provide time delay and ensure effective use between energy production and consumption and provide thermal inertness and thermal protection (including temperature control). Ensure the security of energy supply. A major feature of solar thermal power generation that is superior to PV power generation is the ability to use economical heat storage technology, which is relatively expensive. The purpose of using heat storage technology in solar thermal power generation systems is to reduce power generation costs and improve the effectiveness of power generation. It can achieve: capacity buffering, schedulability, and time shift, improve annual utilization rate, more stable power output, efficient full load operation*, etc.* Heat storage technology can be divided into two categories: direct heat storage and indirect heat storage. The characteristic of a direct heat storage system is the use of forced convection heat transfer to transfer heat to the heat storage medium, and the heat storage medium itself circulates within the heat exchanger.

The main characteristic of an indirect heat storage system is that the heat transfer fluid and the heat storage medium are different media. During the heat storage process, the heat transfer fluid from the heat absorber transfers heat energy to the heat storage medium, while during the heat release process, the heat transfer fluid absorbs heat from the heat storage material. The heat storage medium can be a solid, liquid, or phase change material, and does not participate in the cycle itself [3]. Figure 1 shows the heat storage form. The IoT refers to the combination of technology, computer, and internet technologies, which enables real-time sharing of environmental and state information between objects, as well as intelligent collection, transmission, processing, and execution achieve deeper IoT.

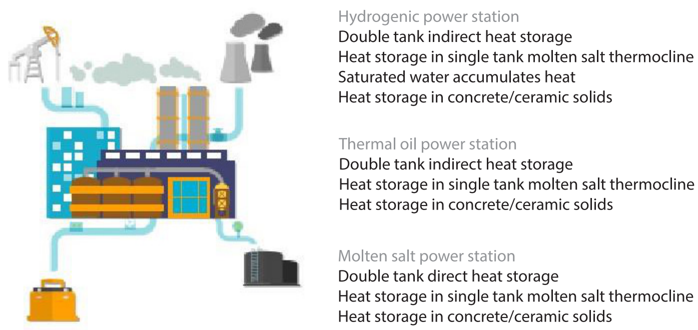

Figure 1. Heat storage form

It has great advantages. By controlling indoor objects, it can achieve various functions such as supervision, alarm, and control. Temperature control circuits are common temperature control devices in daily life, in industrial production, it also occupies an extremely important position. Traditional temperature control circuits mostly use button switches for control. With the arrival of the intelligent era, it can no longer meet people's needs. Therefore, how to combine the IoT and temperature control circuits has become a research direction of modern temperature control technology.

Based on current research, the author proposes a refined design method for the molten salt content and wall thickness of the thermal storage system of a solar thermal power plant. By numerically simulating the flow process of flue gas and molten salt in the storage tank and the real-time wall temperature of the storage tank, a temperature control scheme is obtained that does not exceed the maximum allowable wall temperature difference of the storage tank. This is used to reduce thermal stress during the temperature control process of the storage tank, reduce the risk and failure rate of the storage tank. The temperature control scheme has achieved good results in practical projects [4].

Tank design model and boundary conditions

Design boundary conditions

The author's calculation parameters are based on a 50 MW tower photo-thermal power plant. The design input conditions for the heat storage system include turbine performance parameters for calculating the required heat for heat storage, as well as design parameters related to storage tanks, tab. 1 [5].

Table 1. Design input conditions for heat storage system

Project	Unit	Numerical value
Heat storage hours	[MWe]	12
Gross output of steam turbine	[MWe]	5
Steam turbine thermal efficiency	[MWe]	0.455
Heat storage and pipe-line thermal efficiency	[MWe]	0.961
Cold salt temperature	[°C]	298.2
Hot salt temperature	[°C]	565.3
Cold salt specific heat capacity	[$Jkg^{-1}K^{-1}$]	1494.266
Heat salt specific heat capacity	[$Jkg^{-1}K^{-1}$]	1538.470
Cold salt density at design temperature	[kgm^{-3}]	1900.482
Hot salt density at design temperature	[kgm^{-3}]	1737.030
Tank design straight wall height	[m]	14.53
Minimum tank level	[m]	1.02
Maximum allowable liquid level of storage tank	[m]	13.01
External equipment and pipe-line volume	[m^3]	450

Refined calculation of molten salt content

The design heat storage duration of the project's heat storage system is 12 hours, and the required heat storage capacity Q_s and effective heat storage molten salt amount mste are calculated:

$$Q_s = \frac{P_e}{\eta_t \eta_s \eta_P} t_s$$
$$m_{\mathrm{STE}} = \frac{Q_s}{c_s \Delta t} \tag{1}$$

where P_e is the rated power of the steam turbine, η_t – the thermal efficiency of the steam turbine cycle, η_s – the efficiency of the heat exchange system, η_P – the pipe-line efficiency, t_s – the duration of heat storage, c_s – the specific heat capacity of molten salt, and Δt – the design temperature difference between the cold and hot tanks. Through calculation, the required effective molten salt amount for this project is 12711 tons, which can obtain the required tank height for effective molten salt. Adding the minimum liquid level of the tank can obtain the total molten salt volume of the tank, resulting in a total molten salt amount of 15664 tons. Due to the fact that the total amount of molten salt in the storage tank is calculated based on design parameters, other operating conditions need to be checked after preliminary calculation ensure that the total molten salt level does not exceed the maximum liquid level limit of the storage tank, and to ensure that the effective molten salt amount in the storage tank is not less than 12711 tons under each operating condition [6]. Table 2 shows the various calibration conditions: Condition 1 is a cold condition, and there is no molten salt in the storage tank;

Table 2. Tank verification conditions

Working condition	Temperature [°C]	Inner diameter of cold tank [m]	Inner diameter of hot pot [m]	Molten salt density [kgm^{-3}]
1	25	29.101	30.010	1900.57
2	298	29.213	–	1854.78
3	370	29.242		1835.70
4	400	29.254	30.236	1737.12
5	555	–	30.311	1724.40
6	575		30.326	1712.95
7	593		30.333	1900.57

Working Conditions 2-4 refer to the condition where the minimum liquid level of the hot tank is met, the working condition of storing most of the molten salt in a cold tank. Working Conditions 4-7 refer to the condition of storing most of the molten salt in the hot tank while meeting the minimum liquid level of the cold tank. Condition 4 is actually divided into two conditions: Condition 4 (cold tank) and Condition 4 (hot tank). Through verification and calculation, it was found that the required molten salt amount for Condition 4 (cold tank) is 15810 tons, therefore, the total molten salt amount was corrected and based on this, the tank structure design was carried out. After the design is completed, finite element analysis needs to be conducted on the storage tank to ensure that it meets the stress requirements under all working conditions.

Due to the lack of applicable regulations and specifications for the design of storage tanks in photo-thermal power plants, the API650 standard is commonly used for calculation of storage tank design in photo-thermal power plants. The wall thickness equation:

$$\delta_d = \frac{4.9D(h-0.3)\rho}{\sigma} + C_a$$
$$\delta_t = \frac{4.9D(h-0.3)}{\sigma_t} \tag{2}$$

where δ_d is the calculated wall thickness, D – the diameter of the storage tank, h – the liquid level, σ – the allowable stress for design conditions, ρ – the density of molten salt, C_a – the corrosion allowance, δ_t – the wall thickness of the hydraulic test, and σ_t – the allowable stress for hydraulic testing [7].

Partial refined design

Through finite element calculation, strengthening the local areas where the stress exceeds the limit can effectively ensure the safety of the storage tank and avoid the power plant shutdown caused by local leakage. Table 3 shows the tank wall thickness calculated using the API 650 standard and the tank wall thickness corrected through refinement methods, the wall numbers 1-6 refer to the steel plate numbers from the bottom to the top of the wall. Through comparison, it can be seen that after correction, the steel plates near the top and bottom of the storage tank are more thickened, which is consistent with the finite element calculation results. The stress in these two areas is relatively concentrated and needs to be strengthened.

Table 3. Calculated thickness and refined design thickness of tank wall

Wall number	Calculated thickness [mm]	Thickness after refinement [mm]	Deviation [mm]	Relative deviation [%]
1	34.42	35.60	1.1	3.08
2	28.12	29.10	0.9	3.08
3	21.82	22.60	0.7	3.08
4	15.51	16.60	1.01	6.07
5	9.21	11.10	1.81	16.37
6	6.01	10.10	4.01	40.01

Research on temperature control schemes for storage tanks

Boundary conditions

The refined design of the storage tank only analyzes the stress when the molten salt in the tank is at the design level under design conditions. There are some local stress concentrations during temperature control and actual operation, and there is still a possibility of leakage in the storage tank, therefore, it is necessary to further verify and determine a temperature control plan that does not cause damage. Temperature control of storage tanks is achieved by setting a temperature control air nozzle near the edge of the top of the tank, allowing high temperature flue gas to form a hot air circulation inside the tank to achieve continuous heating of the tank. For this project, the following temperature control parameters and limits are proposed: The diameter of the temperature control nozzle on the top of the storage tank is 508 mm, and a gradually shrinking nozzle is set at the outlet of the pipe-line. Assuming the initial temperature of the storage tank is 0 °C. The flow rate of hot flue gas for temperature control is 7000 m^3 per hour (0-75 hours), and 8500 m^3 per hour (after 75 hours). The initial temperature of the hot flue gas is 150 °C.

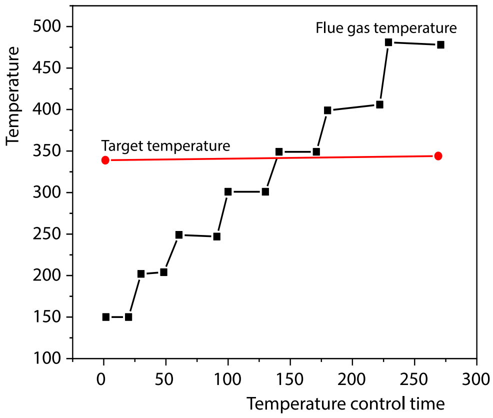

Figure 2. Temperature control curve of storage tank

Figure 2 shows the temperature control smoke control curve of the storage tank [8]. Considering the temperature increase capacity of the storage tank, the maximum allowable temperature rise rate of the storage tank is not more than 3 °C per hour, but it can withstand a temperature rise rate of 5 °C per hour in a short period of time (when the wall temperature of the storage tank is below 150 °C, the time when the temperature rise rate exceeds 3 °C per hour does not exceed 50% of the total heating time). When the wall temperature of the storage tank is higher than 150 °C, the time when the heating rate exceeds 3 °C per hour shall not exceed 20% of the total heating time; The maximum allowable temperature difference of the storage tank shall not exceed 30 °C, and in the initial stage of temperature control (when the tank wall temperature is less than 150 °C), it can be greater than 30 °C, but shall not exceed 50 °C. The target temperature control temperature of the storage tank is 340 °C.

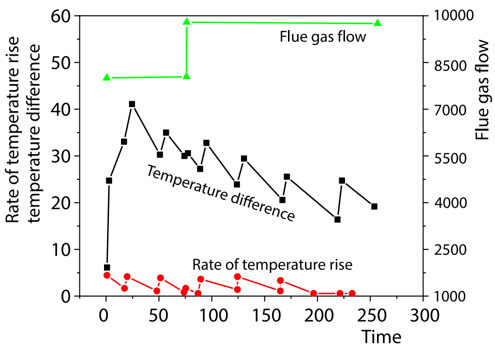

Figure 3. Temperature rise rate and temperature difference control curve of storage tank

Numerical analysis and validation

Calculate the temperature distribution of flue gas inside the storage tank and the characteristics of the temperature distribution on the tank wall over time through °C FD simulation. Real time statistics are conducted on the temperature rise rate of the tank wall and the maximum temperature difference on the tank wall to obtain the maximum wall temperature difference and temperature rise rate control during the tank temperature control process, as shown in fig. 3 [9]. Figure 3 shows the flow control during the temperature control process. After 75 hours, the hot flue gas-flow rate for temperature control increased from 7000-8500 m^3 per hour. This is because the heat dissipation of the second half of the storage tank increased, and it is necessary to increase the temperature control flue gas-flow rate of the storage tank to ensure a certain temperature rise rate. From fig. 3, it can be seen that the temperature rise rate of the storage tank in this temperature control scheme remains basically below 3 °C per hour, with only a few operating conditions experiencing short-term high temperature rise rates (not exceeding 59 °C per hour).

These peaks mainly occur at the initial moment of controlling the temperature step, which can meet the limit requirements determined by the tank stress calculation. Except for the large maximum temperature difference of the storage tank in the initial stage of temperature control (close to 409 °C), the maximum temperature difference of the storage tank gradually decreases over time, and ultimately stabilizes below 30 °C, meeting the maximum temperature difference requirements of the storage tank.

The analysis of temperature control process is a part of the refined design of storage tanks, and a reasonable temperature control strategy for storage tanks helps to protect them from extreme working conditions that may damage them during the temperature control process [10]. After adopting the temperature control strategy for the storage tank of a 50 MW tower type photo-thermal power plant, the wall temperature difference data of the storage tank can be seen. During the entire temperature control process, when the wall temperature of the storage tank is less than 150 °C, the maximum temperature difference of the storage tank is mostly close to 409 °C, and sometimes close to 50 °C. The refined design of a systematic heat storage system mainly involves precise calculation of molten salt content and refined analysis of overall and local stresses in the storage tank. For molten salt storage tanks with a diameter of about 30 m, every 1 cm of liquid level design error will result in economic losses of tens of thousands of Yuan. In addition, the design process of storage tanks should fully consider temperature control, salt injection, and some special operating conditions during operation. By numerically simulating the flow process of flue gas and molten salt in the storage tank and the real-time wall temperature of the storage tank, a temperature control scheme that does not exceed the maximum allowable wall temperature difference of the storage tank is obtained to reduce thermal stress during the temperature control process of the storage tank, reduce the risk and failure rate of the storage tank. The temperature control scheme has achieved good results in practical projects. After the wall temperature of the storage tank exceeds 150 °C, the maximum temperature difference is basically less than 309 °C. The trend of the entire temperature control process is close to the simulation results, which can meet the design limit of the storage tank and will not affect the safety of the storage tank.

Conclusion

The thermal storage system is an important subsystem and one of the accident prone systems of photo-thermal power plants. It is the key to the continuous and stable operation of photo-thermal power plants. The refined design of the thermal storage system is of great significance for cost control and safe and stable operation of photo-thermal power plants. The author proposes a refined calculation method for the molten salt content of storage tanks, which ensures that the effective molten salt content requirements of the tank and the safe and stable operation of the tank can be met under various working conditions through refined design and finite element analysis. By simulating the temperature control process of storage tanks, the author analyzed the temperature difference and temperature rise process parameters during the temperature control process, and obtained a safe and reliable temperature control strategy for storage tanks. The temperature control scheme has been well applied in practical projects, and the temperature control process did not exceed the storage tank limit. The storage tank after temperature control operates well.

Project fund

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