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Thermal Characteristics and Integration Mechanism of Infrared Thermal Imaging (ITI) Solar and Coal-fired Complementary Power Stations

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Abstract: Under the constraints of the dual goals of energy saving and consumption reduction and emission reduction, the rational use of renewable energy can not only be used as an external energy saving measure in energy saving technology, but also can achieve the effect of emission reduction. The main purpose of this paper is to study the thermal characteristics and integration mechanism of complementary power plants between solar and coal-fired units based on ITI technology. Based on the traditional thermal system evaluation method, according to the characteristics of the complementary system and the exergy analysis method, this paper establishes a system evaluation model of the coal-fired complementary system, and evaluates the two complementary systems from two aspects of thermal efficiency growth rate and exergy efficiency growth rate. In this paper, the calculated value of each state point in the complementary system is compared with the parameters in the actual electric field to verify the rationality of the system calculation. The system is selected for comparison at 80%, 65% and 50% of unit load. The error from the actual value is within a reasonable range.

1. Introduction

The energy saving methods of coal-fired units are broadly divided into internal energy saving and external energy saving. The internal energy saving mainly refers to improving or perfecting the system configuration, such as improving the steam parameters of the unit to increase the efficiency and reduce the energy consumption, while the external energy saving refers to The method of introducing external resources such as solar energy (SE) to coal-fired units achieves the effect of improving efficiency and reducing energy consumption. At present, the further development of high-parameter and large-capacity units is restricted by factors such as equipment and materials, and the internal energy-saving potential of the unit has been deeply excavated [1-2].

In a related study, Rahaman et al. introduced the importance of RPA-based infrared imaging for identifying defects in solar photovoltaic systems [3]. Addresses the opportunities achievable through the adoption of RPA-based infrared imaging technologies to add value to the social, economic, and environmental performance of photovoltaic systems. Oliveira et al. proposed a tip thermal infrared enthalpy (in-tip TIE) method for fast enthalpy analysis [4]. In this method, the reaction within the tip of a multichannel pipette is combined with temperature monitoring by an infrared camera.

This paper first analyzes the significance of the research on the thermal characteristics and integration mechanism of complementary power stations based on ITI technology between solar and coal-fired units. Then, the solar-coal complementary system is described, and the thermodynamic performance of the solar-coal complementary system is analyzed. Based on the analysis, the thermal system model of the coal-fired power station is established; at the same time, based on the solar-coal complementary system, a new complementary method is proposed, and then the thermodynamic evaluation index of the complementary system is established.

2. Design Research

2.1. Research Significance

Energy shortage has become an important problem faced by mankind, and China, as a major energy-consuming country, is also facing more and more problems and challenges. In the past few decades, with the rapid growth of the domestic economy, the consumption of primary energy has also increased rapidly. At the same time, due to the unreasonable emissions of CO2, SO2 and NOx caused by the burning of fossil fuels, smog and acid rain have caused people's lives to suffer. Bringing serious impact, reducing the burning of fossil fuels, promoting the widespread application of renewable energy, and actively improving the energy structure have become important issues facing now. The country pointed out in the medium and long-term development and reform plan that SE as a clean energy has become the only way to develop sustainable energy. From the perspective of the national energy strategy and long-term planning and development, strengthening the research and exploration of solar thermal utilization technology has far-reaching significance [5-6].

2.2. Description of Solar-Coal Complementary System

For the integration method of the solar-coal complementary system, after years of research and exploration, the following methods have been formed.

(1) The heat absorbed by the solar mirror field is used to replace the heating surface of the boiler [7-8]. In this complementary system, the heated return water in the thermal system will be divided into two parts, and one part will continue to pass through the boiler water wall to be heated into The steam goes to the steam turbine to do work, and part of it will pass through the heat exchanger (HE) connected to the heat collecting field to absorb the solar heat in the heat collecting field. The working fluid of the path is mixed and then enters the steam turbine to do work. This complementary method has relatively strict requirements on the temperature and stability that can be achieved by the heat collecting field due to the high outlet steam parameters.

(2) The complementary method of replacing the feed water heater with the collector field [9-10], this complementary method is the most common in the solar-coal complementary system today.

Depending on the size of the unit, the collector field replaces the feed water heater. It can also be different, and it can simply replace a certain heater in the circuit, such as a high-pressure heater, or replace a plurality of heaters, or replace all the heaters together. During the integration process, the solar collector mirror field can be directly connected to the system, that is, the return water can directly pass through the mirror field collector tubes, or the heat can be transferred to the feed water through a HE. The advantage of this complementary method is that the requirements for the outlet parameters of the collector field are relatively low and the stability is good.

(3) The collector field is connected in parallel with feedwater heaters and coal-fired boilers [11-12]. This complementary method is a combination of the above two complementary methods. After the parallel connection, the temperature span of the feedwater passing through the collector field is large. The thermal field requirements are relatively high, and the water supply needs to absorb a lot of heat from low parameters to high parameters, so the area and efficiency of the heat collector field should be increased accordingly to increase the absorbed heat, which will increase the investment in system construction. At the same time, the SE contribution of the system is also relatively large.

2.3. Thermodynamic Performance Analysis of Solar-Coal Complementary System

The complementation of solar power and coal-fired power plants involves a variety of factors. The radiation intensity is dominant in each factor. The change of radiation intensity will cause changes in the thermal performance of the system. The complementary system will also adjust accordingly with the difference in radiation intensity [13-14]. Compared with the traditional complementary method, the new complementary system proposed in this paper is evaluated in terms of coal saving rate and total thermal efficiency. The performance of the two complementary systems under different complementary methods under different unit loads reflects the advantages and disadvantages of the systems. In terms of using SE heating, the current methods are mostly aimed at a single building or a small heating area, and there is no precedent for using SE central heating. In order to provide a theoretical basis in the direction of solar central heating. At the same time, the use of oil-water HEs in the complementary method will inevitably lead to changes in thermal performance due to the temperature change of the heat transfer oil inside the HE. Aiming at the thermal performance of the heat transfer oil itself, and under different heat transfer oil temperatures, the difference in heat exchange efficiency will cause changes in the performance of the thermal system. In order to provide the best operating parameters during the operation of the system, it can provide a theoretical basis for the popularization and application of the system in the future [15-16].

2.4. Thermal System Model of Coal-Fired Power Station

(1) Coal-fired boilers

The boiler is one of the three main engines of a coal-fired power station and an important system component. Its main function is to absorb the heat of coal combustion to heat the feed water in the soda-water system, and generate steam after reaching certain parameters. The boiler energy exchange process is a typical complex heat exchange system, and the boiler part is modeled and analyzed with a simplified algorithm [17-18].

$$Q_b = m_b (h_{b,out} - h_{b,in}) \eta_b \tag{1}$$

In the formula, Qb—coal combustion provides heat, kJ; nb—boiler thermal efficiency, %; mb—feed water flow, t/h.

In addition, the basic calculation method of boiler exergy efficiency is:

$$\eta_{exb} = (E_{b,out} - E_{b,in}) / E_{coal} \tag{2}$$

In the formula, Eb, coal—the exergy value provided by coal combustion, kJ/kg; Eb, in—the exergy value of the boiler inlet water supply, kJ/kg; Eb, out—the exergy value of the boiler outlet steam, kJ/kg.

The exergy value Ecoal of coal includes two parts: physical exergy Etm and chemical exergy Ech. For the specific calculation method, please refer to the reference materials.

(2) Steam turbine

In general theoretical studies, a steam turbine is usually defined as an open system, and the heat loss in this system is zero. That is, the superheated steam and the reheated steam perform reversible adiabatic expansion work in the steam turbine stage group, and the change of kinetic potential energy is assumed to be zero. Based on the above reasonable assumptions, as shown in the following formula:

$$w_i = h_{in} - h_{out} = \Delta h \tag{3}$$

In the formula, hin——the specific enthalpy value of the steam at the inlet of the steam turbine, kJ/kg; hout——the specific enthalpy value of the steam at the steam turbine outlet, kJ/kg.

However, under actual operating conditions, there must be frictional resistance between the steam and the inner wall in the process of steam doing work in the steam turbine, so there is an irreversible heat loss. Therefore, the relative internal efficiency of the steam turbine is introduced:

$$w_i' = \eta_{ri} \cdot \Delta h \tag{4}$$

In the formula, nri is the relative internal efficiency, %; w'i is the actual working capacity, kJ/kg. The enthalpy change is the enthalpy difference between the inlet and outlet steam.

3. Experimental Study

3.1. New Ways of Complementarity

The above three complementary methods are the traditional integration methods of the solar-coal complementary thermal power generation system. On these basis, a new complementary method is proposed here, as shown in Figure 1.

With the gradual reform of the national energy policy and environmental policy, more and more attention has been paid to environmental pollution. The small-unit heating power stations in northern cities have relatively large pollution due to their small units. Insufficient urban heating and other problems. In this case, the article proposes to use the combination of SE and coal-fired units to transform small-unit heating power stations to improve the energy utilization rate of the power station and save energy. The combustion of fossil fuels reduces pollutant emissions, and at the same time reduces the investment brought by the elimination of small-unit power stations and the new construction of large-scale units.

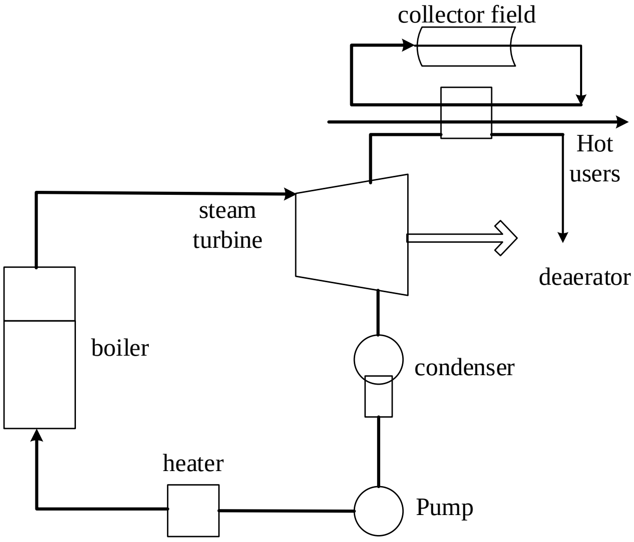

Figure 1. The collector field is directly connected to the thermal user

3.2. Thermodynamic Evaluation Index of Complementary System

The SE complementary system is a combination of two systems. It is necessary to consider the energy absorbed by the SE, as well as the energy consumption and work of the system itself. In this paper, the evaluation indexes of the two systems are used according to the characteristics of complementary systems.

The coal saving rate is to characterize the coal saving degree of the solar-coal complementary system compared with the pure coal-fired unit after converting into standard coal consumption.

$$b = \frac{b_{CF} - b_{SCAF}}{b_{CF}} \times 100\% \tag{5}$$

In the formula, b is the coal saving rate of the complementary system, %; bCF is the standard coal consumption, g/(kw ·h); bSCAF is the complementary coal consumption.

The total thermal efficiency of the complementary system is used to evaluate the relationship between the input and output energy of the system. Ignoring the system steam leakage, assuming that there is no heat exchange loss for the feedwater heaters at all levels, the expression of the total thermal efficiency is as follows:

$$\eta_{tp} = \frac{3600 N_{el} + Q_h}{B_{tp} Q_L} \tag{6}$$

where ηtp—the total thermal efficiency of the complementary system, %.

3.3. Model of Trough Solar Collector System

A typical solar thermal utilization method that transfers heat to the HE fluid in the collector tube to achieve heating. The system mainly includes: parabolic reflector, tracking system, oil-water HE, heat transfer oil circulating pump, oil storage tank, expansion tank, etc.

(1) Trough solar collector model

The straight-through vacuum collector tube in the trough solar collector is a typical high-temperature solar collector tube. The metal outer wall is coated with a coating, and there is a glass cover tube on the outside to maintain a vacuum state in the middle, so as to reduce the convective heat loss of the metal collector tube and improve the efficiency. heat collection efficiency. The following is a schematic diagram of energy transfer in a trough solar collector.

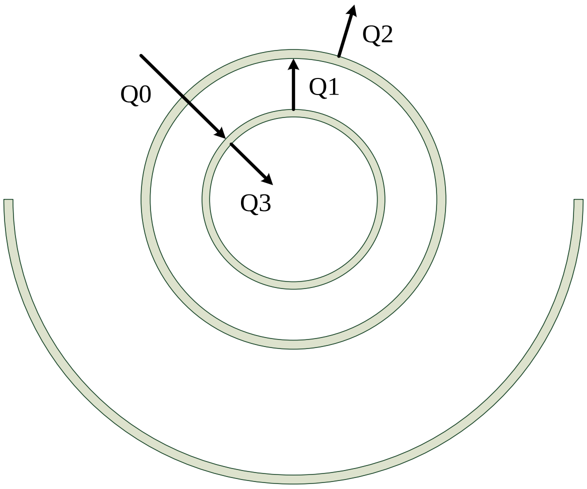

Figure 2. Schematic diagram of energy transfer in trough solar collectors

(2) The collector tube absorbs solar radiation heat Q0

Factors such as the incident angle of the sun's rays and the mutual influence of the shadow of the heat collection tube row should be considered in the calculation:

$$Q_0 = G\cos(\theta) f_\theta f_s f_e \eta_f \eta_e f_0 \tag{7}$$

Among them, G is the direct radiation intensity, W/m2; f0 is the influence factor of solar tracking efficiency.

3.4. Evaluation Index of Thermal Economy

For coal-fired units, the main indicators for evaluating their thermal performance are as follows:

(1) The specific internal power of 1kg of new steam is
(2) Electric power actually generated by the generator:
(3) Specific heat consumption of steam turbine:
(4) Absolute internal efficiency of steam turbine:
(5) Absolute electrical efficiency of steam turbine:
(6) Turbine heat consumption rate:
(7) Turbine steam consumption rate:
(8) Calculation of thermal efficiency of the whole plant:
(9) Standard coal consumption rate for power generation, g/(kW·h):
(10) Heat consumption rate of the whole plant, kJ/(kW·h):

According to the parameters of the regenerative system of the original coal-fired power station, the data is substituted into the relevant formula, and the thermal performance index of the unit under each working condition can be obtained from the calculation, as shown in Table 1.

Table 1. Unit thermal performance index

Thermal performance index	THA	75%THA	50%THA
The AIE of the unit	0.48142	0.46994	0.45133
SCR (kg/(kW·h))	2.809	2.746	2.715
HCR (kJ/(kW·h))	7629.595	7816.156	8138.375
SCCR for power generation (g/(kW·h))	286.019	293.013	305.092

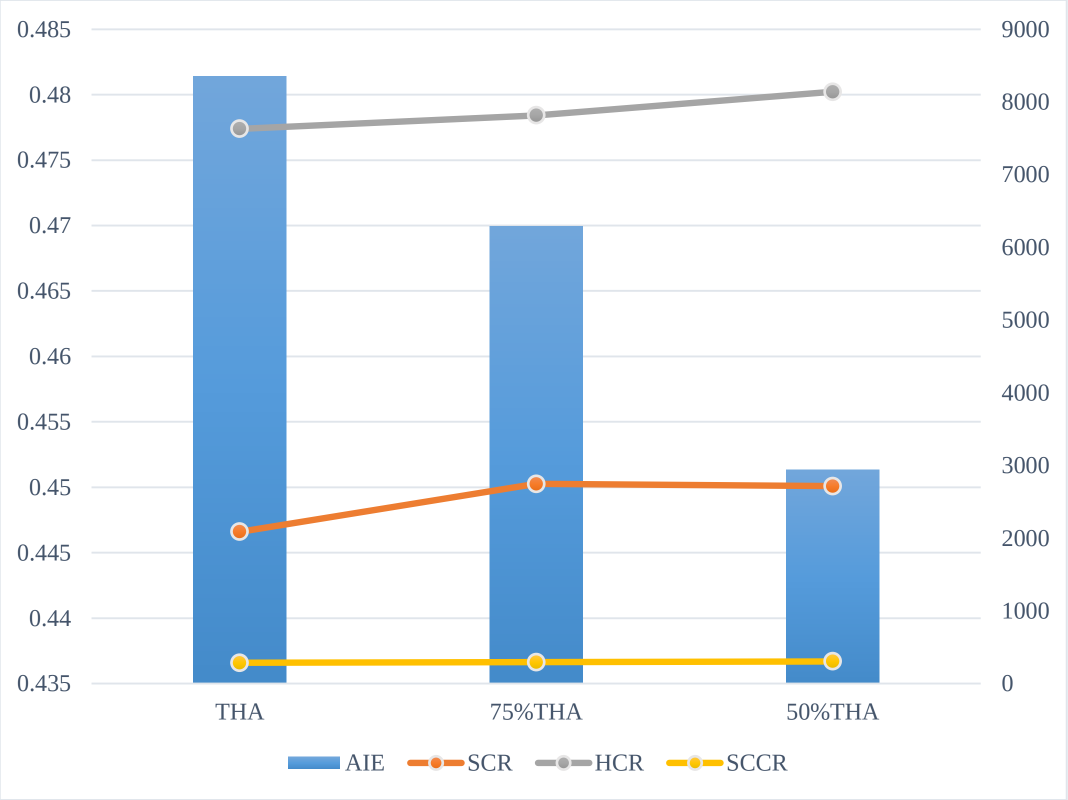

Figure 3. Analysis of unit thermal performance indicators

4. Experiment Analysis

In this paper, solar collectors and coal-fired units are integrated in two ways:

Method 1: Use the collector to heat the return water system, a part of the feed water from the feed pump is heated by the heater and then enters the boiler, and the other part is mixed with the feed water at the outlet of the superheater after heat conversion, and is made of hot water. exchangers and solar collectors, and press the boiler together.

Method 2: According to the characteristics of the heating unit, following the principle of "correspondence of temperature", this paper proposes a new integration method, that is, the solar heat collection system is connected to the primary heat network, and the heat collection field is used to control the heating and return section 4. The return water is heated, and the heated water is returned to 3 again to exchange heat for the hot user.

After the complementary system, the main steam of the steam turbine and the extraction steam parameters at all levels remain unchanged, the working fluid parameters at the inlet and outlet of the coal-fired boiler remain unchanged, and the outlet temperature of the condenser outlet and the heaters at all levels in the return water system also remain unchanged. Compare the calculated value of each state point in the complementary system with the parameters in the actual electric field to verify the rationality of the system calculation, and select the system for comparison at 80%, 65% and 50% of the unit load. The specific data is shown in Figure 4 below.

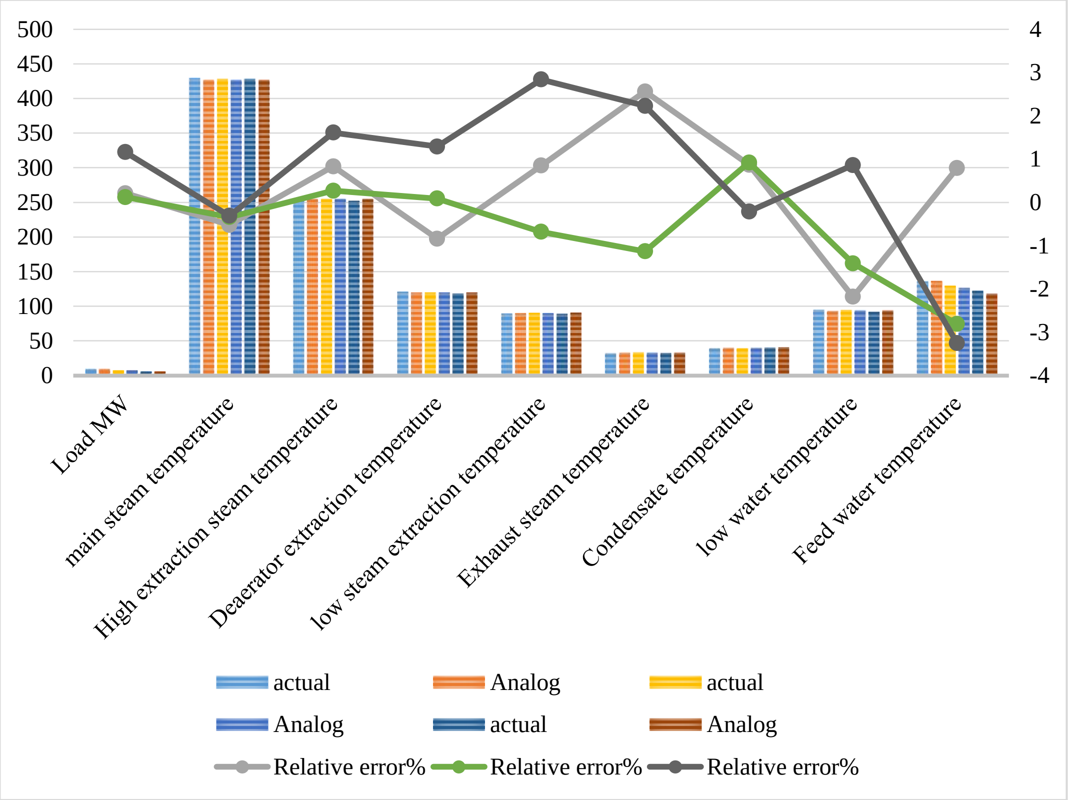

Figure 4. Error parameter analysis of thermal system under different unit loads

The above results show that the error between the simulated value and the actual value is within a reasonable range.

Based on the traditional thermal system evaluation method, according to the characteristics of the complementary system, the exergy analysis method is used to establish a system evaluation model of the coal-fired complementary system, and the two complementary systems are evaluated from the thermal efficiency growth rate and the exergy efficiency growth rate. At the same time, the thermal system exergy efficiency and energy distribution characteristics of pure coal-fired units and complementary mode 2 are compared on this basis. The results show that:

(1) The thermal efficiency growth rate and exergy efficiency growth rate of the system of complementary mode 2 are higher than those of the system of complementary mode 1, and this analysis method shows that compared with the traditional thermodynamic analysis method, the exergy analysis method has a better effect on the introduction of the two complementary systems.

The improvement in system performance after solar can be shown directly.

(2) On the basis of comparing the thermal efficiency growth rate and exergy efficiency growth rate of the two complementary systems, the system of complementary mode 2 is compared with the equipment exergy efficiency and exergy loss coefficient of a simple coal-fired unit. The system reduces the irreversible losses in the system.

5. Conclusion

ITI monitoring is more and more accepted by all walks of life, and has been widely used in military, social security monitoring, mining exploration, industrial high temperature detection, power line maintenance and so on. ITI monitoring system is the intersection and synthesis of optical technology, video technology, radio technology, communication technology, computer network technology, information technology and image compression coding technology. Based on the solar-assisted coal-fired power generation system, the medium and low temperature SE is combined with the small-unit heating power station, in order to provide a basis for the upgrading and transformation of the small-unit heating power station, and at the same time solve the problems of insufficient heating in the northern region.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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