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Optimizing operation of a solar-aided coal-fired power system based on the solar contribution evaluation method

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HIGHLIGHTS

- The solar contribution of the solar-aided coal-fired power plant was calculated.
- Adjusting heat transfer fluid flow rate to improve the performance of the system.
- The generation revenue function was proposed to evaluate the system.

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ABSTRACT

A solar-aided coal-fired power system (SACFPS) model with five load conditions (100%, 85%, 75%, 50%, and 40%) was built based on thermodynamic and thermoeconomic theories. SACFPS is a combination of a parabolic trough solar power system and a 660 MW coal-fired generation plant. The solar contribution evaluation method was introduced into the model to calculate the generation share of the solar power system. Results show that solar contribution decreases after an initial increase as effective solar normal irradiation increases. Optimization strategies, adjusting heat transfer fluid flow rate, have been proposed to maintain solar contribution at a high level. Thus, SACFPS with five load conditions has been optimized. This study also establishes a generation revenue function to evaluate the economics of SACFPS. Income generation of SACFPS after optimization is significantly higher than that without optimization.

1. Introduction

Fossil fuel is the dominated energy source in China, with coal utilization accounting for nearly 70% in the total energy consumption [1]. Greenhouse gas emissions caused by fossil fuel utilization become one of the great issues in the world. According to the IPCC report, there are three categories for CO_2 mitigation in the power industry as: the development of power units with greater capacity; more utilization of renewable energy for power generation and CO_2 capture from flue gas of power plant [2].

Solar energy is taken as one kind of the potential renewable energy to handle the energy issues in the future. But there are two drawbacks of solar thermal power generation as: high cost and low overall efficiency [3]. It is crucial for increasing the efficiency of solar thermal power generation and solving the environmental issues of fossil utilization to combine the solar thermal energy with fossil power system [4]. In the field of the combination, there are two ways. One is to take solar energy as the main energy source, and the fossil is used to keep the stable operation of the solar energy; while the other is using the fossil power system as the dominated system, and the solar energy is viewed as the supplemental energy source [5]. More specifically, in the second catalogue, when the fossil energy is natural gas, the combined system is known as integrated solar combined cycle (ISCC) [6–8]; while when the fossil energy is coal, the combined system is called solar aided coal-fired power plant (SACFPS) [9–20].

Recent years, many researches in the field of SACFPS are focused on the system integration [9–11], thermodynamic and exergy evaluation [12–15], the operation characteristics of the system [16–17] and the economic analysis [18–20]. Firstly, in the respect of the system integration, the system integration of coal-fired power plant and solar thermal energy was performed and the basic rules for system integration were obtained [9]. The SACFPS was proposed to work in two modes as power boosting mode and fuel saving mode [10]. Genetic algorithms were used to optimize the integration scheme, collector field area as well as thermal storage capacity of SACFPS [11]. Secondly, for the thermodynamic and exergy evaluation, the 4-E (energy, exergy, environment, and economic) method was proposed to enable SACFPS to establish

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techno-economic viability [12]. The exergy inequality in SACFPS was evaluated and a case study was performed to prove the theory [13]. The solar contribution evaluation methods based on second law of thermodynamics and thermoeconomic theory was proposed [14]. A new SACFPS evaluation criterion was proposed and the system design principle was presented [15]. Thirdly, in the respect of the operation characteristics of the system, the possible schemes to improve the SACFPS on off-design operation were proposed [16]. The performance analysis of a SACFPS was done at designed point under various load conditions [17]. In addition, in the field of economic evaluation, the economics of different solar integration alternatives was calculated [18]; the optimal contribution rate of solar field taking into consideration the results of various simulation scenarios through an economic analysis was found in Greece [19]; An economic assessment of solar power tower electricity generating plant employing molten salt technology was performed [20].

However, the operation of SACFPS is dependent on the whether condition and the load condition of the system output. There is little research on the characteristic of the solar stream distribution and evaluation of the distribution. The originality of this paper lies in that the solar contribution ratio is taken as the objective to analysis the operation of SACFPS based on deep research in the characteristics of the system with the variation of whether condition and load condition, and the generation revenue function is proposed to evaluate the modified operation strategies.

In the current study, a 660 MW SACFPS model was established under different working conditions, and solar contribution to the total generation of the combined system was calculated by using the solar contribution evaluation method. The operation optimization strategy for SACFPS was proposed to maintain solar contribution at an optimal range. In addition, the generation revenue function was established to evaluate the economics of the integrated system.

2. System description

The diagram of SACFPS is shown in Fig. 1. The system includes two subsystems: the solar trough collector subsystem, and the 660 MW coal-fired subsystem. The former includes a series of parabolic trough solar collectors, oil–water heat exchangers, oil circulating pumps, and an electric heater, among other components. Solar collectors are installed along the north–south horizontal axis, and can track from east to west through the driving equipment. The electric heater ensures the stable operation of the system during sudden weather changes. The turbines used in the coal-fired subsystem are of type N660-24.2/566/566. They have a 660 MW supercritical condenser steam unit, a single intermediate reheater, three cylinders, four exhaust extractors, and a single shaft. The feedwater heating system is composed of three high-pressure reheaters (#1, #2, and #3), four low-pressure reheaters (#5, #6, #7 and #8), and a deaerator (#4). The four operating strategies are as follows.

(1) When the received solar energy cannot provide sufficient heat to raise the feedwater temperature to the outlet temperature of #3, the third extraction will be partially substituted. In this case, this proportion of feedwater will be pumped into the outlet of #3 after being heated in the oil–water exchanger.
(2) When the received solar energy can provide sufficient heat to raise the feedwater temperature to the outlet temperature of #3 but is unable to do the same to that of #2, the third extraction will be completely substituted and the second extraction will be partially replaced. The feedwater flows from the feedwater pump to the oil–water exchanger, before reaching the outlet of #2.
(3) When the received solar energy can provide sufficient heat to raise the feedwater temperature to the outlet temperature of #2 but is unable to do the same to that of #1, both the third and second extractions will be completely substituted, whereas the first extraction will be partially replaced.
(4) When the received solar energy can provide sufficient heat to raise the feedwater temperature to the outlet temperature of #1, all three extractions will be completely substituted. After being heated in the oil–water exchanger, the feedwater will be pumped into the boiler.

In this study, the 660 MW SACFPS model with five load conditions (100%, 85%, 75%, 50%, and 40%) was built using MATLAB software.

3. Evaluation methodologies

A solar contribution evaluation method [14] was proposed by the authors in previous research. The proposed method can evaluate the quantity and quality of energy, as well as the non-equivalence of

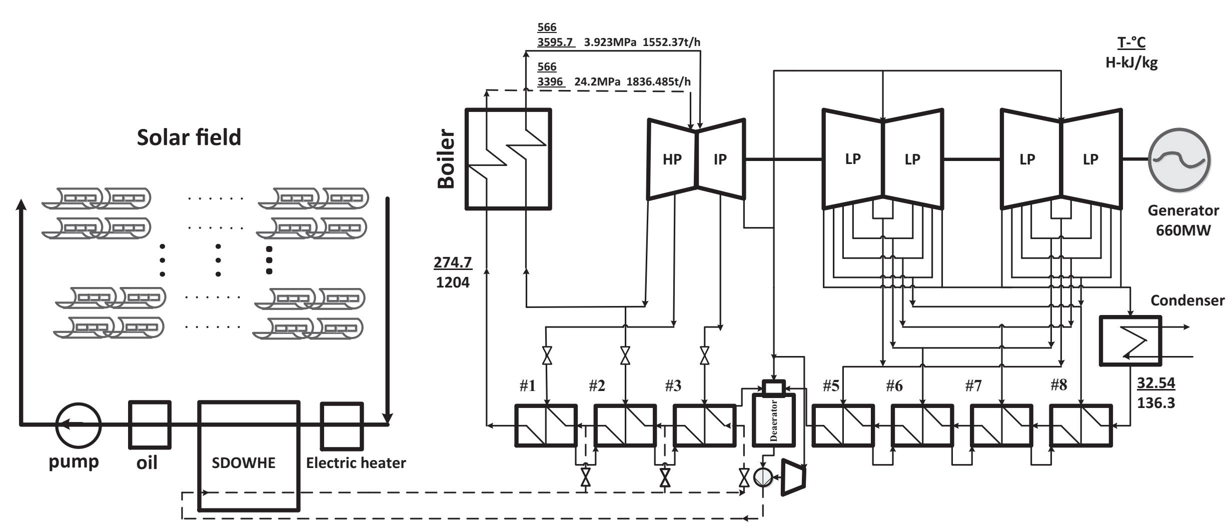

Fig. 1. The diagram of 660 MW trough solar-aided coal-fired power plant.