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Full operating conditions optimization study of new co-generation heating system based on waste heat utilization of exhausted steam

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A B S T R A C T

Utilizing the waste heat of exhausted steam in power plant as a new type of heat source is a key direction to achieve both energy-saving and clean urban heating. In order to recycle all the exhausted steam waste heat of multiple turbine units in designing condition, the authors' research group proposed a new cascade heating system with multi-heat source and applied it in several air cooling power plants in China. This paper focused on the system integration improving and operation strategy formulating, the main studies included: (1) Established the calculation model of system heating characteristics, and analyzed the problems about energy efficiency of system and safety of air cooled condenser in full operating conditions. (2) Introduced the "equivalent electricity of heating" as the evaluation method of comprehensive energy efficiency of the new co-generation heating system. (3) Improved the integration of heating system to further realize energy cascade utilization between turbine units. (4) Aiming at the improved heating system, the comprehensive optimization ideas of operational parameters in full operating conditions were put forward. By above methods, on one hand the "equivalent electricity of heating" of the new co-generation heating system is decreased by 16%, the comprehensive energy efficiency of system is improved, on the other the freezing risk of air cooled condenser is relieved, the operation safety of system is improved.

1. Introduction

Co-generation is an effective way to improve the energy efficiency of thermal power plant [1]. In recent years, China attached great importance to the development of coal-fired cogeneration [2] and vigorously developed 300 MW turbine units in power plants [3]. In these turbine units there is a large amount of condensation heat of exhausted steam releasing through the condenser, which is more than 30% of unit total heat consumption [4]. If this wasted heat (condensation heat) of exhausted steam can be recycled to supply district heating, both the heating output and the energy efficiency of power plants can be increased significantly [5]. China planned to reduce the coal consumption of average electricity supply of new-built and existing coal-fired thermal units to 300 gce/kW h and 310 gce/kW h respectively till 2020, the waste heat utilization is one of the key methods to achieve this goal.

However, the temperature of exhausted steam is too low to heat the heat network return water (about 60 °C) directly. The common ideas to recycle the wasted heat currently are as follows:

(1) Set up the absorption heat pump (AHP) in power plant: Drive the AHP with the extraction steam of turbines to recycle the waste heat of exhausted steam [6,7]. This technology doesn't consume extra high-grade energy (such as electricity), if all the waste heat can be recovered, a higher system energy efficiency will be achieved [8,9]. Some scholars have studied the match of the parameters between heat pumps and steam turbines [10] and analyzed the system thermodynamic performance [11]. The design temperature of the primary heat network water is usually 120/60 °C, restricted by the heating temperature (about 90 °C) and heating performance of AHP ($COP_h \approx 1.7$), the recovery rate of waste heat is only about 50% [12].
(2) Increasing backpressure of turbines: The temperature of exhausted steam is increased to heat the return water of heat network directly [13]. Some scholars have studied the heating process characteristics of direct air-cooled units with high back pressure [14,15]. However, due to the high temperature of return water, the back pressure of turbine needs to be increased sharply, which will reduce the electricity generation of power plants inevitably, the energy efficiency is unsatisfactory.

The power plants usually install two or more sets of turbine units, and the two technologies above are not applicable to achieve the

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Nomenclature

COP_h	coefficient of performance of AHP
c_p	mass heat capacity at constant pressure of water, kJ/(kg °C)
D_e	flow of extraction steam, t/h
D_t	flow of exhausted steam from low pressure cylinder, t/h
G	flow of heat network water, t/h
h_c	specific enthalpy of exhausted steam, kJ/kg
h_{cs}	specific enthalpy of condensed water, kJ/kg
h_e	specific enthalpy of extraction steam, kJ/kg
i	a certain moment
N	days of heating period
P_b	backpressure of turbine units, kPa
P_e	pressure of extraction steam, MPa
q_c	heat output of exhausted steam, MW
q_e	heat output of extraction steam, MW
q_n	total heat output of system, MW
q_0	heat load of consumers, MW
q_t	heat of exhausted steam from low pressure cylinder, MW
$\bar{q}$	relative heat load ratio
Q_c	heat output of exhausted steam in the heating period, GJ
Q_e	heat output of extraction steam in the heating period, GJ
Q_n	heat output of system in the heating period, GJ
t_g	design temperature of secondary network supply water, °C
t_h	design temperature of secondary network return water, °C
t_n	design indoor temperature, °C
t_w	a certain outdoor temperature, °C
t_{H1}	outlet water temperature of exhausted steam-water heat exchanger, °C
$tH2$	outlet water temperature of AHP, °C
weq,c	equivalent electric power of exhausted steam heating, MW/MW
weq,e	equivalent electric power of extraction steam heating, MW/MW
weq,s	comprehensive equivalent electric power of system heating, MW/MW
Weq,c	equivalent electricity of exhausted steam heating, kW h/GJ
Weq,e	equivalent electricity of extraction steam heating, kW h/GJ
Weq,s	comprehensive equivalent electricity of system heating, kW h/GJ
xA	heat load proportion of the absorption heat exchanger substations
xec	extraction-condensed ratio of turbine unit
Xec	extraction-condensed ratio of heating system

Greek letters

$\triangle d$	the terminal temperature difference of heat exchanger, °C
$\triangle t$	logarithmic mean temperature difference of water-water heat exchanger in substations
$\triangle wc$	electric power loss caused by exhausted steam heating, MW
$\triangle we$	electric power loss caused by extraction steam heating, MW
ε	recovery rate of wasted heat
$\tau 1$	temperature of primary heat network supply water, °C
$\tau 2$	temperature of primary heat network return water, °C
$\tau 2\text{-}1$	temperature of primary heat network return water which comes from water-water heat exchanger substations, °C
$\tau 2\text{-}2$	temperature of primary heat network return water which comes from absorption heat exchanger substations, °C

Superscript

′	the design value

Subscript

i	the instantaneous value

efficient recovery of exhausted steam waste heat of multiple turbine units due to their respective limitations. Aimed at this case, the authors' research group proposed a new cascade heating system with multi-heat sources [12,16]. Taking the heating system which contains two sets of 300 MW direct air cooling cogeneration turbine units as example, the process is shown in Fig. 1.

Setting up absorption heat exchange units **8** at parts of substations: drive these units with the primary heat network supply water

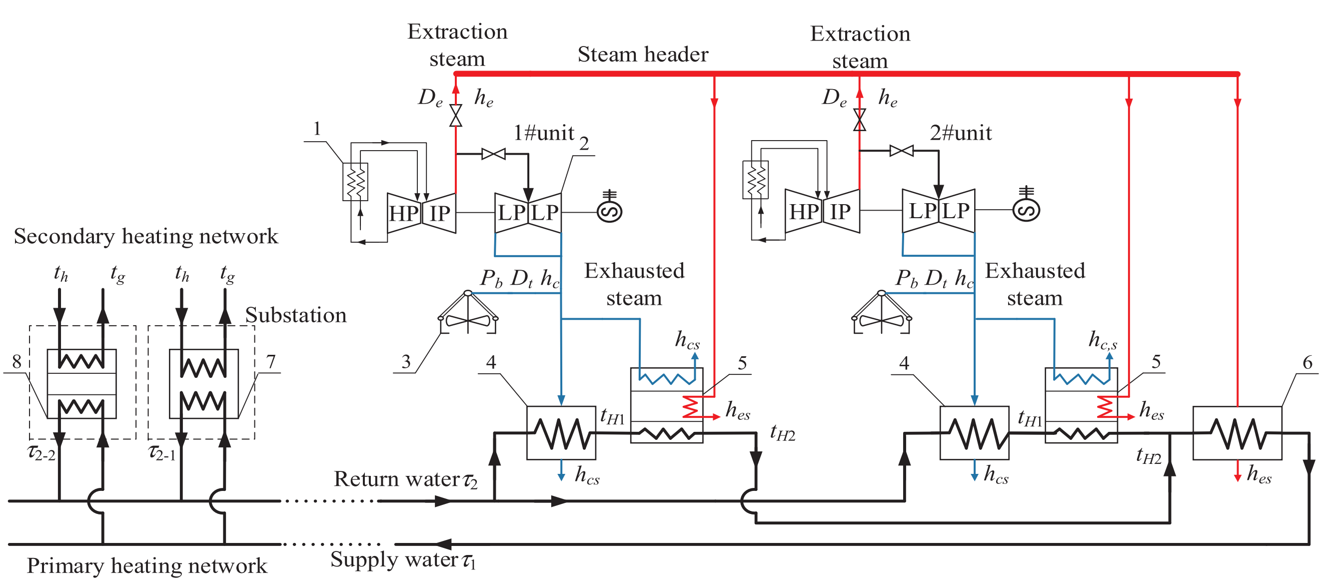

Fig. 1. A new cascade heating system with multi-heat source.