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Summer performance analysis of coal-based CCHP with new configurations comparing with separate system

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ABSTRACT

Conventional coal-based CCHP system currently is believed to be less efficient than separate vapor compression cooling system in summer. In this paper, new configurations of CCHP system (N-CCHP) are proposed and studied which apply comprehensive methods to improve the system performance. In the N-CCHP, an absorption heat pump is applied in power plant to heat the primary water instead of a traditional heat exchanger. And, a small turbine is used to improve system performance with high bleeding steam pressure. In substation, the primary water is used to drive an absorption chiller and liquid desiccant equipment in series. The domestic water is also produced by the primary water after regeneration of liquid desiccant. Key influencing factors of the N-CCHP system have been fully discussed. In this way, a highly efficient N-CCHP system configuration is obtained and is analyzed to compare with the electricity driven vapor compression (VC) refrigeration system in summer. Results show that the N-CCHP is energy saving and own better performances when the primary water transmission distance is less than 60 km, or the COP of the vapor compression chiller is lower than 7.

1. Introduction

Coal-based cogeneration power plants occupy large amount of the power supply in China. Because of the simultaneous production of electricity and heat, the cogeneration is energy efficient and environmental friendly in winter [1,2]. In 2016 winter, an unique cogeneration system with ultra-long distance heating network of more than 40 km is completed and put into operation in Taiyuan, China, which is believed to achieve significant energy saving and much less air pollution for the city in winter. Yet in summer, the conclusion is uncertain – for the lack of heat demand, the cogeneration is always off design condition, which results in lower primary energy efficiency [3]. Besides, the steam turbine condensing pressure is high due to high environment temperature in summer days, which also leads to a reduction of turbine generation efficiency. However, because of additional consumption of air-conditioning, the electricity demand is much larger in summer than in winter [4]. Here, the contradiction between low power efficiency and high electricity load makes the cogeneration poor economic. To mitigate the contradiction, CCHP (combined cooling, heating and power) system is considered, which applies a heat driven chiller for cooling, thus the heat load of the plant is expanded and the electricity demand for air-conditioning is reduced in summer. It also can help to balance the peak-valley power load caused by fluctuation of power demand in day and night [5]. Many researches on various types of CCHP systems have been brought out, the results indicate that the CCHP system is energy saving and economic when it is established onsite and waste heat such as flue gas or jacket water is used as driving heat resource for the chiller [6]. But when large-scale steam turbine is considered as the prime mover, the CCHP system is always less energy efficient than separate compression cooling system [7–10]. A typical conventional coal-based CCHP system consists of a steam turbine, a steam-water heat exchanger, and an absorption chiller, as shown in Fig. 1.

Zhang [11,12] et al. analyzed the economic feasibility of a typical CCHP system. The results indicated that the system performance was limited by the lower primary energy efficiency, which was caused by irreversible losses in steam-water heat transfer process, poor COP of absorption chiller and excess transmission cost of hot

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Nomenclature

COP	Coefficient of performance
E	Electricity (MW)
EER	Energy consumption rate
EGE	Equivalent generating efficiency
H	Enthalpy (*kJ/kg*)
L	Distance (m)
m	Mass flow rate (*kg*/*s*)
η	Efficiency
n	Proportion
P	Pressure (MPa)
Q	Heat quantity (MW)
T	Temperature (°C)
v	Value
ε	Error rate

Superscripts and subscripts

af	After
ah	Absorption heat pump
ac	Absorption chiller
be	Before
c	Cooling
cb	Combined cooling heating and power system
dw	Domestic water
de	Dehumidifier
e	Electricity
ec	Electric chiller
et	Isentropic
h	heating
hc	Heat used for cooling
is	Inlet steam
os	Outlet steam
pw	Primary water
pws	Primary supply water
s	Steam
sp	Separate cooling system
tr	Transmission

water. Li [13] et al. replaced the single-effect absorption chiller with a double-effect absorption chiller, which owned a much higher COP of 1.2, yet according to calculation, the conclusion was the same — the system is still not efficient in cooling mode. Zhang [14] et al. brought out a new coal-based system in which the extraction steam was firstly used to generate electricity through a small turbine, and then drive the absorption chiller. The new system achieved higher efficiency than the typical one because of significant reduction of irreversible losses in steam-water heat transfer process. However, the transmission cost was not considered, and for long-distance transmission, steam-driven absorption chiller was not appropriate.

Different methods have been taken to improve the system efficiency in aforementioned researches, but the modified CCHP systems are still not comparable with separate compression cooling system. The existing system improvement measures such as using hybrid chiller, reducing extraction steam exergy losses or applying desiccant dehumidifier all focus on local optimization [15–18]. No optimization for the whole system has been conducted or proposed. To achieve better system overall performance, improvement methods should be applied both in the power plant and in the substation.

In the power plant, the problem is how to make full use of the steam exergy via a proper heat transfer procedure. Typical system uses a valve to keep the steam pressure constant and applies a steam-water heat exchanger to produce hot water, both lead to huge irreversible losses. The valve can be replaced by a small turbine, thus the exergy losses caused by throttling process is reduced. The steam-heat exchanger also can be partly replaced by an absorption heat pump. Driven by low-pressure steam, the absorption heat pump can supply high temperature water and recycle waste condensing heat simultaneously. This configuration has already been widely used in CHP power plants [19–21], yet not found in literature about CCHP systems.

In the substation, the problem is how to improve the coefficient of refrigeration performance. Typically, single-effect absorption chillers are used in CCHP systems. Their performances are not comparable with vapor compression chillers. Using multi-effect absorption chiller or hybrid chiller can help to improve system refrigeration performances. For example, in some BCHP systems, dehumidifier integrated cooling system has been researched, due to application of independent humidity control strategy, the system performance is improved [22–24].

In this paper, a coal-based novel CCHP (N-CCHP) system that owns high system efficiency is proposed. The N-CCHP applies improvement measures both in the power plant and in the substation. In the power plant, a small turbine is used to keep a constant extraction steam pressure; an absorption heat pump is applied to generate hot water; the existing primary network is used to transport hot water. In substation, a liquid desiccant integrated hybrid cooling system is involved to achieve separate treatment of heat and humidity. Besides, domestic hot water is also produced. Performances of the N-CCHP in different configurations are discussed, key influencing factors such as extraction steam pressure, primary supply hot water temperature and transmission distance are all studied. Through simulation of applying the N-CCHP in an urban area during a whole summer, the N-CCHP is proven to be

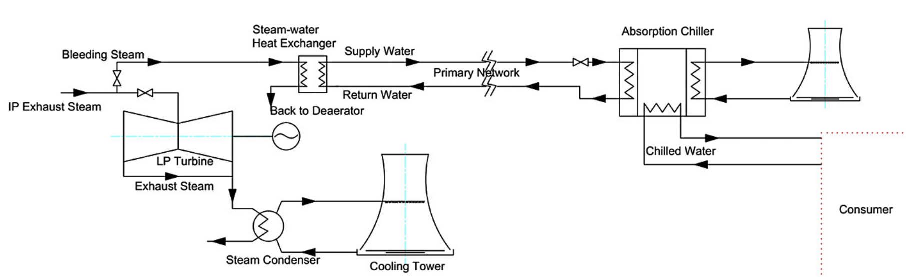

Fig. 1. Flow chart of conventional coal-based CCHP system.