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Multi-objective operation optimization and evaluation model for CCHP and renewable energy based hybrid energy system driven by distributed energy resources in China

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ABSTRACT

This paper construct a CCHP and renewable energy based hybrid energy system driven by distributed energy resources (DERs CCHP). Then, the paper constructs performance indexes from energy, economic and environment. Thirdly, the paper proposes a multi-objective optimization model for DERs CCHP system under four optimization of energy rate (ER), total operation cost (TOC), carbon dioxide emission reductions (CER) and joint optimization. Finally, Guangzhou Higher Education Mega Center (GHEMC) in China is taken as the object for comparatively analyzing the operation performance of DERs CCHP system and CCHP system driven by natural gas (NG CCHP system). Results show: Joint optimization mode could balance the results of different optimization modes. DERs CCHP system shows better operation performance. ER of ER optimization, CER optimization and joint optimization are higher than that of NG CCHP system. NPV of all optimization modes is positive, IRR are bigger than the expected yield rate. DERs CCHP system could reduce CO_2 emission by utilizing wind energy and solar energy to replace NG. The sensitivity analysis indicates the performance of the DERs CCHP system will become better with the increase of chiller COP, decrease of NG price and wind-photovoltaic equipment cost.

1. Introduction

Nowadays, energy crisis and greenhouse effect are becoming increasing urgent issue all over the word. In China, the energy consume structure mainly depend on fossil energy [1], which make the contradiction between energy consume and environment protection become more and more severe. Under this background, distributed energy resources (DERs) represented by natural gas (NG), solar energy and wind energy are playing more important roles in energy structure with the advantages of abundant resources, little pollutant etc. [2]. Meanwhile, the multi-energy customer demand promotes multi-energy systems integration for achieving higher energy utilization. The combined cooling, heating and power (CCHP) system has proved to be an efficient way to achieve energy saving, economic saving and reduce greenhouse gas emissions [3]. How to make full use of DERs to drive CCHP system and build reasonable operation performance evaluation indexes of CCHP system has great significant for realizing energy saving and environment protection.

In recent years, many pilot projects of CCHP system have been in operation in China, which brought abundant operation experience. Shanghai Minhang Hospital project, Shanghai Universal International Financial Center project, Shanghai for Science and Technology project have been in operation from 2002 April 2008 August, and 2010 June respectively with CCHP system driven by natural gas (NG) [4–6]. Beijing Future Science and Technology City Gas CCHP project has been in operation from 2013 October with a series of E-level Gas-Steam Combined Cycle Heating unit [7]. The first stage construction of Guangzhou Higher Education Mega Center (GHEMC) has been completed in 2009 October with NG-CCHP system consist of Gas-Steam Combined Cycle Heating unit [8]. The area of GHEMC has reached 18 km^2, containing 10 universities and a central business district. According to GHEMC development planning, the scale of the second construction project is the same to the first construction. Compared with other pilot projects, GHEMC could represent the development trend of CCHP system better, therefore, the paper take GHEMC as project examples to analyze the operation results of the

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NG CCHP system and DERs CCHP system.

Currently, researches related with CCHP system have been carried out all over the word, which could be divided into three aspects: system structure, operation strategy and performance evaluation. H Cho et al. [9] summarizes the methods used to perform energetic and exergetic analyses, system optimization, performance improvement studies of CCHP systems. In terms of system structure, Tan et al. [8] put forward a CCHP system driven by NG distributed energy consist of two gas turbines, two unfired dual pressure natural circulation heat recover steam generators, two extraction condensing steam turbines with two auxiliary generators, and other modules. Sepehr et al. [10] proposed a CCHP system driven by solar energy including consists of two subsystems, namely the solar collection subsystem and the CCHP subsystem. M. et al. [11] put forward a CCHP system driven by NG, biomass and solar, which consist of primary energy devices, secondary energy devices and a thermal storage section. Wang et al. [12] also put forward a CCHP system with biomass air gasification consist of a biomass gasifier, a heat pipe heat exchanger, an internal combustion engine etc. Wu et al. [13] put forward a micro-CCHP consisting of an internal combustion engine (ICE), an adsorption chiller (AD), a thermal management controller (TMC) and some other devices. Gao et al. [14] integrates waste to energy CCHP system with exergy and energy level, which consist of the components of CCHP system and waste incineration system. Overall, the structure of CCHP is mainly determined by the main drive energy. The existing CCHP system could be driven by NG, solar energy, biomass, waste and GSHP.

The operation strategy of CCHP system mainly include following the electric load (FEL) model [15] and following the thermal load (FTL) model [16]. In the FEL operation mode, the prime mover is loaded according to electricity demand. The waste heat from this loading is recovered to meet the thermal demand. If the recovered heat could not meet thermal load requirement, the auxiliary boiler of CCHP system would be called [17]. In the FTL mode, the prime mover is loaded according to the thermal demand and the cooling demand so that the recovered waste heat is enough. But the electricity may be insufficient for the electricity demand [18]. To optimize the operation strategy of CCHP system, Mago et al. [19] evaluates the CCHP system operating under FEL and FTL strategies based on energy, cost, and emissions, which found CCHP system should be operated following the electric load for some months and following the thermal load for others to obtain the maximum PEC reduction. Wang et al. [20] finds the selection of CCHP operation modes is systemically based on building loads, CCHP system and local separated production system. In addition to the basic operation strategies (FEL and FTL), Kong et al. [21] presents a simple linear programming model to determine the optimal strategies that minimize the overall cost of energy for the CCHP system. Basrawi F et al. [22] investigates the economic and environmental performance of a photovoltaic (PV) and microgas turbine trigeneration system based hybrid energy system with various operation strategies. Mago PJ et al. [23] evaluated and optimized CCHP systems operated following FEL and FTL strategies based on: primary energy consumption, operation cost, and carbon dioxide emissions. Overall, the operation strategy of CCHP system mainly includes FEL, FTL and other multi-objective optimization mode.

In order to evaluate the operation performance of CCHP system, some researchers have investigated the performance evaluation of CCHP systems under different optimization modes. Wang et al. [10] and Gao et al. [14] both only consider the energy performance reflected by thermal index. Ebrahimi M et al. [24] mainly consider the performance of combined gas and steam cycle performance for CCHP system. Liu et al. [25] constructs performance indexes including primary energy savings, hourly total cost savings and carbon dioxide emission reduction. Maraver et al. [26] put forward the environmental and energy performance for CCHP system based on the Life Cycle Assessment methodology. Wang et al. [27] also use LCA to evaluate optimization results, energy consumption and environmental impact potential for CCHP system. Mago et al. [28] evaluate primary energy consumption, operation cost, and carbon dioxide emissions for CCHP system driven by NG, which is an important experience for the DERs CCHP system. Shah KK et al. [29] determine the technical viability of such systems by simulating PV + battery + CHP hybrid systems deployed in three representative regions in the U.S. Nosrat AH et al. [30] applied PVTOM to representative houses in select Canadian regions to assess the fuel utilization efficiency and reduction in greenhouse gas emissions. Cho H et al. [31] optimize the operation of CCHP systems based on operational cost, primary energy consumption, and carbon dioxide emissions. Javan S et al. [32] deals with a comprehensive techno-economic modeling and multi-objective optimization of a CCHP system for residential application.

Based on the above analysis, we can see that the existing literature have already involved CCHP operation. But some problems still exist: Firstly, the driving energy of CCHP system has already contains NG, solar energy, biomass and GSHP system, but few literature researched on how CCHP system driven by wind energy. Wind power could be directly used to meet load demand, or through regenerative electric boiler (RE) to meet thermal energy for load demand of heating and cooling indirectly [26]. In China, currently wind power has great installed capacity, but also high abandoned wind rate. Therefore, studying how to make use of wind power to drive CCHP system has great actual significant to improve wind power grid connection. Secondly, the existing literature have already involved FTL, FEL and other operation strategies, but they did not discuss the influence of environmental optimization objective on the operation of CCHP system. As environment problem being studied, the environment friendly of CCHP system would be an important factor that influences its development. Thirdly, some literature only construct performance indexes from energy performance, economic performance or environmental performance for CCHP system driven by DERs. Other literature construct performance indexes from all aspects of performance for CCHP system driven by NG, which limit the applicability of performance indexes. According to the above mentioned analysis, the contribution of this paper lies in the following aspects.

- A CCHP and renewable energy based hybrid energy system driven by distributed energy resources (DERs CCHP) is construct, which include three subsystems: electricity subsystem, CCHP subsystem and auxiliary heating subsystem. Electricity subsystem consists of solar photovoltaic generator, wind power plant and gas turbines. Auxiliary heating subsystem consists of solar heater collectors, thermal storage tank and regenerative electric boiler. SK is taken as heat source when solar radiation is not sufficient. RE is used to meet thermal energy by consuming wind energy.
- A multi-objective operation optimization and evaluation mode for DERs CCHP system is proposed under four different optimization modes: ER optimization, TOC optimization, CER optimization and joint optimization. Then, in order to solve the proposed model, entropy weight method is applied to weight different objective functions for solving joint optimization model based on the input-output matrix of signal objective optimization modes.
- The operation performance indexes are constructed from three aspects of energy performance, economic performance and environmental performance. Energy performance is mainly reflected by energy rate and NG saving rate. Economic