Energy 85 (2015) 654–666

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

An improved operation strategy of combined cooling heating and power system following electrical load

Jiangjiang Wang [a, b, *], Jun Sui [a], Hongguang Jin [a]

[a] Institute of Engineering Thermophysics, Chinese Academy of Sciences, Beijing 100190, China
[b] School of Energy, Power and Mechanical Engineering, North China Electric Power University, Baoding, Hebei Province 071003, China

ARTICLE INFO

Article history:
Received 11 December 2014
Received in revised form
24 March 2015
Accepted 3 April 2015
Available online 25 April 2015

Keywords:
CCHP (combined cooling heating and power) system
Operation strategy
Following electrical load
Primary energy saving ratio

ABSTRACT

The operation strategy of CCHP (combined cooling heating and power) system is a vital factor governing its overall performance. This paper proposed an improved operation strategy of CCHP system FEL (following electrical load) to minimize primary energy consumption. In this strategy, the generated electricity of PGU (power generation unit) is optimized to improve the average generation efficiency at the lower electrical load of building. Battery is cooperated with PGU to finish a charge and discharge cycle in 24 hours so as to limit the size of battery. Different operation logics of the proposed operation strategy are presented with the combination of PGU and battery. The energetic performance analysis demonstrates the feasibility of the improved operation strategy. The energy saving potential influenced by fluctuation characteristic of electrical load is discussed to find out the impact relationship of PGU average generation factor, charge factor and supplementary electricity factor on primary energy saving ratio. The comparison results between four types of building indicated that the proposed strategy can achieve more energy saving in the building where the electrical demand has dramatic fluctuation during a day, whereas it is not suitable to the buildings with stable electrical load.

1. Introduction

CCHP (combined cooling, heating and power) system is considered as an alternative way to improve energy utilization efficiency and mitigate negative environmental impacts simultaneously [1,2]. CCHP systems, especially those operating standalone, are subject to variable demands of electrical, heating and cooling loads. Consequently, a key problem between design and operation is that the operation characteristics may be far away from the design condition [3].

A good design of CCHP system results from many factors such as advanced technology [4,5], system configuration [6,7], capacity optimization [8,9], and operation strategy [10,11]. The operation strategy is one of vital factors to govern the overall performances including energy, cost and environment [2]. The base operation strategies include FEL (following electrical load), and FTL (following thermal load) [12]. At the FEL strategy, the electricity generated by the PGU (power generation unit) is equal to the electric load at any moment as long as its capacity could cover the demand. Contrarily, the PGU firstly satisfies the thermal demand at the FTL strategy. The two base operation strategies have been discussed and compared in different systems. Wang et al. [12] compared PESR (primary energy saving ratio), exergy efficiency and CO_2 (carbon dioxide) emission reduction of CCHP system in the two strategies for a commercial building. Mago et al. [13] employed PEC (primary energy consumption), CO_2 emission and payback period to present the performance comparison of a turbine driven CCHP system for a large office building in different strategies. Furthermore, the base studies have been extended. Smith et al. [14] focused on input and model data uncertainty and presented an uncertainty analysis of a representative steady-state model of a CCHP system under the two base strategies. Jing et al. [15] performed life cycle assessment of a hybrid CCHP system driven by solar and natural gas in the two strategies. Basrawi et al. [16] compared the performances of hybrid photovoltaic and micro gas turbine CCHP system between the two operation strategies and the base load operation strategy, and concluded that the base load strategy is the best in terms of economic and environmental performance.

* Corresponding author. School of Energy, Power and Mechanical Engineering, North China Electric Power University, Baoding, Hebei Province 071003, China. Tel.: +86 312 7522443; fax: +86 312 7522440.
E-mail address: jiangjiang3330@sina.com (J. Wang).

http://dx.doi.org/10.1016/j.energy.2015.04.003
0360-5442/

Both of the base operation strategies generally lead to excess electricity or heat in variable loads. To decrease or avoid excess energy output, some researchers have developed some hybrid and improved operation strategies. FHETL (following hybrid electric-thermal load) strategy is one of hybrid operation strategies. Mago et al. [17] proposed an FHETL strategy to switch between FEL and FTL to eliminate excess products and analyzed its benefits on primary energy consumption, operational cost, and CO_2 emission reduction. Han et al. [18] developed an FHELT strategy using the efficacy coefficient method and applied it to a CCHP case for a hotel to obtain the performances including operation cost, CO_2 emission and exergy efficiency. Additionally, Zheng et al. [19] proposed an optimized strategy based on the minimum distance in order to make CCHP system fully use with less excess energy and compared its performances with FEL, FTL and FHETL strategies. Kavvadias et al. [20] proposed a following electrical-equivalent load strategy and reported that the strategy provides better load coincidence and peak reduction compared to the base operation strategies.

Besides to the studies of operation strategy for PGU (power generation unit) in CCHP system, some works have performed to hybrid cooling mode, thermal energy storage and so on to match loads and improve performances, such as the dispatch strategy for matching the thermal load proposed by Nosrat and Pearce [21]. Hybrid cooling mode with electrical chiller and absorption chiller is one of adjustable methods to match the ratio of heat to electricity between PGU output and user loads. Wang et al. [8] proposed a fixed electric cooling ratio to direct the operation of hybrid cooling and to decrease PEC. Moreover, Liu et al. [11] and Hajabdollahi et al. [22] refined the fixed cooling ratio and applied variational electric cooling ratio for hybrid chillers to achieve better performances. Additionally, energy storage including thermal storage and electricity battery is also one of effective ways to utilize the waste energy fully [23–25]. Nosrat et al. [25] integrated battery storage to hybrid photovoltaic and CCHP system to improve the energy utilization efficiency and also concluded that the charging limit is necessarily investigated to be incorporated as a decision parameter. Commonly, thermal storage is more employed in natural gas CCHP system. Wang et al. [26] optimized heat storage capacity to achieve the most energetic and environmental benefits in the least cost and analyzed the operation strategy in different seasons. Li et al. [27] integrated a thermal energy storage unit with a two-tank configuration in which the hot and cold fluids are stored separately into CCHP system and the operating strategy is much more straightforward by controlling the flow rate of the thermal fluid.

The originality of this work lies in proposing an improved operation strategy of CCHP system on the base FEL strategy to minimize PEC. Section 2 describes the energy flow of a CCHP system integrated with solar thermal collectors; Section 3 proposes the improved operation strategy and presents the operation logics under different conditions; Section 4 demonstrates the effectiveness of the improved strategy and discusses its applicability; and Section 5 summarizes some conclusions.

2. System description

A natural gas CCHP system integrated with solar heat collectors is shown in Fig. 1. The electrical demand is satisfied through three ways: PGU, battery and electrical grid. Generally, the battery is not integrated into the CCHP system connected with grid, and the grid is used to supplement the electrical shortage. Herein, the battery combined to the proposed operation strategy in Section 3.2 is employed to store or supplement electricity and to enhance energetic performance.

The heat demand is provided by heat recovered from PGU, heat absorbed by solar thermal collectors and auxiliary boiler. The thermal storage tank is used to store the total collected heat by solar collectors and excess recovered heat, which is an adjustable heat source to store or release heat. The boiler is installed as a backup heat source in case that other heat sources don't simultaneously meet the heat demand. The cooling demand is provided by

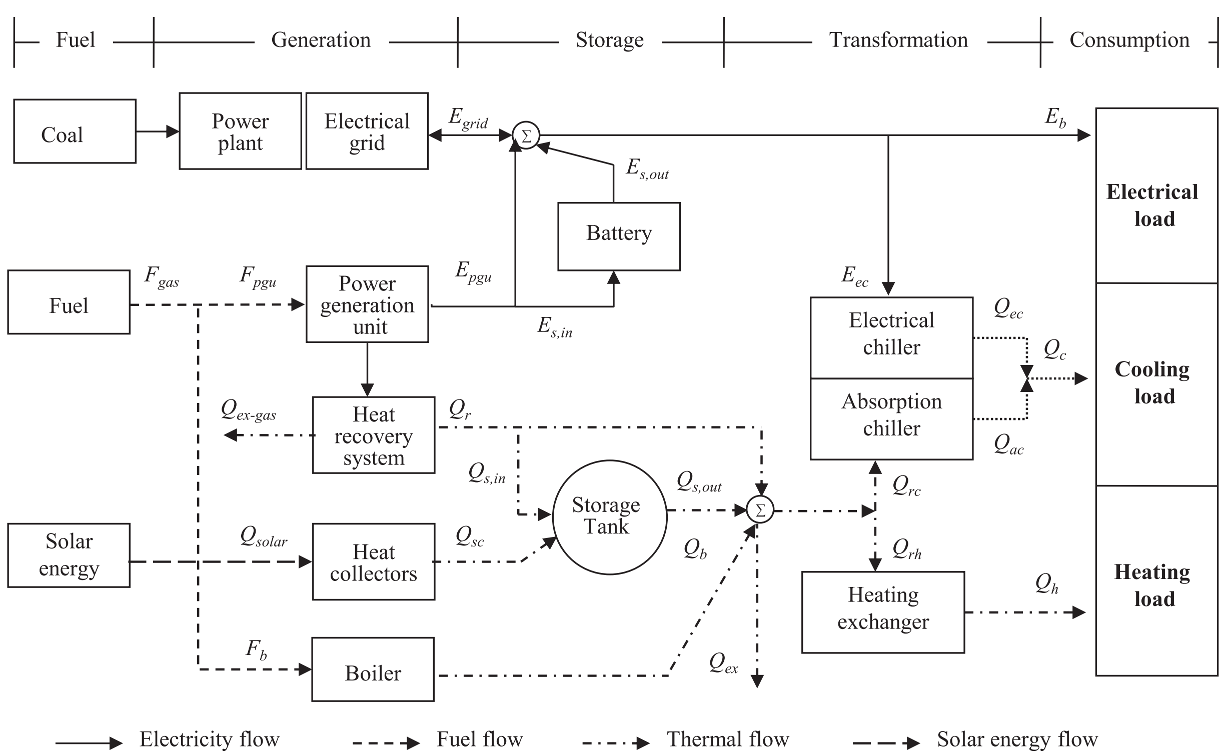

Fig. 1. Schematic of a CCHP system integrated with solar heat collectors.