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Optimal phase change temperature for BCHP system with PCM-TES based on energy storage effectiveness

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Abstract

Integrating thermal energy storage (TES) equipment with building cooling heating and power (BCHP) system can improve system thermal performance. In this paper, a simplified model of TES-BCHP system is presented with phase change material (PCM). Moreover, a new index, energy storage effectiveness, is proposed and its relationship with primary energy consumption is established. To maximize energy storage effectiveness, the optimal phase change temperature of PCM-TES-BCHP system is obtained. The results show that the theoretically optimal phase change temperature is just the geometrical average value of ambient temperature and exhaust gas temperature from gas turbine for ideal PCM-TES equipment with infinite NTU. It also indicates that both energy storage effectiveness and optimal phase change temperature increase with increasing NTU. So improving the thermal performance of PCM-TES device is favorable for increasing energy efficiency and saving primary energy consumption. This work can provide guidance for the design of PCM-TES-BCHP systems.

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Keywords: co-generation; energy storage; phase change material; thermal optimization; energy efficiency

1. Introduction

With the rapid development over the recent two decades, the global total energy consumption has grown by 49\%. Therein, buildings account for about 30\% of total energy consumption [1]. As a result, the increasing demand for cooling, heating and power supplies in buildings stimulates the search for more high-efficient and low-emission

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energy production, conservation and usage methods [2]. Building cooling heating and power (BCHP) is a novel kind of building energy supply system which can meet users different load demands simultaneously with a single primary energy input [3]. Compared to traditional separated generation system, BCHP systems show high energy efficiency, low pollutions emission and good economic benefit. However, the energy supply units in a BCHP system often show poor thermal performance under part load working conditions, due to the non-synchronized and fluctuating thermal and electrical demands [4]. It is found that introducing TES equipment into BCHP systems proves to be an effective way to improve the part load performance of the whole system and saving the primary energy consumption [5].

Many researchers investigated the thermal and economic performance of the co-generation or tri-generation system with different types of TES equipment. Bogdan et al. [6] found that profitability of co-generation system with TES equipment was impacted by various external factors. The results inferred that the water tanks might substantially improve the economic performance when electricity price was governed by the dual-time tariff policy. Furthermore, Bailey et al. [7] applied sensible TES to the co-generation system and optimized its installed capacity based on completely mixing assumption for the water tanks. On the other hand, compared to sensible heat storage (e.g., water tank), latent heat storage with phase change material (PCM) was of relatively high energy storage density, which makes them increasingly attractive for applications [8]. Pite et al. [9] presented the potential usage of PCM particles for high temperature energy capture and storage in industry fields through a fluidized bed. Zhang et al. [10] briefly reviewed the TES development, with special emphasis on the important applications of PCMs in both solar energy projects and waste heat recovery from industrial processes. Fiorentini et al. [11] applied PCM-TES to HVAC systems and found that the PCM tank can effectively shift the cooling load and increase the overall efficiency of a heat pump system for space cooling. However, even though PCM-TES application in BCHP system has a great potential for energy saving, relevant researches are not enough. Zhang et al. [12] proposed a new method to pre-estimate the feasibility of TES-BCHP system before design of practical systems, under ideal assumption that there is no irreversible loss during the heat transfer processes for the TES equipment.

Nevertheless, few researchers focused on the key parameter optimization, such as the phase change temperature of PCM-TES, even though it had a great influence on the performance of the whole PCM-TES-BCHP system. Therefore, how to determine the optimal phase change temperature for the PCM-TES-BCHP system is an important but unsolved problem. In this paper, a simplified model of PCM-TES-BCHP system is established and the analytical optimal phase change temperature is determined based on the proposed energy storage effectiveness. Moreover, the impact of NTU of the PCM-TES equipment is analyzed to evaluate the energy saving effect of the whole system. This work can provide guidance for PCM-TES-BCHP system design.

2. Methods

2.1. BCHP system

The typical BCHP system under summer working condition is shown in Fig. 1. The gas turbine (GT) is driven by natural gas and the mechanical energy is further changed into electricity power, which is then delivered to the users directly. At the same time, the absorption chiller (AC), activated by the high temperature exhaust gas, produces low temperature water to fulfil the cooling requirement. For the operation strategy, Teng et al. [13] found that following thermal load (FTL) was more energy-saving than following electrical load (FEL) for BCHP systems. Thus the system gives priority to meet cooling demand, and insufficient electricity can be bought from the power grid.
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