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Analytical method to evaluate energy saving potential of thermal energy storage in cogeneration system based on load characteristics

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Abstract

Integrating thermal energy storage (TES) with building cogeneration system is an effective way to improve part load efficiency and save primary energy consumption. In this paper, a novel analytical method is put forward to evaluate the energy saving potential of cogeneration system with TES equipment under following thermal load operation strategy. Moreover, the load fluctuation factor is defined, based on the maximal and average load amount, and its relationship with primary energy consumption and system exergy losses are established. The results show that the primary energy consumption is mainly influenced by three factors: (1) no-load fuel consumption ratio and rated efficiency of gas turbine; (2) heating load fluctuation factor; (3) ratio of heat to electricity load. Furthermore, with increasing gas turbine efficiency and heating load fluctuation factor, the primary energy saving ratio grows whereas system exergy loss declines. The illustrative example in Beijing indicates that the primary energy consumption decreases by 16% and 23% for the hotel and office building respectively in one typical winter day. This work can provide guidance for practical design cogeneration system with TES equipment.

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Keywords: Building cooling heating and power (BCHP), Thermal energy storage, Load fluctuation, Primary energy consumption, Exergy loss

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1. Introduction

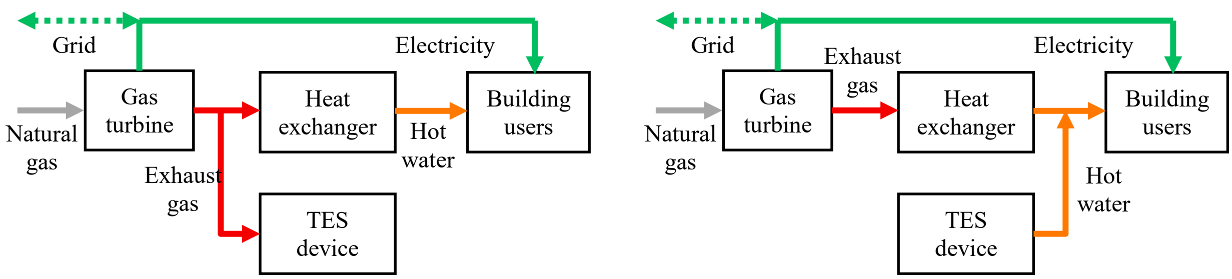
Natural gas-driven building cogeneration system is of high energy efficiency, low emission, high energy supply safety and reliability [1, 2]. Nevertheless, some practical cogeneration systems often show bad thermal performance under part load working conditions, due to the non-synchronized and fluctuating thermal and electrical loads [3]. Integrating thermal energy storage (TES) equipment with cogeneration system is an effective way to improve part load efficiency and save primary energy consumption (PEC) [4]. Many researchers investigated the performance of TES-cogeneration system through simulation and experiment [5]. Most existing research relied on numerical analysis to evaluate the energy saving effect of cogeneration system, whereas failed to find the common mechanism between user load characteristics and optimal system design parameters [6]. Teng [5] stated that the applicability of cogeneration system with TES device highly depends on the thermal performance of the chosen prime mover, such as micro gas turbine. Zhang [3] proposed a new approach to pre-estimate the energy saving amount for cogeneration system with ideal TES equipment without any irreversible losses, and established the relationship between thermal power ratio and primary energy consumption.

How to assess the energy saving potential of such systems based on user load characteristics during the feasibility analysis stage of a practical project is an important but unsolved problem. In this paper, a novel method is put forward, based on the established system model for energy saving evaluation of TES-cogeneration system. Moreover, the analytical relationship among PEC, system exergy loss and user load fluctuation characteristics is built and an illustrative example in Beijing is analyzed to show the preliminary application of the propose method. This work can provide guidance for practical design cogeneration system with TES equipment.

2. Method

2.1. System model

The typical TES-cogeneration system in winter working condition is shown in Fig. 1. The gas turbine (GT) is driven by natural gas and the generated electricity is delivered to users directly. Meanwhile, the high temperature exhaust gas flows into heat exchanger to produce hot water to fulfil heating demand. In addition, the TES equipment works in parallel with the heat exchanger. During off-peak hours, extra exhaust heat is restored in TES, whereas it releases during peak hours to compensate for the high heating load. The system works under following thermal load mode that it gives priority to meet heating demand and insufficient electricity is bought from power grid (η_{grid}) [7].



(a) TES charge process (off-peak hours) (b) TES discharge process (peak hours)

Fig. 1. Typical building heating and power cogeneration system with TES equipment.

Without TES equipment, the gas turbine often runs under part load conditions because of the fluctuating load. Eq. (1) gives an explicit analytical solution of part-load performances of constant rotating speed single shaft gas turbine [7]. In this equation, η (%), E (kW) and PEC represent the efficiency, electrical power and primary energy consumption of gas turbine respectively and subscript r denotes the value in rated condition.