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Research Paper

Evaluation of combined cooling, heating and power (CCHP) systems with energy storage units at different locations

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HIGHLIGHTS

- Show expressions of ESRs of CCHP systems with ESUs at different locations.
- Discuss the trend of ESR changing with a single variable (COP or χ).
- Demonstrate the existence of χ boundaries and show the upper and lower limit values.
- Summarize ESU merits at different locations in two situations.

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ABSTRACT

Incorporating energy storage units (ESUs) enables components of Combined Cooling, Heating and Power (CCHP) systems to operate stably as well as to decrease the system scales. In the premise of “priority of providing cooling” regime, two potential locations of ESUs which individually represent different energy storage technologies were involved to study their location and performance impacts on energy saving rates (ESRs) of CCHP systems. Detailed discussions were undertaken to study how critical parameters (Efficiency of Energy Utilization and Coefficient of Performance) affect ESRs of CCHP systems. Theoretical analysis has indicated that how the electrical demand is satisfied will have distinct influence on the final results. When CCHP systems can solely satisfy the electrical demand, a cooling storage system is recommended to be installed between absorption refrigerator and the CCHP user. If supplementary electricity from the grid is required to meet the electrical demand, the selections of ESU locations will depend on efficiencies of both the grid and the power generation unit of the CCHP system. Furthermore, the authors also demonstrate the existence of boundaries of Efficiency of Energy Utilization and show the upper and lower limit values.

1. Introduction

Combined Cooling, Heating and Power (CCHP) systems have been demonstrated to be effective in reducing energy consumption and greenhouse gas emissions [1–3]. However, the influences of variable energy demands from the CCHP users have limited the wide promotion of this advanced technology [4]. Under the circumstances of varying energy demands, CCHP components are usually installed at large-scale capacities to ensure the maximum energy demands of their users to be satisfied. However, the maximum energy demands only constitute a small proportion of the total demands. As a result, each component has to operate under variable working conditions for a long period [5], which may reduce the energy utilization efficiency of CCHP systems. Moreover, large-scale apparatus tends to increase the cost, which is detrimental for the economy of CCHP systems.

To ensure CCHP components to operate stably as well as to reduce the capacities of CCHP systems, energy storage units (ESUs) are usually incorporated into CCHP systems [6–9]. Liu et al. [10] employed a CCHP case in Tianjin, China to study the performance of CCHP systems with thermal energy storage under variable loads, and results have shown that thermal energy storage reduces 15.8% of the total installed cooling capacity and 37.5% of the total installed heating capacity of the CCHP system. Meanwhile, Brahman et al. [11] have reported that thermal energy storage is a mean to hinder energy spillage and enables more CCHP production with cost savings of up to 40% compared with CCHP systems without energy ESUs. Li et al. [12] have proposed a novel energy storage system which stores excessive energy in the form of compressed air and thermal heat, and the average comprehensive efficiency can be around 50% and 35% in winter and summer, respectively, which are much higher than the conventional CCHP system.

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Although numerous studies have been published regarding ESUs and their positive effects on CCHP systems, most of these studies are based on actual cases or simulations. Theoretical studies concerning how ESUs influence the performance of CCHP systems or which kind of energy storage technology prevails in energy savings are rarely reported. Theoretical studies are indispensable for designers to select appropriate energy storage technologies for CCHP systems. Therefore, it is essential to establish a theoretical system to evaluate the performance of CCHP systems with ESUs. In this research two potential locations of ESUs which individually represent different energy storage technologies will be involved to theoretically study the impacts of locations on energy saving rates. Critical parameters and assessment criteria will be proposed first, and then detailed discussion will be undertaken to show how ESUs affect CCHP systems as well as comparisons between ESUs installed at different locations.

2. Assumptions and system description

This research mainly concerns the regime of the “priority of providing cooling”, which means cooling demand of the CCHP users has priority over the other outputs of the CCHP system.

2.1. Assumptions

Assumption 1 Cooling and electricity are indispensable parts of CCHP user energy demands, however, heating demand is excluded for simplification. This assumption is reasonable and is usually true in summer.

Assumption 2 Cooling demand from CCHP users can be appropriately satisfied by CCHP systems without redundant cooling being wasted and without supplementary cooling from traditional energy systems.

Assumption 3 The main energy source of the CCHP system is fossil fuel (e.g. natural gas). Sustainable or renewable energies (e.g. solar and geothermal energy) serving as sources are temporarily out of the scope of our research.

2.2. System description

Fig. 1 is the schematic diagram of the CCHP system based on the assumptions. A stream of the thermal energy generated from the fuel combustion in the Power Generation Unit (PGU) is converted to electricity. Hot exhausted gas after combustion in PGU drives the absorption refrigerator (AR) to provide cooling for the users.

Although cooling demand from CCHP users is assumed to be appropriately satisfied by CCHP systems, deviations between electrical supply and demand may still exist. To reconcile the deviations, the electrical grid is introduced as an electrical capacitor: redundant electricity produced by CCHP systems will be sold or donated to the grid (Situation 1); and the shortage of electricity will be supplemented by the grid (Situation 2). In Fig. 1, the lines of “Possible Delivery of Electricity” are drawn to illustrate the reconciling effects of the grid.

2.2.1. CCHP systems with heat recovery systems

In Fig. 1, a Heat Recovery System (HRS) installed between PGU and AR (Position A) is expected to store the thermal energy generated by PGU. Meanwhile, through introducing an HRS into the CCHP system, PGU is capable of operating stably at its optimal working conditions. When CCHP users have low cooling demand, a small proportion of heat is required to drive AR, so spare heat from PGU will be stored in HRS. When the cooling demand increases, the heat stored in the HRS will be released and serve as auxiliary heat source for AR to satisfy the increasing cooling demand. In this scenario, AR has to operate under variable working conditions due to the changing cooling demand of CCHP users. In Fig. 1, η_e represents the power generation efficiency, and α_W represents the total proportion of the thermal energy both stored in HRS and directly released to drive the AR.

2.2.2. CCHP systems with cooling storage systems

A Cooling Storage System (CSS) established at Position B enables both PGU and AR to operate stably at their optimal conditions, since stable cooling output from AR usually means constant heat input and thereby stable operation of a PGU. When CCHP users have low

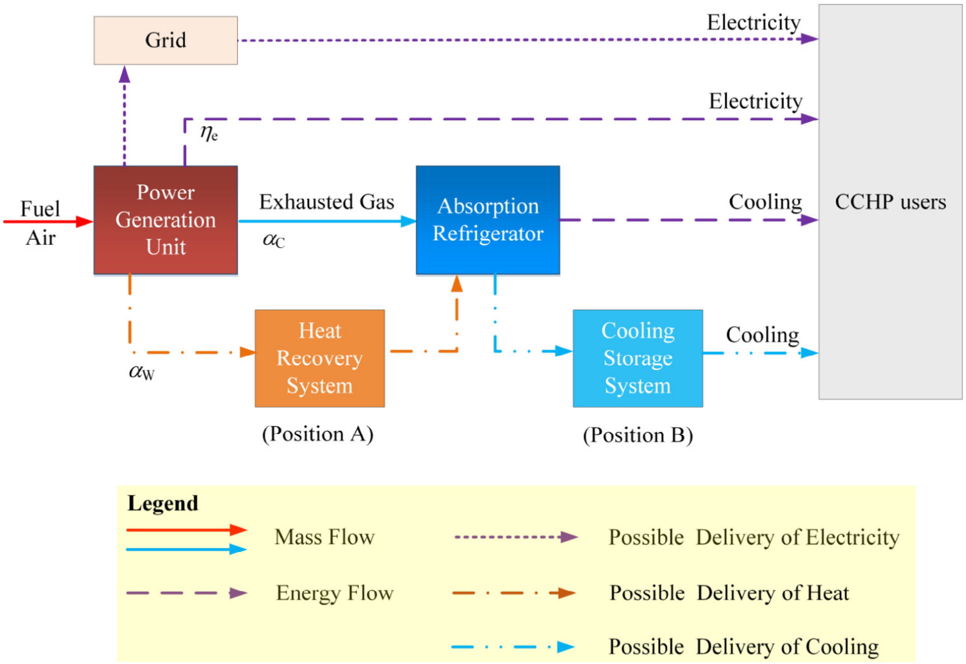

Fig. 1. Scheme of the CCHP system investigated in this research.