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Performance evaluation of district cooling plant with ice storage

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Abstract

District cooling system (DCS) is a massive cooling energy production scheme that serves a group of buildings. The system performance can often be improved by the incorporation of a cool-storage system, in that part of the cooling demand is shifted from peak hours to non-peak hours. This brings mutual benefits to the power supplier and the consumers. In order to evaluate the energy performance and cost effectiveness of such an integrated technology, a feasible district cooling plus ice-storage system was developed for a hypothetical site in Hong Kong. A parametric study making use of the DOE-2 and TRNSYS simulation software was conducted to evaluate the system performance at different partial storage capacities, control strategies, and tariff structures. Other than the basic design factors, the results from 27 cases showed the importance of the tariff structure, the capital and electricity costs in this issue.

Keywords: District cooling system; Ice storage; Tariff structure

1. Introduction

District cooling system (DCS) is a massive and collective cooling energy production scheme. Chilled water is produced in a remote central chiller plant, and is delivered to serve a group of buildings and/or facilities through a closed-loop piping network. The overall system efficiency is higher than the individual chiller plants installed at single buildings. This is achieved, firstly, through the mass-scale production in that larger chillers with higher efficiency are in use, and secondly, through the thermal load diversion in that the installed cooling capacity at the central chiller plant can be smaller than the total capacity to be installed at the customer buildings. Moreover, DCS customers can utilize their building space more effectively since the installation of their own cooling facilities is no longer required. From the environment point of view, the pollutant emissions and wastes (like CFC) from a remote district cooling plant site are easier to be taken care of than those released from small and scattered cooling plants all over the district. The above economical and environmental benefits are best experienced in a modern tropical or subtropical city where the cooling load density is high—typically in association with tall buildings—like the urban environment in Hong Kong [1].

A typical district cooling plant consists of chillers, pumping stations, distribution pipelines, underground tunnels, and associated facilities. Both the plant capacity and the pipe length are huge, with the order of

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magnitude in hundreds of megawatts and multi-kilometers. Because of the substantial capital investment involved, alternative DCS schemes should be thoroughly evaluated so that a well-planned and optimized system can be finally implemented. Possible alternative schemes involve the incorporation of various inter-related thermal technologies, like cool thermal storage, waste heat recovery, and tri-generation. In this paper, our focus is on cool thermal storage.

2. Cool thermal storage

Cool-storage technology is an effective means of leveling the electrical loads as a part of the energy management strategy. The technology is able to help the power utilities to cut down the peak loads by increasing the load during the off-peak periods. This shifting of load improves the utilization of the base-load production units, and thereby reducing the reliance on the peak-operating units which otherwise elevate the operating costs. In this way, the power utilities benefit from a reduction of the peak electricity generation [2–6]. At the same time the consumers, like the DCS provider, also benefit with lower electricity bills, by taking advantage of the lower off-peak rates and reduced peak demand billing charges.

Three cool-storage media are commonly in use, including chilled water, ice and eutectic salt. In a chilled water storage system, the cooling capacity depends on the temperature differential across the stratified storage tank. Chilled water charging at 4–6 °C is stored at night in the tank and during the daytime, the water in tank is circulated to serve the cooling demands. A higher system performance is expected, because the storage takes place during the night-time when the lower ambient temperature allows a better condenser performance. However, this advantage is less obvious in Hong Kong because of the narrow diurnal temperature range throughout the year in this coastal city. In an ice-storage system, water is used as a phase-change storage medium to take advantage of its higher cooling capacity for the same physical storage space. The basic refrigeration components are similar to those of the conventional refrigeration plants, namely compressor, condenser, expansion device and evaporator. Ice storage involves heat exchange with time-variant performance; the ice layer progressively increases the resistance to heat transfer, which causes the evaporating temperatures to fall and consequently reduces the chiller coefficient of performance (COP). On the other hand, eutectic salts are mixtures of inorganic salts, water and nucleating and stabilizing agents. Like ice storage, the cooling capacity of a eutectic salt system depends on the latent heat of fusion of the salt and the amount of frozen salt. Hasnain compared the above three storage systems and rated ice storage over the other two [7]. The most obvious benefit of ice as a storage medium is the more reasonable storage volume. While the capital cost can be saved by downsizing the chillers, the cost of the system does vary with the project size and other site specific considerations, such as the geographical area and local economic environment. The following presents a numerical study of evaluating the possible use of ice storage for district cooling application in Hong Kong.

3. District cooling plant

3.1. The hypothetical site and cooling load profile

A reclaimed land area of 107 ha at the west side of the city center was selected as the hypothetical site [8]. The building mix planned by the Hong Kong Government for this district in majority includes offices, hotels, retails, government depots, schools, indoor recreational centers, and magistracy. All were considered as the potential DCS customers in this study. In order to determine the required capacity of the district cooling plant, a database of the space cooling loads per unit floor area of the above types of buildings was first developed. The buildings in the entire district were categorized based on the similarity in their nature of operation and energy consumption profiles. The generic model building of each building category, with regard to the construction materials, physical size and facilities, was then developed. The internal load densities and the daily operating schedules for the three day types (weekday, weekend and holiday) were assigned, making reference to the local building energy code [9]. Using a dynamic building simulation software DOE-2 [10] and the typical weather year of Hong Kong, the thermal load analysis of each generic model building was executed. Through the process, normalized cooling load profiles of each model building in W/m^2 were