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Optimization of an ice-storage air conditioning system using dynamic programming method

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Abstract

This paper explores the optimization of an ice-storage air conditioning system in consideration of both minimal life-cycle cost and efficiency of ice-storage tank. Such air-conditioning system consists primarily of ice-storage tank, screw-type chiller and auxiliary equipment. Optimization is carried out using dynamic programming algorithm, where the power consumption models of the chiller and its auxiliary equipment as well as the heat transport in ice-storage tank are established based on manufacturer's data. Initial cost and operation cost are objective functions, and the performance of chiller and ice-storage tanks are constraints. Through simulation analysis using numerical program, system optimization and analysis are carried out to obtain optimum chiller and ice-storage tank capacity. Finally, results are used to probe some design guidelines regarding life-cycle cost and payback period under chiller priority and ice priority control strategies.

Keywords: Ice-storage air conditioning system; Dynamic programming method

1. Introduction

The rapid pace of industrial development and the increasingly higher standard of living in Taiwan have led to continual rise in industrial and residential power consumption. The peak load in the summertime also climbs by the year. Of the various demands for power, supply to air-conditioning systems account for more than 30% of consumption in the summer. Any

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conservation in this area will help improve the power supply situation. Ice-storage air conditioning system works by making ice in the nighttime and then melting the ice to release cold energy in the daytime to meet air-conditioning needs. As such, it will help shift the power consumption at peak hours during the day to the nighttime and improve the power shortage condition.

In relevant studies of ice-storage air conditioning system, Arnold [1] created a theoretical model for dynamic simulation of encapsulated ice storage. Musgrove [2] used program simulation to predict the operation of ice-storage air conditioning system. Chen et al. [3] simulated the heat transfer of packed capsule air conditioning system based on lump model and obtained an empirical equation for heat transfer of ice-storage tank based on experimental data. Dorgan and Elleson [4] gave comprehensive description of the ice-storage system and proposed design guide and economic analysis method. King and Potter [5] created a steady-state chiller model, which contained cooling tower, pump and fan to simulate the operation of ice-storage system. Rawlings [6,7] studied the energy management of ice-storage air conditioning system using ethylene glycol as working fluid.

The ice-storage operation of air conditioning system offers many options. But the majority of designs are not optimal, particularly in the aspect of matching chiller performance and tank size. Improper choice of chiller will result in cost increase if the chiller is over-sized, or insufficient cooling power if the chiller is under-sized. Some chillers are ill suited for ice-storage system where load change and cooling capability vary significantly that either not enough ice is made or ice making cannot occur. A poor choice of ice-storage tank undermines the effect of energy storing and energy release. For ice-storage tank with poor thermal storage efficiency, the chiller must provide lower temperature for ice making, which might disable the chiller ahead of time, resulting in incomplete ice making. Moreover, the load profiles of air conditioning systems for different types of buildings are not quite the same that adds more variables to the matching of chiller performance and storage size.

A good ice-storage air conditioning system should be able to operate in an optimal state. But little discussions of system optimization are seen up to the present. This paper purports to explore the optimization of ice-storage air conditioning system for commercial buildings in consideration of minimal life-cycle cost with the use of the dynamic programming method. The power consumption models of chiller and auxiliary equipment as well as the relationship between the ice formation and heat transfer of ice-storage tank are created based on manufacturer's data. From the dynamic programming method the optimum chiller capacity, number of ice-storage tank can be obtained for different operating modes.

2. Theoretical analysis

As shown in Fig. 1, an ice-storage air conditioning system consists of principally chiller, cooling tower, ice-storage tank and pump, in which, chiller is the major power consumption component. The efficiency of the chiller is under the influence of load and ambient climate. The cold energy stored during ice-making is preserved in the ice-storage system to meet the cooling load during air conditioning. The thermal charge and discharge behaviors of an ice-storage system are associated with its matching chiller as well as its own ice content, which results in different heat transfer