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Optimization for ice-storage air-conditioning system using particle swarm algorithm

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ABSTRACT

Ice-storage air-conditioning system, while known for its advantage of shifting power consumption at peak hours during the day to the nighttime, can increase both energy consumption and CO_2 emission. The study adopts particle swarm algorithm to facilitate optimization of ice-storage air-conditioning systems and to develop optimal operating strategies, using minimal life cycle cost as the objective function. Increase in power consumption and CO_2 emission triggered by the use of ice-storage air-conditioning system is also examined and analyzed. Case study is based on a typical air-conditioning system in an office building. Results indicate that, with proper parameters, particle swarm algorithm can be effectively applied to the optimization of ice-storage air-conditioning system. In addition, optimal capacity of the ice-storage tank can be obtained. However, the volume of power consumption and CO_2 emission rises with the increase in ice-storage tank capacity. Consideration of additional costs of power consumption like carbon tax can therefore lead to changes in the optimal system configuration.

1. Introduction

Air-conditioning systems account for more than 30% of the summertime power consumption in Taiwan [1] and remain a major cause of the increase in peak load. Use of ice-storage air-conditioning systems to take advantage of off-peak electricity rate is accordingly introduced as an effective measure for reducing the peak load demanded by air-conditioning systems. However, while capable of shifting power consumption at peak hours during the day to the nighttime, the use of ice-storage air-conditioning system can lead to substantial increases in power consumption [2]. How to strike a fine balance between power consumption and economic benefit thus becomes a critical issue in the design and optimization of ice-storage air-conditioning system.

Most of the previous studies on the optimization of ice-storage air-conditioning system are guided by a concern for operating costs and economic benefits, without giving much attention to the impacts increased power consumption may cause. For example, Chen et al. [1] optimized an ice-storage air-conditioning system using dynamic programming algorithm while taking into consideration both life cycle cost and payback period. Dorgan and Elleson [3] presented a comprehensive description of the ice-storage system and proposed design guide and economic analysis method. King and Potter [4] developed a steady-state cooling plant model to assess the effect of control strategy on the operating cost of the plant. Liu and Wang [5] designed an optimal scheme for ice-storage air-conditioning system aiming at minimizing operating costs and shortening the payback period. Henze et al. [6] developed a simulation model to calculate and compare energy usage in different control strategies, such as chiller-priority, constant-proportion, storage-priority control and optimum strategy. Ashok and Banerjee [7] investigated the optimal cool storage capacity for load management. The results of a case study showed that peak demand may be reduced 38% by adopting the optimal chilled water storage strategy under time of use tariff. Chan et al. [8] used DOE-2 and TRNSYS simulation software to evaluate a district cooling plant with ice-storage. They presented that in a specific case study, the district cooling plant with about 40% ice-storage capacity and chiller-priority control sequence can provide better energy performance.

In an effort to amend the failure of previous studies to address the issues of increased power consumption, this paper proposes to approach the optimization of ice-storage air-conditioning system with the particle swarm algorithm that has been introduced as an efficient method of solving continuous parameter optimization problems [9,10] and applied in the energy management system for factories [11] and optimum design of thermal system [12].

The study uses minimal life cycle cost as the objective function and adopts the particle swarm algorithm not only to achieve the optimization of cold-storage air-conditioning systems, but also to analyze the increase in power consumption and CO_2 emission and its potential influences on the optimization. The approach is applied to a typical air-conditioning system in an office building as a case study to explore related parameters, and the results of

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Nomenclature

Q_c	chiller load (tons)	P_k	electricity power during the time stage k (kW)
$Q_{c,ncap}$	nominal chiller capacity (tons)	E_k	electricity rate (US$)
$T_{con,rtn}$	condenser water return temperature (°C)	Δt	time interval
$T_{con,nom}$	nominal cooling water return temperature (°C)	M_{chi}	equipment cost of chillers (US$)
$T_{ch,out}$	chiller water supply temperature (°C)	M_{it}	equipment cost of ice tanks (US$)
$T_{ch,nom}$	nominal chiller water supply temperature (°C)	M_{ct}	equipment cost of cooling towers (US$)
T_{eq}	departure of actual operating temperatures from nominal values (°C)	M_{pm}	equipment cost of pumps (US$)
		M_{pow}	cost for power capacity application (US$)
Z	temperature change ratio of the nominal chiller capacity	$PWEF$	present worth escalation factor
$Rcav$	full-load capacity ratio	AER	annual escalation rate (%)
G	full-load power ratio	AIR	annual interest rate (%)
PLR	part load ratio	Q_k	charge rate of chiller (tons)
$NFLPR$	nominal full-load power ratio ($1/COP_R$ in kW/ton)	S_k	charge rate of ice-storage (tons)
FFL	fraction of full-load power	M_k	maximum discharge of ice-storage (tons)
$Chpow$	chiller power consumption (kW)	L_k	cooling load (tons)
P_{twr}	cooling tower power consumption (kW)	v_i	velocity of particle i
t_{wrld}	cooling tower load (kW)	w	inertial weight c_1 acceleration constant
P_{pump}	pump power (kW)	c_2	acceleration constant
E	life cycle cost (US$)	r_1	random functions (range [0,1])
E_p	energy cost in the first year of operation (US$)	r_2	random functions (range [0,1])
E_s	initial equipment cost (US$)	x_i	current position of particle i
P_{max}	maximum power demand (kW)	y_i	personal best position of particle i
RD	demand rate (US$)	y_g	best position of all the particles found at present

optimization are consulted as the basis to examine the impacts of the increase in power consumption and CO_2 emission on the optimization.

2. System description

As illustrated by Fig. 1 [1], an ice-storage air-conditioning system is composed of an ice chiller, cooling tower, ice-storage tank, pump and other auxiliary equipment with the ice chiller being the main source of power consumption.

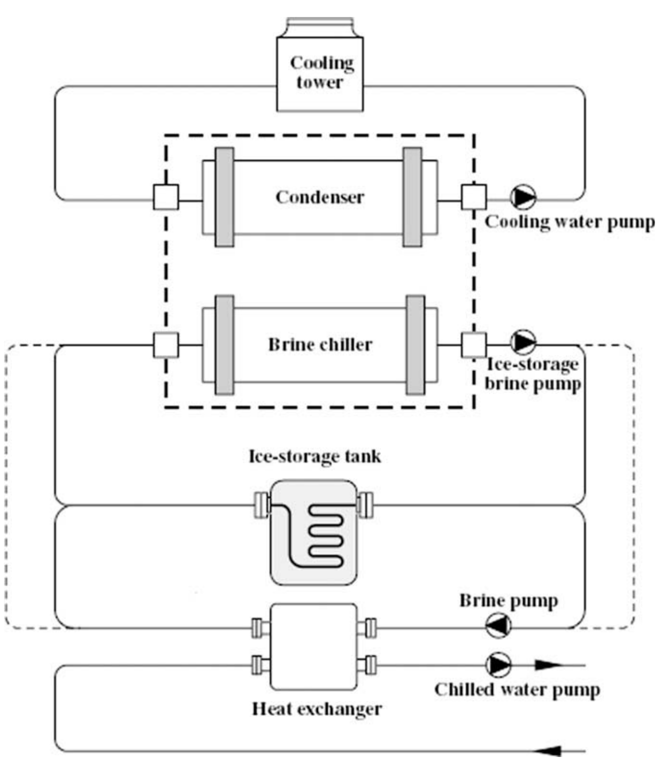

Fig. 1. Ice-storage air-conditioning system [1].

Based on the characteristics and the specifications of the ice chiller, the ice-storage tank and the other equipment, the paper builds the mathematical models for these equipment and uses these models for optimization calculation.

3. Method

3.1. Power consumption of chiller and auxiliary equipment

The paper uses the mathematical models developed by King and Potter [4] for the components of an ice-storage system to model the operation and performance of the main ice chiller.

3.1.1. Modeling chiller performance

The chiller capacity and power consumption listed in the manufacturer's documents are termed, respectively, nominal cooling capacity and nominal power consumption under standard operating condition and full-load state.

While the ambient temperature or cooling load changes, the chiller may not be operated under the standard operating conditions. Thus, its performance under non-standard operating conditions and partial load should be factored in as well. Power consumption of the chiller can be measured using the following equations. First of all

$$T_eq = \frac{T_{con,rtn} - T_{con,nom}}{Z} - (T_{ch,out} - T_{ch,nom}) \quad (1)$$

where $T_{ch,nom}$ is the nominal chilled water supply temperature, $T_{con,nom}$ is the nominal cooling water return temperature, $T_{ch,out}$ is the chilled water supply temperature from evaporator, $T_{con,rtn}$ is the condenser water return temperature and T_{eq} is calculated to quantify the departure of actual operating temperatures from nominal values.

$$Z = \frac{T_{con} - T_{con,nom}}{T_{ch,out} - T_{ch,nom}} \quad (2)$$