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Research paper

Using two improved particle swarm optimization variants for optimization of daily electrical power consumption in multi-chiller systems

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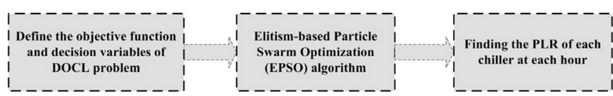
HIGHLIGHTS

- MA-PSO and EPSO increase the diversity of PSO algorithm.
- EPSO produces better results than PSO and MA-PSO algorithms.
- EPSO is an efficient tool for solving DOCL problem.

GRAPHICAL ABSTRACT



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ABSTRACT

One of the most important issues in multi-chiller systems (MCSs) is more energy saving by the minimization of the total electrical power consumption (TEPC) of the chillers. In this paper, daily optimal chiller loading (DOCL) problem is introduced where a 24-h cooling load profile should be satisfied by a number of chillers so that the total power consumption of the chillers during 24-h is minimized. Since in DOCL problem, the number of the decision variables which should be tuned simultaneously is 24 times greater than OCL, DOCL is a more complex optimization technique than OCL. Particle swarm optimization is an efficient stochastic metaheuristic technique which has shown a promising performance in solving the OCL optimization problem. As a result, in this paper, for efficiently solving the DOCL problem, two variants of PSO named elitism-based PSO (EPSO) and multi-agent PSO (MA-PSO) are developed. Compared with the original PSO, the proposed MA-PSO and EPSO find better results.

1. Introduction

In heating, ventilating and air-conditioning (HVAC) of medium-high cooling capacity, multi-chiller systems (MCSs) are often used. For being more competitive and profitable, many building or industrial owners continually seek for solutions that permit their businesses to offer higher quality. The designers of HVAC systems often employ chilled-water systems to provide high quality and cost-effective air conditioning for the owners.

There are a variety of water chiller types. Most commonly, they are absorption, centrifugal, helical rotary, and scroll. Chillers can be either air- or water-cooled. Chillers for industrial applications can be centralized, where a single chiller serves multiple cooling needs, or decentralized where each application or machine has its own chiller. Each approach has its advantages. It is also possible to have a combination of both centralized and decentralized chillers, especially if the cooling requirements are the same for some applications.

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Nomenclature

PLR	Partial load ratio
$TPC_{24\text{-}h}$	Power consumption during 24 h
P	Power consumption of chiller
a,b,c and *d*	Coefficients of chiller power curve
N_t	Number of hours
N_c	Number of chillers
Q	Chiller cooling rate
Q_n	Chiller nominal capacity
Q_L	Cooling load
P_f	Penalty function
N	Number of decision variables
N_p	Number of particles
t_{max}	Maximum number of iterations
t	Iteration index
r_1 and r_2	Random numbers from [0 1] with uniform distribution
c_1 and c_2	Learning factors
x	Particle position
v	Particle velocity
pbest	Particle best experience
gbest	Population best experience
w, w_{min} and w_{max}	Inertia weights
β	Penalty coefficient

The decrease of energy consumption in MCSs is an important issue. The electrical energy consumption of MCSs markedly increases if the chillers are improperly managed; therefore significant energy savings can be achieved by optimizing the performance of MCSs. As a result, the optimal amount of chiller loading in an MCS is a vital issue.

In recent years, in order to manage the power consumption of MCS, optimal chiller loading (OCL) problem has attracted the attention of various researchers. The final aim of the OCL problem is to determine the value of partial load ratio (PLR) for each chiller in an MCS at a fixed cooling load. Several conventional and heuristic optimization algorithms have been used to solve the OCL problem such as continuous and binary genetic algorithms (GAs) [1,2], particle swarm optimization (PSO) [3,4], cuckoo search (CS) [5], firefly algorithm (FA) [6], neural network (NN) [7], differential evolution (DE) [8], evolution strategy (ES) [9], simulated annealing (SA) [10], general algebraic modeling system (GAMS) [11], Lagrangian method (LGM) [1] and equal loading rate (ELR) [12]. In OCL, the number of the decision variables is equal to the number of the system chillers.

This paper introduces the daily optimal chiller loading (DOCL) problem in which a 24-h cooling demand should be satisfied by an MCS with the aim of minimizing the total electrical power consumption of the MCS during 24 h. Since in DOCL problem, number of decision variables is 24 times greater than OCL, DOCL is a complex optimization technique and needs a superior optimization method.

Study of the recent literature shows that heuristic techniques have produced more promising results than the conventional methods [5,6]. Among the heuristic techniques, PSO has been introduced as an efficient methodology for solving the OCL problem [3,4,7]. Originally invented by Kennedy and Eberhart in 1995 [13], PSO is a population-based metaheuristic algorithm attempting to discover the optimal solution of an optimization problem using the complex social cooperative and competitive behavior by simulating the animals social behavior such as fish schooling, bird flocking, among others. In PSO, a swarm is defined as a population of interacting elements and a particle is a member in the swarm, representing a potential solution in the search space. Each particle adjusts its search patterns through the problem space according to its experience and that of the other particles. PSO has been one of the most popular optimization algorithms because it has a simple concept, is easy to implement and can quickly find a reasonably good solution.

In original PSO, the particles frequently get attracted by sub-optimal solutions, causing premature convergence of the algorithm. Diversity control is an effective way to cope with this disadvantage. In this paper due to the complexity of DOCL problem, two variants of PSO, namely, elitism-based PSO (EPSO) and multi-agent PSO (MA-PSO) are proposed to increase the diversity of the swarm during the iterations by preventing the particles to move too close to each other.

The rest of this paper has been organized as follows: Section 2 introduces the formulation of the DOCL problem in detail. In Section 3, the PSO variants are described. Section 4 discusses on the results of a case study and the conclusion is shown in Section 5.

2. Modeling of DOCL problem

Due to providing operational flexibility and standby capacity, MCSs are usually used in air-conditioning systems. In air conditioning systems, chilled water is typically distributed to heat exchangers, or coils, in air handling units or other types of terminal devices which cool the air in their respective space(s), and then the water is re-circulated back to the chiller to be cooled again. Chillers are the biggest energy consumers in central air conditioning systems. Therefore, their efficiency has a significant effect on the overall energy performance of these buildings [14].

Improving the energy performance of chiller plants is of current interest because this usually presents the greatest energy saving opportunity in air conditioning systems of buildings. In an MCS, since the cooling load of building changes throughout 24-h, chillers operate frequently at their part load ratio (PLR) which is defined by the ratio of chiller cooling rate to the chiller capacity. This kind of operation will cause chiller efficiency to drop, and the drop becomes considerable when the set point of condensing temperature is fixed at a high level while outdoor temperature is low. It is therefore accepted that improving the part-load efficiency of chillers is the cornerstone for building energy effectiveness.

DOCL tries to set the value of PLR for each chiller of an MCS during 24-h so that the total power consumption of the system during a day is minimized. Adopted from Refs. [15,16], the power consumption of a centrifugal chiller for a wet-bulb temperature is a polynomial function of its PLR.

The main goal of DOCL problem is to minimize the total power consumption during 24-h ($TPC_{24\text{-}h}$) in an MCS subject to some constraints. This optimization problem is defined by