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Fuzzy multiobjective nonlinear operation planning in district heating and cooling plants

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Abstract

This paper formulates an operation planning problem of an actual district heating and cooling plant as a multiobjective nonlinear programming problem. For the formulated multiobjective nonlinear programming problem, an interactive fuzzy satisficing method to derive a satisficing solution for the decision maker is presented. Observing the problem is nonconvex and involves hundreds of decision variables, an approximate solution method through particle swarm optimization for nonlinear programming is introduced. Using the operation planning problem of an actual district heating and cooling plant, the feasibility and effectiveness of the proposed method are investigated.

Keywords: District heating and cooling plant; Operation planning; Nonlinear programming; Interactive fuzzy satisficing method; Particle swarm optimization

1. Introduction

District heating and cooling (DHC) systems have often been introduced as energy supply systems in urban areas for the purpose of saving energy, saving space, inhibiting air-pollution or preventing city disaster. In a DHC system, cold water, warm water and steam used for air-conditioning at all facilities in a certain district are made and supplied by a DHC plant, as shown in Fig. 1.

Due to the existence of a number of large-size freezers and boilers in a DHC plant as shown in Fig. 2, the control under an operation plan for these instruments on the basis of the demand of cold water, warm water and steam, called heat load, is important for the stable and economical management of a DHC system.

With the improvement of heat load prediction methods for DHC systems [9,10,5], the importance of the operation planning problem formulation of a DHC plant as a mathematical programming problem has been increasing [1,11]. From this point of view, Sakawa et al. [8] formulated operation planning problems of DHC plants as a mixed 0–1 programming problem and proposed genetic algorithms [4] for mixed 0–1 linear programming as an approximate solution method. Sakawa et al. [7] also introduced a mixed integer linear programming formulation of an operation planning of a DHC plant and presented an approximate solution method through genetic algorithms for mixed integer programming. Furthermore, Sakawa et al. [6] proposed a nonlinear 0–1 programming formulation of operation planning of a DHC plant together with genetic algorithms for nonlinear 0–1 programming.

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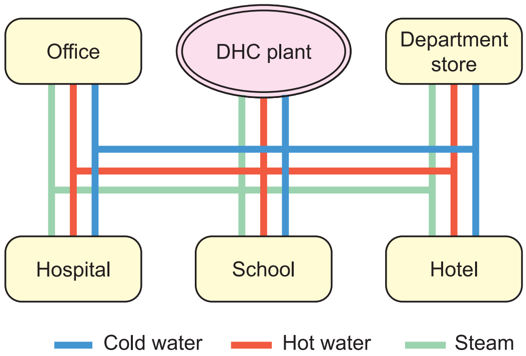

Fig. 1. A DHC system.

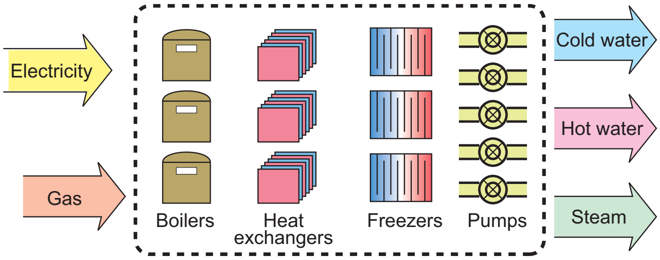

Fig. 2. A DHC plant.

In our previous studies [6–8], however, it is assumed that the states of instruments in operation are represented by an on–off state, i.e., binary zero or binary one, which is consistent with the old specification of the instruments. However, such an assumption does not suit the present specification because, nowadays, the states can be continuously controlled as the operating ratio by the development of the instruments. Moreover, since more saving energy is strongly needed, it is urgently required to deal with the reduction of the energy consumption as well as the minimization of the running cost.

Under these circumstances, in this paper, we formulate an operation planning problem of a DHC plant as a multi-objective nonlinear programming problem to minimize not only the running cost but also the primary energy amount and consider the introduction of inverter controllers. For the formulated problem, after introducing fuzzy goals of the decision maker for objective functions, we propose an interactive fuzzy satisficing method through particle swarm optimization for deriving a satisficing solution for the decision maker from among the Pareto optimal solution set.

2. Operational planning of a DHC plant

In a DHC plant, cold water, warm water and steam are generated by running many instruments using gas and electricity. Relations among instruments in a DHC plant are depicted in Fig. 3. From this figure, it can be seen that warm water and steam required for heating and cold water required for cooling are generated by running boilers (N_{BW} machines), absorbing freezers (N_{DAR} machines), turbo freezers (N_{ER} machines), heat exchangers for thermal storage (N_{CEX} machines), and heat exchangers for warm water (N_{HEX} machines), using gas and electricity in this DHC plant, where pumps and cooling towers are connected with the corresponding freezers.

Given the (predicted) demand for cold water C^t_{load}, that for warm water W^t_{load} and that for steam S^t_{load} at time t, the operation planning problem of the DHC plant can be summarized as follows.

(I) The problem contains $N = N_{\mathrm{BW}} + N_{\mathrm{DAR}} + N_{\mathrm{ER}} + N_{\mathrm{CEX}} + N_{\mathrm{HEX}}$ decision variables. They are all continuous variables in the interval [0, 1] as x^t_i, $i = 1, \ldots, N - N_{\mathrm{BW}}$ which indicate the operating ratio of each of the