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Decentralized control of parallel-connected chillers

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Abstract

This paper introduces a novel idea of a decentralized method for the optimal control of parallel-connected chillers in Heating Ventilation and Air Conditioning (HVAC) systems. In this decentralized control system, each chiller, equipped with a decentralized controller embedded with identical control algorithms, becomes a smart chiller and can communicate with others collaboratively to meet the control requirements and to be energy efficient. A decentralized optimal control algorithm is developed and validated through simulation for different cases, and further demonstrated through hardware application in an actual project in a factory of south China. Compared with the traditional centralized control method, this decentralized control method is much more flexible and more efficient.

Keywords: Decentralized; Optimal control; Smart device; Chiller

1. Introduction

Chillers are the main water cooling devices in HVAC systems, which satisfy the demands of a comfortable indoor environment. The energy consumption of water cooling systems contributes a significant proportion to the total energy consumed in buildings [1] and chillers usually account for most of the energy consumption of these systems. Efficient monitoring and controlling methods can both significantly improve their reliability and lower their energy consumption [2].

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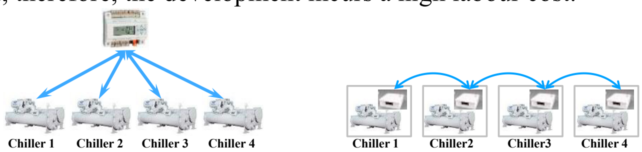
In most real applications, several chillers of the same type are usually parallel-connected into a group or station with consideration given to standby capacity, operation flexibility and, most importantly, high energy efficiency under partial load. Therefore, group operation of the chiller systems becomes an important topic in the optimal control of an HVAC system, where the loading/unloading and corresponding speed or part load ratio (PLR) of all operating equipment must be determined. It is essentially an optimization problem with the objective of minimizing the total energy consumption of the chiller group, subject to each chiller group having to satisfy system requirements such as the cooling load of the chiller group, with each unit within the group satisfying the actual operation limitations.

Extensive studies have been undertaken to determine the optimal group operation of the chiller systems. The majority of previous research efforts have focused on adopting different numerical algorithms to solve such an optimization problem. The optimization algorithms for the group operation of chillers, the algorithms for the optimal chiller load (OCL) include the generalized reduced gradient algorithm, particle swarm algorithm, Lagrangian method, branch and bound method, and simulated annealing [3–8]. Usually, numerical algorithms cannot be applied to every optimization problem. The use of different methods of modeling a chiller plant system would greatly affect the result. As some researchers have pointed out, an evolution strategy can overcome the problem with the Lagrangian method in that it cannot be adapted to the solution of OCL as the power consumption models include nonconvex functions [3]. The genetic algorithm may not attain a minimum energy consumption solution, as is possible when using the Lagrange method to solve the OCL problem with a low demand [8]. However, these algorithms are not straightforward and either require case by case development for different systems or require the input of extensive data for the algorithm training. Unfortunately, high implementation and computation costs prevent these algorithms from being widely adopted for real applications.

2. Centralized and decentralized control

In current practical applications, the chiller group is controlled through a centralized method, as shown in Figure 1, with a centralized controller (DDC or PLC) collecting data from each unit of chiller, performing calculations and making decisions based on a centralized control algorithm and sending out control instructions to each unit of chiller.

With this centralized control structure, a typical control system building process includes control system design, equipment and system modelling, control strategy design, installation and wiring, onsite debugging, and commissioning. The control algorithm or strategy needs to be adjusted or reprogrammed as the system configuration changes. The onsite measuring, wiring, configuring, commissioning, and secondary development work mean that each control system is unique and, therefore, the development incurs a high labour cost.



(a) (b)

Fig. 1. Centralized and Decentralized control structure.

The basic concept of decentralized control is that local interactions between the components of a system establish order and coordination to achieve global goals without a central commanding influence, meaning that the overall system is no longer controlled by one single controller but by several independent local controllers incorporated into each component.

In the decentralized control structure for a chiller group, as shown in Figure 1(b), each unit is equipped with a decentralized controller and thus becomes a smart unit. The smart devices within a group connect with each other through wired or wireless communication and can negotiate with neighbouring, working together to satisfy the control requirements and be energy efficient. There is no centralized controller such as a DDC or PLC in this decentralized control system. A traditional chiller could be upgraded to a smart chiller by installing a decentralized controller, which contains the decentralized control algorithm and detailed performance parameters input by the manufacturer who knows the chiller's performance as it leaves the factory. Therefore, the complicated onsite modelling, configuration, commissioning and secondary development work could be reduced to simply providing communication connections