Optimal Load Distribution Strategy for Multiple Chiller Water Units based on Adaptive Genetic Algorithms

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***Abstract*—For the complexity, constraint, nonlinearity, modeling difficulty of the multiple chiller water units, an approach using adaptive genetic algorithm method to solve the optimal chiller load distribution and to improve the deficiencies of conventional methods is presented in this paper. As an example, 2 chiller water units connected in parallel working using the proposed method was observed. Compared with the conventional method, the results indicated that the adaptive genetic algorithms method has much less power consumption and is very suitable for application in air condition system operation.**

Keywords-energy consumption; energy saving; algorithm; adaptive genetic algorithms; optimal distribution strategy; part load; chiller water units; direct load control, optimal chiller load distribution

I. INTRODUCTION

With the increase of the building scale, more and more chiller water unit and hot water unit was in using, and the energy consumption of the multi chiller and hot water units was depends not only on the feature of these equipment itself, but also the load distribution strategy under the part load condition., therefore, with the chiller water units was given, how to find an optimal load distribution in the running of the equipment become the critical problem in the system energy conservation. There are some conventional and common methods put forward in some paper to obtain good load distribution for energy saving.

In this paper, the author investigate the part load feature of the chiller water units, establish the nonparametric model for the optimal load distribution regardless of the type of the equipment, use adaptive genetic algorithms to solve the load distribution problem for energy saving.

II. OPTIMAL LOAD DISTRIBUTION STRATEGY

A. Nonparametric Model of the Chillers water unit

For simplicity, we think the cold source of the air-conditioning system is composed of n chillers connected in parallel, the output cold of the number *i* chiller water unit is q_i, the input power of the chiller is W_i. The cold load of the building changing with the environment, the practical output cold of the chillers changing with the building cold load, the input power of the chillers changing simultaneously, so, W_i, is a function of q_i ,that is :

$$W_i = f_i(q_i) \tag{1}$$

In the working process of these chillers how to distribute the cold load of each chiller to meet the user's need and to achieve the minimum input power is an optimization problem.

Taking the energy consumption as the optimization goal, when the input power of all the chillers is minimum, the load distribution is optimal. The mathematical model is

$$W_n^*(L) = \min W(Q) = \min \sum_{i=1}^{n} f_i(q_i), \qquad Q \in E^n \tag{2}$$

$$Q = (q_1, q_2, \ldots, q_n,)^{\mathrm{T}} \tag{3}$$

Where W_n^* is the optimal goal function; L is the actual cooling load.

Simultaneously, the total output cooling capacity of all the chillers must satisfy the actual cooling load of the buildings, thus the following constraints condition must be satisfied:

$$H(Q) = \sum_{i=1}^{n} q_i = L \tag{4}$$

In practice, each chiller has an appropriate load range, in which the chiller works at the most high efficiency status. Thus, the following constraints must be satisfied:

$$q_{\min} \le q_i \le q_{\max}, \quad i = 1,2,\ldots,n$$

Where q_i is the actual output cold of the number *i* chiller; $q_{i\min}$ is the minimum output cold of the number *i* chiller; $q_{i\max}$ is the maximum output cold of the number *i* chiller.

For the complexity, constraint, nonlinear, difficulty in modeling of the multiple chiller water units, an optimal load distribution strategy based on adaptive genetic algorithms is presented in this paper.

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B. *Adaptive genetic algorithms*

Genetic algorithm (GA) is a directed random search technique that is widely used in optimization problems. The algorithm uses principles inspired by natural genetics to evolve solutions to problems.

In this paper, the standard GA is modified and a new genetic operator, applied in the adaptive genetic algorithms, are introduced to improve its performance in load distribution for multiple chiller water units to achieve the minimum energy consumption to match the cooling load demand of the user.

The proposed GAs update the number of mutant individuals, crossover, and selection rates as a function of the parent diversity. The parametric adaptation of the proposed GAs is guided by the diversity, which should not be very low or very high, avoiding convergence to local optimum or random search, respectively.

To do this, first, the number of mutations must be reduced, and the crossover and reproduction rates must be increased when the parent diversity grows toward one. Second, when the parent diversity falls, growth of the number of mutations and simultaneous fall of two other rates must occur to increase exploration of the solution space. An adaptive mutation probability was used to keep an adequate level of diversity during evolution. The use of an adaptive probability for a. mutation rate increases the possibility of finding the global optimum and accelerates the convergence time. The random immigrant mechanism aims to increase the diversity of the population, and to avoid premature convergence. To increase the probability of the existence of fit individuals in the next generation, a percentage of the remaining population is selected. Each generation of the proposed models is composed of the following individuals: 10% are potential parents; 20% are random immigrants; and 70% are individuals derived from the use of genetic operators.

C. *Procedure for the Proposed Algorithms*

The Adaptive Genetic Algorithm improves the performance of the standard genetic algorithm. It adjusts the crossover rates and the mutation rates according to the fitness and generations. Adaptation tuning probability of crossover and mutation is one of the effective methods improving search arithmetic. The tuning arithmetic as follows:

$$p_c = \begin{cases} p_{c\max} - \left(\frac{(p_{c\max} - p_{c\min})}{it_{\max}}\right) * \text{iter}, & f' > f_{\text{avg}} \\ p_{c\max} & , f' \le f_{\text{avg}} \end{cases} \tag{5}$$

$$p_m = \begin{cases} p_{m\min} + \left(\frac{(p_{m\max} - p_{m\min})}{it_{\max}}\right) * \text{iter}, & f > f_{\text{avg}} \\ p_{m\min} & , f \le f_{\text{avg}} \end{cases} \tag{6}$$

Where p_c is crossover probability, $p_{c\max}$ is the maximum crossover probability, $p_{c\min}$ is the minimum crossover probability, p_m is mutation probability, $p_{m\max}$ is the maximum mutation probability, $p_{m\min}$ is the minimum mutation probability, $it_{\max}$ is maximum generation, iter is current generation, f_{avg} is the average fitness value, f' is the larger fitness value among the two individuals with crossover, f is fitness value of individual needing mutation.

The procedure for the proposed algorithms to search for the solution of the Optimal Load Distribution Strategy for Multiple Chiller Water Units is as follows, obeying the maximum number of generations or the convergence as the stop criterion.

(1) Initialize the following variables and parameters: population size, maximum number of generations, produce n binary encoded chromosome randomly to create the initial population.

(2) Compute the global fitness function for each individual.

(3) Select and copy the high quality individuals to constitute the temporary collection C comprising N individuals according the fitness value of each individual for the purpose of approaching the optimal solution, In such process the bad individual is weeded out and the good individual is copied.

(4) Make the individuals married in the collection C to create the offspring collection C' according to the matching rule and crossover probability.

(5) Change some individuals in C' to create the new collection C'' according to the mutation rule and mutation probability.

(6) Judge if the stopping criterion is satisfied, if not, let P=C then turn to (2), otherwise turn to (7).

(7) Output the best individual in the population or the best individual produced in all the process of the evolution.

III. EXAMPLES AND RESULTS

The proposed method is tested on two chillers water unit, part load performance parameters is shown in Table 1.

TABLE I. PART LOAD PERFORMANCE PARAMETERS

Load Ratio	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
input power/kW	128	112.4	80.3	65.6	53.6	44	35	27.5	22	16.5

The two chillers are identical, running for 2400h one year in air-conditioning season. The time distribution cold load is shown in Table 2. The construction area is of 18000 square meters, with the total cooling load 1700Kw.

TABLE II. PART LOAD PERFORMANCE PARAMETERS

load ratio	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
runtime/h	150	170	170	280	260	240	300	280	260	290

Because the facilities are operated all day long, the electric energy consumption in the chiller plant will increase immediately if the chiller load distribution is not proper.

The control of cooling water temperature and the flow rate and the supply temperature of chilled water must be taken into consideration simultaneously for executing chiller capacity control.

Many companies still use the equal loading rate manner and lots of power energies are consumed imperceptibly. So, the optimal cold load distribution method based on the adaptive genetic algorithms is proposed in this paper to overcome these shortcomings and reduce the power consumption and the operation costs. The presented method estimates chiller output refrigerating capacity by measuring flow, supply and return temperatures of chilled water. Then, the input power kW-part load ratio curve can be easily obtained for each chiller through regression applied to measured data coming together with the input electric power. The electric energy saving can be achieved in the condition of minimum input electric power and satisfying total cooling load demand.

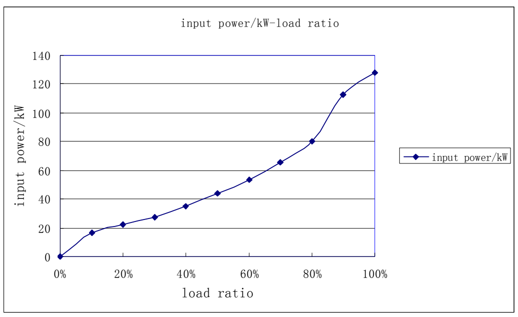

Figure 1. the input power(Kw) —— part load ratio curve

The following is the results of the conventional methods and the proposed method. The potential performance of the proposed method is demonstrated by mean of two screw type water chiller systems. Compared with the conventional method, the proposed method has much less power consumption and is very suitable for application in air condition system operation.

The cooling load (Refrigeration Ton) of a chiller can be calculated by the formula (7):[8]

$$Q = fm(T_{CHr} - T_{CHs})/3517 \quad (7)$$

where f is the flow rate of chilled water(kg • s^{-1});

m is the specific heat of chilled water(J • kg^{-1} • k^{-1});

T_{CHr} is the return temperature of chiller water(k);

T_{CHs} is the supply temperature of chiller water(k);

Because of constant chilled water flow in a chiller, its cooling load can be determined if the supplied temperature and the return temperature of chilled water are measured. The input power (kW) can be gotten by usage of a power meter and then the input power (kW)-part load ratio data can be obtained by applying regression. The load demand variation can also be determined from measuring the water flow and the temperature in the main pipe on the load side.

Three groups of data obtained by two kind of conventional methods and the proposed method are illustrated as follows:

Table III is the energy consumption of the chiller water unit running at the one of the conventional methods. The total energy consumption of it is 316,870.00kWh in one year. Table Ⅳ is the energy consumption of the chiller water unit running at the other one of the conventional methods. The total energy consumption of it is 338,272.00kWh in one year. Table Ⅴ is the energy consumption of the chiller water unit running at the adaptive genetic algorithm methods. The total energy consumption of it is 294,616.00kWh in one year.

These tables show that the proposed method has much larger saved powers than those in the conventional method.

Consequently, the adaptive genetic method is better than the conventional method. The energy consumption comparison for these two systems is shown in Fig.2.

It is obvious that the adaptive genetic method has larger saved powers compared to the conventional method. The execution of program is so fast that the CPU times can’t be found out in these two methods.

TABLE III. OPERATION SCHEME 1 USING CONVENTIONAL METHOD

system load ratio	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
runtime/h	150	170	170	280	260	240	300	280	260	290
load ratio of chiller 1	0.20	0.40	0.60	0.80	1.00	0.60	0.70	0.80	0.90	1.00
input power of chiller 1/kW	22.00	35.00	53.60	80.30	128.00	53.60	65.60	80.30	112.40	128.00
load ratio of chiller 2	0.00	0.00	0.00	0.00	0.00	0.60	0.70	0.80	0.90	1.00
input power of chiller 2/kW	0.00	0.00	0.00	0.00	0.00	53.60	65.60	80.30	112.40	128.00
part energy consumption of chiller1/kWh	3,300.00	5,950.00	9,112.00	22,484.00	33,280.00	12,864.00	19,680.00	22,484.00	29,224.00	37,120.00
part energy consumption of chiller2/kWh	0.00	0.00	0.00	0.00	0.00	12,864.00	19,680.00	22,484.00	29,224.00	37,120.00
total energy consumption of operation scheme 1/kWh(1 year)				316,870.00						

TABLE IV. OPERATION SCHEME 2 USING CONVENTIONAL METHOD

system load ratio	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
runtime/h	150	170	170	280	260	240	300	280	260	290
load ratio of chiller 1	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%
input power of chiller 1/kW	22	35	53.6	80.3	128	128	128	128	128	128
load ratio of chiller 2	0	0	0	0	0	20%	40%	60%	80%	100%
input power of chiller 2/kW	0	0	0	0	0	22	35	53.6	80.3	128
part energy consumption of chiller1/kWh	3,300.00	5,950.00	9,112.00	22,484.00	33,280.00	30,720.00	38,400.00	35,840.00	33,280.00	37,120.00
part energy consumption of chiller2/kWh	0.00	0.00	0.00	0.00	0.00	5,280.00	10,500.00	15,008.00	20,878.00	37,120.00
total energy consumption of operation scheme 1 kWh(1year)				338,272.00						

TABLE V. OPERATION SCHEME USING THE ADAPTIVE GENETIC ALGORITHM

system load ratio	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
runtime/h	150	170	170	280	260	240	300	280	260	290
load ratio of chiller 1	20%	40%	60%	40%	40%	60%	70%	80%	100%	100%
input power of chiller 1/kW	22	35	53.6	35	35	53.6	65.6	80.3	128	128
load ratio of chiller 2	0	0	0	40%	40%	60%	70%	80%	80%	100%
input power of chiller 2/kW	0	0	0	35	35	53.6	65.6	80.3	80.3	128
total energy consumption of chiller1/kWh	3,300.00	5,950.00	9,112.00	9,800.00	9,100.00	12,864.00	19,680.00	22,484.00	33,280.00	37,120.00
total energy consumption of chiller2/kWh	0.00	0.00	0.00	9,800.00	9,100.00	12,864.00	19,680.00	22,484.00	20,878.00	37,120.00
total energy consumption of operation scheme 1 kWh(1 year)		294,616.00								

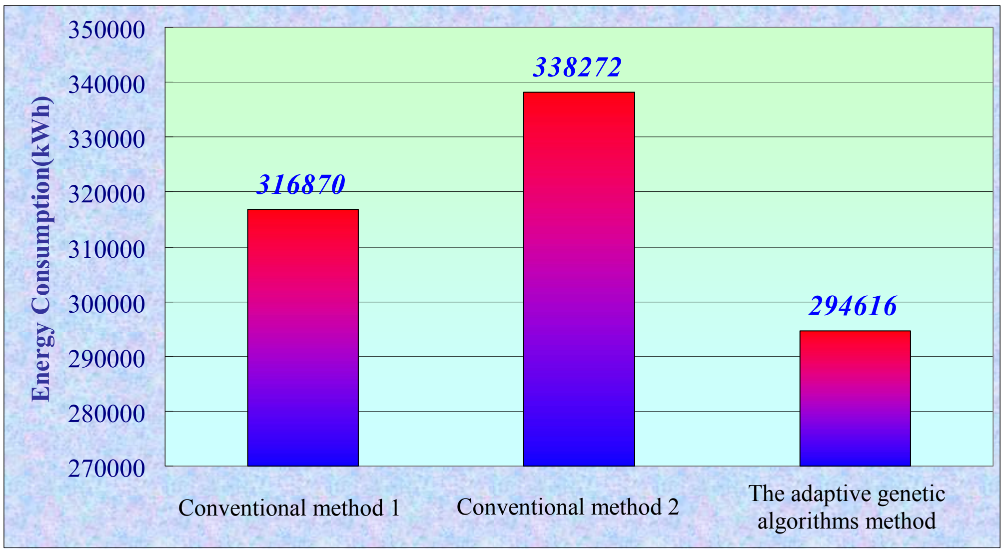

Figure 2. Energy consumption comparision between the conventional methods and the adaptive genetic algorithms method

IV. CONCLUSION

The cooling load has increased enormously during recent years along with the development of economy. We have to pay much attention to the optimal load cold distribution problem for the sake of reducing power consumption by way of operating chiller in the best effect according to different feature. In this paper, the nonparametric model of the optimal load cold distribution problem has been derived. The optimal problem is solved by usage of Adaptive Genetic Algorithm method. The proposed method has been tested on two example systems and compared with the conventional method. Test results show that the proposed method reduces large energy consumption and is superior to the conventional method.

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