Research on Operation Optimization of Central Air Conditioning Cold Source System Based on PSO-SA Algorithm

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Abstract—This paper takes a data center air-conditioning cold source system as the research object. According to the historical operating data of the cold source system in the transition season, a cold source model is built on the EBSILON platform. The total energy consumption of the cold source system is the research goal. This paper establishes an overall optimization strategy based on PSO-SA. A simulation experiment was conducted on a typical day in the transition season, and the results showed that the optimization strategy can achieve 21.68% energy saving based on the original operation mode when the wet bulb temperature in the transition season is low.

1. Introduction
Comparing the operating energy consumption of various emerging buildings, it is found that because of the long running time of the equipment inside the data center, the energy consumption of its daily operation is huge [1-2]. The central air-conditioning system inside the data center generally consists of two parts: the water system and the wind system of the central air-conditioning. When the central air-conditioning is running, the energy consumption of the equipment in the water system accounts for a large proportion.

Therefore, domestic and foreign researchers, experts and scholars conducted a lot of research on energy saving operation of central air conditioning water system. In 2016, Yan [3] discussed load distribution optimization strategy of multiple chillers based on genetic algorithms. Re [4-5] analyzed the effect of simultaneously changing the air rate and cooling water flow (dual-variables adjustment or dual-machines frequency variation) of the cooling tower on the energy consumption of the chilled water system. In 2018, Majid Karami [6] used the particle swarm algorithm to optimize the temperature setting values of chilled water and chillers, as well as the sequence of chillers, which improves the overall performance and optimized all the control variables for central air conditioning operation. In the hot season, it could save 10.5% of the average daily energy, and in the temperate season, it could save 13.6%. In 2019, Lee [7] analyzed the impact of large temperature differences on air conditioning systems, and introduced the specific improvement measures, pointing out some problems that should be paid attention to when choosing the large temperature difference in air conditioning chilled water systems. Lee [7] took the total energy consumption of air conditioning units as the objective function for optimizing and calculating the scheme for the large temperature difference in air conditioning chilled water systems. The results showed that the optimal temperature difference between supply and return water of the air conditioning chilled water system was 7.2°C.
Because the air conditioning system of the data center contains a backup cold source. Considering the performance difference between the backup cold source and the cold source in operation, there are few reports on the work of load distribution. In order to fill these gaps, relevant research has been carried out. This paper first analyzes the model mechanism of the central air-conditioning refrigeration system, and then performs the algorithm implementation and simulation experiment of the overall optimization strategy, and finally performs optimization analysis for the typical days of the transition season.

2. Air-conditioning cold source system model

2.1 Introduction to Central Air Conditioning Water System

This article takes a data center in Shanghai as the research object. The data center has 6 centralized cold sources, including 6 centrifugal chillers, 6 cooling pumps, 6 refrigerating primary pumps, 6 refrigerating secondary pumps, and 12 Cooling tower fans, 12 cooling tower circulating water pumps, and at least one set of cold source equipment are in standby. A single cold source is operated by one machine to one pump and two towers. The cooling tower includes two energy-consuming equipment: a fan and a circulating water pump (the cooling pump, the freezing primary pump, the freezing secondary pump and the cooling tower fan use frequency conversion technology. The circulating water pump is power frequency). The energy consumption of the air conditioning cold source system is composed of chillers, cooling pumps, primary refrigeration pumps, secondary refrigeration pumps, and cooling towers.

2.2 Equipment energy consumption model

The energy consumption model[8] of the chiller can be expressed as:

\[
P_{ch} = a_0 + a_1(T_{cws} - T_{chws}) + a_2(T_{cws} - T_{chws})^2 + a_3Q_{ch} + a_4Q_{ch}^2 + a_5(T_{cws} - T_{chws})Q_{ch}
\]  

(1)

where \(P_{ch}\) — Power of chillers, kW, \(T_{cws}\) — temperature of chilled water supplied, ℃, \(T_{chws}\) — temperature of cooling water supplied, ℃, \(Q_{ch}\) — actual cooling capacity of chillers, kW, \(a_0\), \(a_1\), \(a_2\), \(a_3\), \(a_4\), \(a_5\) — model identification parameters.

Take No.1 chiller as an example, first determine the model parameters through model identification[9]. After parameter identification, the energy consumption model is:

\[
P_{ch,1} = -373.446 + 11.681 \times (T_{cws} - T_{chws}) + 0.779 \times (T_{cws} - T_{chws})^2 + 0.29 \times Q_{ch} - 3.45 \times 10^{-5} \times Q_{ch}^2 - 0.0051 \times (T_{cws} - T_{chws})Q_{ch}
\]  

(2)

In order to verify the accuracy of the energy consumption model of the chiller, the historical operating data during the period between October 1st 2018 00:00 and October 3rd 2018 24:00 was used to model and analyze the energy consumption model portrayed in Equation (2). The data acquisition was performed once every 30 minutes, and a total of 192 sets of data was obtained. As shown in Figure 1, Figure 2 shows that the absolute error between the measured value of chiller power and the simulation value of the model is 9.6kW, is-8.4kW, and the average error in 192 data points is 2.05%, and the overall accuracy of the model is high. The rest of the equipment energy consumption model analysis method is the same as that of the chiller, so I will not repeat it.
2.3 Optimization target model
When multiple air-conditioning cold sources are connected in parallel, the optimization objective is that the total energy consumption of the air-conditioning chiller and cold source system is minimum under conditions of given the two boundaries of the total cooling load and the ambient wet-bulb temperature. The total optimization objective function is:

\[
\min P_{\text{total}} = \min \sum_{i=1}^{\text{N}} (P_{\text{ch},i} + P_{\text{cwp},i} + P_{\text{tower},i}) = \min \sum_{i=1}^{\text{N}} \frac{Q_{\text{total},i}}{\text{EER}_i} \tag{3}
\]

\[
\text{St.} \quad Q_{\text{total}} = \sum_{i=1}^{\text{N}} Q_{\text{ch},i} \tag{4}
\]

2.4 Optimization variables and ranges
Variables of the optimization objective function that can be determined are listed in Table 1.

| Variable                        | symbol | range        |
|---------------------------------|--------|--------------|
| Number of cold source open      | N      | N=1,2,3,4,5  |
| Cold source equipment open number | i      | 1#, 2#, 3#, 4#, 5#, 6# |
| Cooling capacity of single chiller | Q_{ch,i} | 1000-2800kW |
| Cooling pump frequency          | f_{cwp} | 25-50Hz      |
| Frozen primary pump frequency   | f_{chp-1} | 30-50Hz     |
| Refrigerating secondary pump frequency | f_{chp-2} | 30-50Hz     |
| Cooling tower frequency         | f_{fan} | 25-50Hz      |

3. Materials and Methods
3.1 Algorithm optimization strategy
The overall optimization strategy for the air-conditioning cold source can be expressed as follows: after the total refrigeration load of the air-conditioning cold source is determined, the corresponding number of cold sources starting and shutting have been determined. In view of the characteristics of the backup cold source of the data center, the next step is to determine the unit combination mode, and prefer to turn on the better-performance air-conditioning cold source for cooling, and turn off some poor-
performance air-conditioning cold sources. Secondly, according to the total refrigeration load, optimize the load distribution of each air conditioning cold source, and finally realize the overall optimization control of the air conditioning cold source system.

3.2 Algorithm realization of PSO-SA optimization strategy

3.2.1 Particle Swarm Algorithm

This paper chooses PSO-SA\cite{10} algorithm to calculate the overall optimization control strategy. Particle swarm algorithm is a random optimization technique based on the group. It has the characteristics of simple algorithm and easy implementation. However, due to the lack of effective constraints and control of particle flight, it has the disadvantages of trapping into local extreme points and low convergence accuracy and not easy to converge, and it is not easy to converge to the global optimum. Therefore, the particle swarm algorithm needs to be upgraded and evolved.

3.2.2 Simulated annealing algorithm

Simulated annealing\cite{11} is a stochastic combinatorial optimization method developed in the early 1980s. From a conceptual point of view, it is a global optimal algorithm, which can converge to the global optimal solution with probability 1 under certain conditions.

Both the initial solution and the final solution of the simulated annealing algorithm are randomly selected and are not related to each other, so it has good robustness, that is, the ability to resist external unstable factors is very strong.

3.2.3 Implementation of particle swarm optimization algorithm based on simulated annealing (PSO-SA)

The particle swarm algorithm based on simulated annealing introduces the simulated annealing mechanism into the basic particle swarm optimization algorithm\cite{12}, combines the advantages of the two algorithms, keeps the particle swarm algorithm simple and easy to implement, and improves the ability of the particle swarm algorithm to get rid of local extreme points, Improve the convergence and accuracy of the algorithm.

The overall optimization fitness function of the air-conditioning cold source system is:

\[
\text{function value} = \text{fun}_\text{12345}(x, pn, y) \\
\text{value} = \sum_{i=1}^{N} \frac{x(i)}{f_i(x, y)} + \text{abs}(\sum_{i=1}^{N} x(i) - pn)
\]  \hspace{1cm} (5)

where \(x\) —— distributive cooling capacity of each cold source, kW; \(pn\) ——Total cooling load, kW; \(y\) ——ambient wet-bulb temperature, °C; \(N\) ——the Number of cold source opening, \(i\) ——cold open number opening, \(f_i(x, y)\) ——optimization EFfunction of cold source,

\[
\text{abs}(\sum_{i=1}^{N} x(i) - pn) \quad \text{— compensated function establishing equality constraints for cooling load.}
\]

Figure 2 shows the optimization flow chart of the air conditioning cold source system.
4. Results & Discussion

4.1 Typical Days in the Transition Season

In the transition season, 4 air-conditioning cold sources are used in parallel, and there is a combination of air-conditioning cold sources in practical applications. Take the total cooling capacity of 9000kW, the wet bulb temperature of 14℃, and the historical operating conditions of the air-conditioning cold source under 1#, 2#, 3#, 4# work. It can be seen from Figure 3 that the optimization trend of the PSO algorithm shows a stepwise decline. After 49 iterations, the fitness function is close to convergence. At the 149th iteration, the fitness function reaches the minimum value of 882.0478kw. The PSO-SA algorithm also takes the total cooling capacity of 9000KW, the wet bulb temperature of 14℃, and the historical operating conditions of the air-conditioning cold source under 1#, 2#, 3#, 4# work; the simulated annealing algorithm is combined with the particle swarm algorithm after the upgrade. The PSO-SA algorithm approaches convergence after 19 iterations, and reaches the minimum value of 876.0457KW at the 107th iteration. It can be seen that the upgraded algorithm improves the speed and accuracy of algorithm convergence. It provides a good foundation for practical applications.

![Fig3 Evolution curve of fitness function](image)

Based on the preliminary study of the combination method, this paper proposes two optimization schemes: Option one does not change the unit combination method of the original system, and optimizes the load distribution on the basis of the existing combination method; Option two changes the original system Unit combination mode, the unit combination mode with the least energy consumption is preferred, and the refrigeration load is redistributed. In order to verify the actual energy-saving effect of the optimization strategy after simulation and optimization, under the condition of consistent external boundary conditions, select the historical data of a typical day in the transition season (November 9, 2018) to optimize the energy-saving effect of air-conditioning cold sources. Carry out testing. The optimization result is recorded every 30 minutes from 0:00 to 24:00 at the test time. The outdoor weather
parameters tested during the transition season are shown in Figure 4, and the total cooling load of the air-conditioning system is shown in Figure 5. On the subject day, select the combination of turning on the air-conditioning cold source (1#, 2#, 3#, 4#). After the simulation optimization, the full-day energy consumption comparison of the original system, the optimization plan 1, and the optimization plan 2 are shown in Figure 6. The energy consumption data statistics of the optimization energy saving effect table for the typical days of the three plans in the transition season are shown in Table 2.

![Fig 4 Outdoor weather parameters](image1)

![Fig 5 Total cooling load](image2)

![Fig 6 Comparison of typical daily energy consumption in the transition season](image3)

| Cold source number | Original system | Optimization plan 1 | Optimization plan 2 |
|--------------------|----------------|---------------------|---------------------|
| Cumulative cooling capacity/kW | 437096.59 | 437096.59 | 437096.59 |
| Cumulative power consumption/kW·h | 42882.35 | 40629.22 | 34603.35 |
| Energy saving/ kW·h | — | 2253.13 | 8278.99 |
| Energy saving rate/% | — | 5.39 | 21.68 |
| Average daily EER | 10.19 | 10.76 | 12.63 |

It can be seen from Table 2 that the energy-saving rate of the whole day is 5.39% by using the optimized solution 1, and the unit combination mode is optimized by the optimized solution 2, and the energy-saving rate reaches 21.68%. The energy-saving effect of the second optimization scheme has been significantly improved. Choose the 13:30 time of the day to study the cooling capacity distribution plan, as shown in the following tables 3 and 4, the optimization plan 2 changes the unit combination mode, adding 5#, 6#, closing 2#, 4#, and 5#, Unit 6# bears more cooling capacity. Therefore, the total energy consumption is reduced by 71.46kW under the unit combination mode in the optimization scheme 1. The addition of 5# and 6# units in the second optimization plan can significantly reduce the energy consumption of the total air conditioning cold source (225.73kW), and the energy saving effect
is obvious. In terms of cooling capacity distribution, 6# > 5# > 3# > 1# is satisfied, and higher-performance air-conditioning cold sources take on more cooling capacity in turn, which can further increase energy-saving benefits on the basis of the optimization scheme 1.

Table 3 Distribution table of cold source cooling capacity of air-conditioning in transition season

| Cold source number | 1#      | 2#      | 3#      | 4#      | 5#      | 6#      |
|--------------------|---------|---------|---------|---------|---------|---------|
| Original system    | 2310.3  | 2053.59 | 2537.36 | 2129.40 | /       | /       |
| Optimization scheme 1/KW | 2293.14 | 2310.56 | 2480.56 | 1987.47 | /       | /       |
| Optimization scheme 2/KW | 2025.4  | /       | 2067.5  | /       | 2284.8 | 2653    |

Table 4 Energy consumption of air-conditioning cold source in transition season (based on the original plan)

| Cold source number | 1#      | 2#      | 3#      | 4#      | 5#      | 6#      | Total energy consumption |
|--------------------|---------|---------|---------|---------|---------|---------|--------------------------|
| Original system    | 233.81  | 246.89  | 272.19  | 259.01  | /       | /       | 1011.9                   |
| Optimization scheme 1 | -15.58  | -16.12  | -18.15  | -21.61  | /       | /       | -71.46                   |
| Optimization scheme 2 | -61.98  | -246.89 | -71.71  | -259.01 | 205.96  | 207.90  | -225.73                  |

5. Conclusions

(1) The energy consumption model established in this paper has high calculation accuracy. The average error of the chiller energy consumption model is 2.05%; the average error of the cooling pump energy consumption model is 2.01%; the average error of the refrigeration primary pump energy consumption model is 1.87%; the average error of the secondary refrigeration pump is 1.90%; the average error of the cooling tower energy consumption model is 1.67%, which can provide good support for the optimization and energy saving research of the refrigeration system.

(2) Research on energy saving of multiple parallel cold source systems based on PSO-SA algorithm shows: during the transitional season, the energy-saving rate of optimized program 1 was 5.39%, and the energy-saving rate of optimized program 2 reached 21.68%. For the transition season, the second optimization plan is more energy efficient.

(3) The overall optimization strategy fully takes into account the performance difference between the standby cold source and the running cold source, so as to allocate the cooling capacity; in the transition season, choose to increase the cold source 5 and the cold source 6, turn off the cold source 2, and the cold source 4. The energy efficiency ratio has been increased from 10.18 of the original system to 12.63; it shows that the energy-saving optimization strategy based on PSO-SA has better energy-saving performance.

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