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Analysis of parallel operation characteristics of chillers under partial load conditions

Yulan-ZHENG[a], Xuefeng LIU[a,*], Zhitao LU[a], Guanyu FANG[b], Wenjing CHEN[b], Shiming DENG[b]

[a]*South China University of Technology, School of Electric Power, Wushan RD., Tianhe District, Guangzhou, 510641, P.R. China*
[b]*The Hong Kong Polytechnic University, Department of Building Services Engineering, Hung Hom, Kowloon, 999077, Hong Kong*

Abstract

The rational allocation of chiller group plays an important role in the efficient operation of generating units. In this paper, the running characteristics of chiller group under full load are studied. Through the construction of the operation model of the chiller group, the relationship between the start and stop collocation and the operation characteristics of the unit group was explored, and the influence of the unit capacity configuration and the number of table number configuration on the running energy consumption characteristics was studied. The results showed that: the greater the difference of host capacity in the group, the lower the energy consumption under full load. In this example, the difference of energy consumption can reach 8%. At the same time, through the increase in the number of generating units, the difference in host capacity within the group had less impact on energy consumption at full load. For a unit group with the same host capacity, the more the number of units was configured, the lower the operating energy consumption. It provided theoretical support for the selection, collocation and operation management of chillers in practical projects.

Keywords: Chiller group,Characteristic analysis, Energy saving

* Corresponding author. Tel.: +86 13580456068
E-mail address: lyxfliu@scut.edu.cn

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1. Introduction

Under partial load conditions, the operating load of the single machine is improved by switching the number of parallel hosts, which is an effective method to improve the thermal efficiency of the unit group[1].

At present, the research on the rationality of the initial configuration of the generating unit and the optimization of the later stage control strategy and the parallel operation performance are relatively few. J.A.Heyns put forward the empirical formula of water film heat transfer coefficient and air mass flow rate through experiments[2]. M.Fiorention analyzed the influence of regulating the mass flow rate of chilled water on the parallel operation characteristics of chiller by setting up the heat transfer model of evaporator condenser[3]. H.W.Liu studied the effect of changing the running condition of the compressor and evaporator on the performance of the condenser[4]. Shengrui Yu analyzed the energy efficiency ratio of centrifugal chillers under various influencing factors and variable operating conditions, and proposed the optimal operating conditions and the performance model formula for large chillers[5]. Zhenhui Wang discussed the constraints and influencing factors of energy saving analysis, and simulated the change law of dynamic cold load, and proposed the optimal allocation of chillers and the optimization of air conditioning system[6]. Jinshan Chen analyzed the rational allocation method of chillers through multiple angles of reserve and operation time between units[7].

In this paper, the energy efficiency ratio of all chillers in the chiller group was compared to obtain the best switching point for chiller unit start-up and shut-down by constructing a chiller group operation model. On this basis, the influence of frequent start and stop on the optimization process of control strategy was analyzed, and the influence of capacity allocation and number allocation on energy consumption in parallel operation was studied. In the result, reasonable arrangement of unit group was obtained.

2. Physical Model Construction

2.1 chiller group parallel characteristic model

When multiple chillers with different cooling capacity are connected in parallel, the function relationship for calculating the resistance of a chiller is as follows[8]:

$$\Delta p = \Delta p(Z, L_O, D_i, v_o, n_o, G_O) \tag{1}$$

Among, L_o is the effective heat transfer tube length of evaporator, Di is the inner diameter of tube, Z is a frozen water flow process, n_o is the number of pipes, v_o is the flow rate of frozen water, ΔP is the total resistance of frozen water passing through the evaporator, G_o is Flow of evaporator.When the Di，Z，n_o，L_o is known. The distribution of frozen water flow can be obtained.

2.2 Thermal characteristics model of cold water chiller

According to the literature [8], when the evaporating temperature is used as the design value, the function relationship for calculating evaporation temperature to is as follows [9]:

$$t_o = t_o(Q_O, G_O, t_{ch\_en}, t_{ch\_ex}) \tag{2}$$

Among, Q_O is the side heat transfer coefficient of evaporator refrigerant, t_{ch_ex} is the Chilled water outlet temperature ,t_{ch_en} is the Chilled water inlet temperature .According to the literature [9], the heat transfer characteristics of shell and tube condenser can be expressed by the following function relationship.

$$t_k = t_k(Q_k, G_k, t_{cool\_en}, t_{cool\_ex}) \tag{3}$$

Among, Qk is the side heat transfer coefficient of condenser refrigerant,Gk is Flow of condenser,t_{cool_ex} is the cooling water outlet temperature ,t_{cool_en} is the cooling water inlet temperature .

The operating characteristics of chillers are determined by the working characteristics of evaporators, condensers and compressors. Compressor shaft power P can be obtained through enthalpy difference between compressor inlet and outlet. According to the conservation of refrigeration cycle and energy, it can be obtained:

$$Q_k = Q_o + P \tag{4}$$

By calculating the evaporating temperature, condensing temperature and compressor outlet pressure, the energy efficiency ratio and shaft power of chillers under different load rates can be obtained.

3. Analysis of relationship between operating characteristics and load rate of chillers

3.1 Influence of frequent start-up and shutdown on optimization of control strategy for generating units

Taking an office building in Guangzhou as the research object, the configuration of the unit is shown as shown in the left of Table 1. All parallel modes of each unit group are got by permutation and combination, as shown in the right of Table 1.

Table 1 Unit group calculation parameters and all parallel modes

Project	Parameter			Parallel mode	Unit
Unit group1	Unit 1	Unit 2	Unit 3	Unit group1	
Capacity（RT）	400	700	700	Parallel mode1	Unit 1
Cooling water flow (kg/s)	119	200	200	Parallel mode2	Unit 2
Rated power consumption（kW）	406	698	698	Parallel mode3	Unit 1，Unit 2
				Parallel mode4	Unit 2，Unit 3
Unit group2	Unit 1	Unit 2	Unit 3	Parallel mode5	Unit 1，Unit 2，Unit 3
Capacity（RT）	500	600	700		
Cooling water flow (kg/s)	119	159	200	Unit group2	
Rated power consumption（kW）	406	535	698	Parallel mode1	Unit 1
				Parallel mode2	Unit 2
Operating conditions				Parallel mode3	Unit 3
Cooling water inlet temperature（℃）	32	32	32	Parallel mode4	Unit 1，Unit 2
Cooling water outlet temperature（℃）	7	7	7	Parallel mode5	Unit 1，Unit 3
Chilled water temperature difference（℃）	5	5	5	Parallel mode6	Unit 2，Unit 3
				Parallel mode7	Unit 1，Unit 2，Unit 3

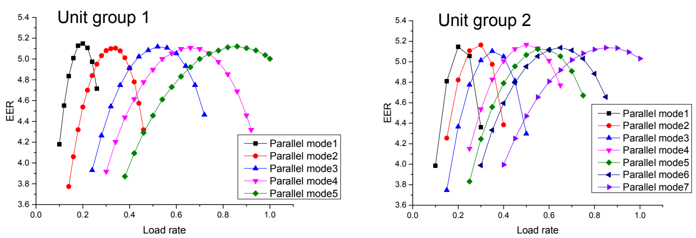

Fig. 1 EER- total load rate curve

Through parallel characteristic model calculation of cold water chiller group, EER- total load rate curve under different parallel modes can be made, as shown in Fig.1. Through the highest EER load range in Fig.1, the best switching point of parallel mode can be known, as shown in Table 2:

Table 2 The best switching point of parallel mode

Load rate	Parallel mode	Load rate	Parallel mode
Unit group1		Unit group2	
15%~25%	Parallel mode1	15%~25%	Parallel mode1
25%~40%	Parallel mode2	25%~33%	Parallel mode2
40%~60%	Parallel mode3	33%~43%	Parallel mode3
60%~74%	Parallel mode4	43%~55%	Parallel mode4
74%~100%	Parallel mode5	55%~60%	Parallel mode5
		60%~73%	Parallel mode6
		73%~100%	Parallel mode7

3.2 The influence of the difference of unit capacity matching on the performance of unit parallel operation

Taking the unit group which the total cooling amount is 2400RT and the number of units is 4 units as the research object, unit capacity collocation is shown as shown in Table 3.

Table 3 Unit group capacity matching scheme (4 units)

Scheme	capacity matching（RT）	Unit capacity standard deviation(RT)
Scheme1	600×4	0
Scheme2	900+500×3	200
Scheme3	800×2+400×2	230.940

Based on overall load changes between the two different parallel EER- total load curves, it should avoid the principle of frequent start and stop in pursuit of high energy efficiency ratio to eliminate of parallel mode(the number of units below 5 sets follows this principle). The optimal energy efficiency ratio curve of the three schemes is shown in Fig. 2, and convert it can be converted to the power curve as shown in Fig. 3.

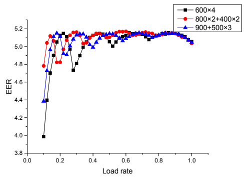

Fig. 2 optimal EER curve (4 units)

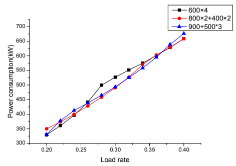

Fig. 3 power consumption curve (4 units)

The analysis of the amplitude of the curve in Fig.2 is shown in Table 4.

Table 4 amplitude of the optimal energy efficiency ratio curve (4 units)

Scheme	Unit capacity standard deviation(RT)	Optimal EER standard deviation	Optimal EER average value
Scheme1	0	0.214	5.034
Scheme2	200	0.132	5.075
Scheme3	230.940	0.088	5.099

It is known from table 4 that When the number of units is 4 units, the standard deviation of the unit capacity is bigger, and the optimal energy efficiency standard deviation is smaller, and the parallel operation performance of the unit is better. It is known from table 5 that relative to A collocation scheme with the lowest difference degree, the difference in energy consumption of the highest degree of matching scheme can reach 8% when the load rate is 28%.

When selecting 5 units, taking the unit with total cooling capacity of 2400RT, 2700RT and 3000RT as the research object, the capacity allocation scheme for the three generating units is presented in Table 5:

Table 5 Unit group capacity matching scheme (5 units)

Scheme	capacity matching（RT）	Unit capacity standard deviation(RT)	Scheme	capacity matching（RT）	Unit capacity standard deviation(RT)	Scheme	capacity matching（RT）	Unit capacity standard deviation(RT)
2400RT			2700RT			3000RT		
Scheme1	400+500×4	44.721	Scheme1	600×2+500×3	54.772	Scheme1	600×5	0
Scheme2	600×3+300×2	164.316	Scheme2	700+500×4	89.442	Scheme2	700×2+800+400×2	167.332
Scheme3	800+400×4	178.885	Scheme3	600×4+300	134.164	Scheme3	1000+500×4	258.198

The optimal energy efficiency curves of the three unit groups are shown in Fig.4.

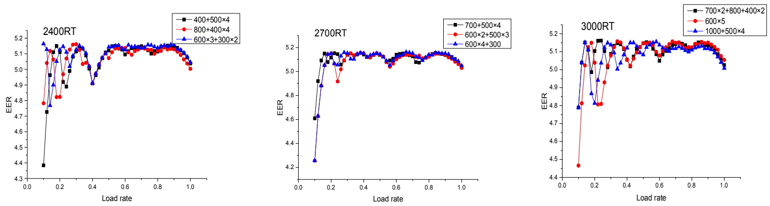

Fig. 4 optimal EER curve (5 units)

The analysis of curve fluctuation in fig.4 is shown in Table 6:

Table 6 amplitude of the optimal energy efficiency ratio curve (5 units)

Scheme	Unit capacity standard deviation(RT)	Optimal EER standard deviation	Scheme	Unit capacity standard deviation(RT)	Optimal EER standard deviation	Scheme	Unit capacity standard deviation(RT)	Optimal EER standard deviation
2400RT			2700RT			3000RT		
Scheme1	44.721	0.0559	Scheme1	54.772	0.0323	Scheme1	0	0.0342
Scheme2	164.316	0.0562	Scheme2	89.442	0.0287	Scheme2	167.332	0.0366
Scheme3	178.885	0.0547	Scheme3	134.164	0.0290	Scheme3	258.198	0.0368

It is known from table 6 that When there are 5 units, the relationship between standard deviation of unit capacity and optimal energy efficiency ratio is not obvious. When there are 5 units, take 2400RT unit group plan two (600×3+300×2) as an example.it can obtain 11 kinds of parallel modes. If all parallel methods are used, frequent start and stop phenomenon is serious. The difference between the optimal energy efficiency ratio curves is less than 1.4%, as shown in Figure 11. In the same way, the above conclusions are also applicable for a group of more than 5 units.

3.3 Influence of unit number matching on performance of unit parallel operation

Taking the unit group with total cooling capacity of 2400RT, 3000RT and 3600RT as the research object. The parallel schemes of different number of stations are respectively formulated as shown in Table 7:

Table 7 Unit group collocation scheme (different number of units)

Scheme	capacity matching（RT）	Scheme	capacity matching（RT）	Scheme	capacity matching（RT）
2400RT		3000RT		3600RT	
Scheme1	800×3	Scheme1	1000×3	Scheme1	1200×3
Scheme2	600×4	Scheme2	900×4	Scheme2	900×4
Scheme3	400×6	Scheme3	600×5	Scheme3	600×6

The optimal power consumption curves of the three generating units are shown in Fig.5.

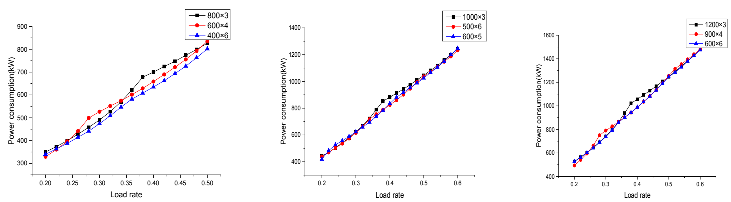

Fig. 5 optimal EER curve of 2400RT

It is known from figures 13, 14, and 15 that relative to the least number of collocation schemes, the energy consumption difference of the largest number of collocation schemes can reach 11% when the load rate is 38% for the 2400RT unit group. When the load rate of 2700RT unit is 38%, the difference of energy consumption can reach 9%. When the load rate of 3600RT unit is 38%, the difference of energy consumption can reach 8%.

4. Conclusion and Prospect

- When the number of unit units is less than 5, the greater the degree of difference in the host capacity in the group, the lower the energy consumption under full load. the difference of energy consumption can reach 8%. When the number of units of the unit is greater than or equal to 5, the difference of unit capacity matching is not obvious for the overall parallel operation performance of generating units.
- In the process of optimizing the control strategy of chillers through the EER- load rate curve diagram, it is more prone to frequent start and stop of the unit, its alternative parallel methods and overall performance in actual operation can't compare with unit group which the collocation of capacity is looser
- The more the number of units, the better the overall performance of the unit. The maximum energy consumption difference can reach 11%. It is suggested that the number of generating units should be set up more frequently when the site is permitted.

This article only analyzed the configuration of the chiller. The influence of the water pump configuration on the operating characteristics of the main engine is not considered, and the relationship between the climate and environment difference in different regions and the selection and collocation of the chiller unit and the operation management are also not analyzed. In the next research work, we hope to solve these problems and improve them.

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