Exploration on Energy-saving Control Strategy for Data Center Refrigeration Stations Based on PID Control Algorithm

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Abstract: With the advent of the digital era, data centers play a crucial role in supporting the information needs and cloud computing applications of various industries. The high power requirements and high levels of emissions of data centers have become a serious problem. This article aimed to explore energy-saving control strategies for data center refrigeration stations based on PID (Process Identification) control algorithm. This paper analyzed data centre chiller station energy saving based PID controller algorithm control strategies to reduce data centre energy consumption. By combining the PID control algorithm with the data center refrigeration system, dynamic monitoring and adjustment of the parameters of the refrigeration station can be achieved, making it more adaptable to real-time environmental changes and fluctuations in load demand. This helps to improve energy efficiency and reduce energy waste and carbon emissions, while ensuring the stable operation of the data center. To investigate the impact of PID control algorithm on energy-saving control of data center refrigeration stations, simulation experiments based on PID control algorithm and traditional control methods were conducted under different operating conditions. It was found that PID control algorithms can effectively control the cooling stations in data centers and reduce the power consumed by the cooling stations. When the usage time reached 1000h, the energy consumption of the data center refrigeration station was reduced by 0.42*10^7J under the PID control algorithm. The PID control algorithm can ensure the temperature stability of the data center refrigeration station. By optimizing the energy utilization efficiency of the refrigeration station, the sustainable development of the data center can be achieved, and the transformation of the Low-carbon economy can be promoted.

Keyword: Energy Saving Controls For Refrigeration Stations, Data Centre, Process Identification Control Algorithms, Cooling Water Pump, Energy Consumption

1. Introduction

Refrigeration stations are one of the most significant sources of power consumed by data centers. During the operation of the data center, a large amount of heat is

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generated, which needs to be dissipated through a refrigeration station to maintain the normal operating temperature range of servers and other equipment. Traditional data center refrigeration stations generally suffer from energy waste and low efficiency. Refrigeration stations usually operate with fixed parameters and are not adapted to real-time environmental changes and fluctuations in load demand, resulting in resource waste and increased energy consumption. There is a need to investigate energy saving control strategies for data centre cooling stations.

Refrigeration is one of the core aspects of a data center, as the work of the equipment inside the data center requires a lot of power and generates a lot of heat. An appropriate refrigeration station can ensure the normal operation of the equipment and provide a stable temperature environment. Chunxia Yin proposed an effort-saving policy based on multiple-server leave of absence ranking theory, whereby the open and sleep of servers are switched within a group. The research findings are useful for examining the weight of cloud computing data centres in terms of their power consumption capability [1]. Huiwen Cheng focused on analyzing and exploring energy-saving technologies for information equipment and cooling systems, and elaborated on a new energy consumption optimization scheme for connecting computing systems and cooling systems [2]. Feihu Chen proposed a simplified statistical summation algorithm that focuses on energy conservation and consumption in data centers, and found that it can save approximately 34% of energy and cooling [3]. Sameh A. Nada investigated the impact of the number and arrangement of switching units on the heating and power handling of cooling architectures within data centers, and identified hot air circulation problems and poor performance indicators for hot spots [4]. The above research has achieved good results, but no new technologies have been introduced.

To address the increasing power consumed and carbon emissions of data centers, researchers proposed a number of improvements to the control of energy consumption in cooling stations. Haoqian Wang proposed a PID method and further proposed a PID-based extraction method to optimize the system using past, present and gradient changes to update the network parameters [5]. Enrique Z. Losoya designed and implemented a planned gain PID controller in a microcontroller to accurately adjust the weights on the bits and avoid interference. This algorithm used real-time instrument data to achieve automatic step testing and dynamically optimize drilling parameters [6]. PID control algorithm is a commonly used and classic feedback control method. It achieves stability and accuracy of the refrigeration station by adaptively adjusting the output signal.

This article applied an energy-saving control strategy for data center refrigeration stations based on PID control algorithm, which combined the dynamic characteristics of data center operation and optimized and adjusted the working status of the refrigeration station based on real-time ambient factors like humidity and warmth. Specifically, the PID control algorithm was used to adaptively adjust parameters such as fan speed, compressor operating frequency, and supply cold water temperature of the refrigeration station, in order to minimize energy consumption.

2. Energy Saving Control of Data Center Refrigeration Station

2.1 Working Process of Data Center Refrigeration Station

The data center refrigeration station consists of two main components: a cooling source unit and a terminal unit, where the cooling source unit is responsible for providing cooling load to the terminal unit [7]. In the cooling source circuit, the warm circulating water is cooled by the cold coolant from the cooler and exchanged for heat with the hot circulating air in the terminal equipment computer room. Low temperature air supply is sent by a fan to the floor vent of the central computer room to absorb the heat dissipated by the equipment. In the cooling water circuit, the cryogenic return water cools the refrigerant at high ambient levels in the chiller. The discharge of high thermal water through the cooling tower provides the cooling function of circulating heat to the outdoor air and providing central air conditioning. The water pump is responsible for providing circulation capacity, and the opening of the water valve and bypass valve is responsible for regulating the flow rate of the circulating liquid, as shown in Figure 1.

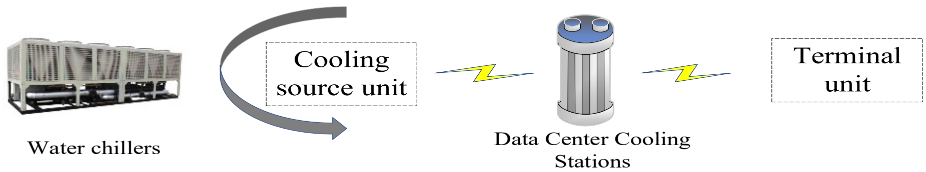

Fig.1 Working process of data center refrigeration station

The data center cooling station achieves natural cooling by integrating plate heat exchangers in the cooling station [8]. Mechanical cooling can be continuously reduced or even stopped by using cold cooling water to pre-cool some or all of the returning hot cooling water in the cooling water circuit. Therefore, the data center has strict climate requirements for natural cooling through plate heat exchangers, and according to the starting conditions of plate heat exchangers, the cooling station can be divided into three operating states [9-10]. Table 1 provides information on the equipment start stop and cooling modes for each operating state.

Table 1. Information on Start stop and Cooling Modes of Equipment in Different Operating States

Operation status	Plate heat exchangers	Heat exchange method
Summer	Shut down	Separate cooling of the chiller
Transition period	Open	Plate heat exchanger pre-cooling, chiller down to set temperature
Winter	Shut down	Separate cooling of plate heat exchangers

In summer, the climate is hot, so turn off the plate heat exchanger and cool the radiator separately. During the transitional period, the climate may partially meet the natural cooling requirements, so the plate heat exchanger is preheated and the radiator compensates for cooling power to reach the set value. In winter, the climate fully meets the natural cooling requirements, so turn off the plate radiator.

2.2 Refrigeration Station Equipment

The main operating equipment of the refrigeration station includes cooling composite machines, cooling towers, cooling water pumps, and chilled water pumps [11]. The cooling load provided by the chiller can be calculated using Formula (1):

$$Q_{ch} = c \cdot m_{chw} \cdot (T_{chwr} - T_{chws}) \quad (1)$$

Among them, Q_{ch} represents the cooling load, in kW; C is the Specific heat capacity of water, in J/(kg-K); m_{chw} represents the cooling water flow rate, in kg/s; T_{chws} represents the inlet temperature of the cooling water, in ℃; T_{chwr} represents the return temperature of the cooling water, in ℃.

Energy efficiency can be effectively measured by the concept of operating efficiency ratio of chiller, which is defined as the ratio of cooling load provided by chiller to operating power of chiller, and can be expressed by Formula (2):

$$COP = Q_{ch}/P_{ch} \quad (2)$$

Among them, P_{ch} is the total operating power of the cold air fan, in kW; Q_{ch} is the cooling load provided by the cooling fan, in kW.

In data center cooling, high-temperature refrigerant is provided in the low-temperature cooler [12-13]. The returned high temperature cooling water is then sent to the column by the cooling water pump for heat exchange with the air in the form of a spray to achieve cooling. Therefore, the major pieces of the energy using devices of the cooling tower are the cooling tower fan, whose operating power can be represented by Formula (3):

$$P_{tower} = (f_t|f_0)^3 \cdot P_{tower,rated} \quad (3)$$

Among them, P_{tower} is the operating power of the cooling tower fan, and $P_{tower,rated}$ is the rated fan power; f_t is the operating frequency of the fan, and f_0 is the rated fan frequency, usually 50 Hz.

In cooling stations, the transfer of hot water between the refrigerant at low operating temperatures in the cooling water circuit and the refrigerant at high temperatures, as well as the transfer of hot water between the cooling water circuit and the return air at high operating temperatures in the final cooling station, should be carried out by pumps. This makes the pump one of the important equipment for coordinating the overall operation of the cooling station. The operating power of the pump can be calculated, as shown in Formula (4):

$$P_{pump} = \frac{\rho \cdot g \cdot V \cdot H}{3.6\times10^{6} \cdot \eta_p \cdot \eta_m \cdot \eta_{VFD}} \quad (4)$$

Among them, P_{pump} is the operating power of the pump; ρ and V are the fluid density and volumetric flow rate, respectively; g is Gravitational acceleration, H is height; η_p, η_m, and η_{VFD} are the efficiency of pumps, motors, and frequency converters.

2.3 Application of PID Control Algorithm Parameter Optimization

The temperature control of data center cooling stations is nonlinear, has high inertia, and is complex in terms of time changes [14]. Therefore, it is necessary to find powerful and sensitive control methods to achieve rapid and stable control of room temperature. The PID control algorithm combines the advantages of robustness and fast response of the PID algorithm and relies on no exact numerical pattern of the subject matter to be managed . In recent years, PID control has been increasingly applied in the control of refrigeration stations, meeting the requirements for precision and fast stability in power control of refrigeration stations [15].

The temperature of the data centre power supply has a direct impact on the cooling energy consumption of the data centre, so keeping the temperature of the data centre nodes stable plays a key role in setting a reasonable power supply temperature and reducing the energy consumed by the data centre. This article analyzed the impact of PID control algorithm on data center temperature, with a focus on reducing cooling energy consumption. The algorithm used advanced control model prediction algorithms to allocate power consumption between nodes. Then, the temperature of each node was estimated based on a time-domain model of the working temperature, and a temperature feedback control algorithm was used to control the frequency of each node in real-time to accurately monitor the reference temperature. If temperature anomalies occur during task execution, leading to the appearance of hotspots, scheduling algorithms can be used to dynamically adjust node frequencies to minimize cooling energy consumption in refrigeration stations, while achieving lower temperatures with minimal impact on transmission rates.

3. Impact of PID Control Algorithm on Energy-saving Control of Data Center Refrigeration Stations

Data centers are a core component of modern IT infrastructure. The data center is a core component of modern information technology infrastructure. Refrigeration stations play a crucial role in data centers, ensuring that servers operate within the appropriate temperature range. Traditional normally open or constant temperature control methods have the problem of high energy consumption in practical applications. The aim of this paper is to investigate a PID control algorithm based cooling station power efficiency control strategy to improve the energy efficiency performance of data centre cooling stations. To investigate the impact of PID control algorithm on energy-saving control of data center refrigeration stations, simulation experiments based on PID control algorithm and traditional control methods were conducted under different operating conditions. The energy consumption, temperature stability and other indicators under various experimental conditions were recorded, compared and analyzed.

3.1 Energy Consumption Testing of Data Center Refrigeration Stations

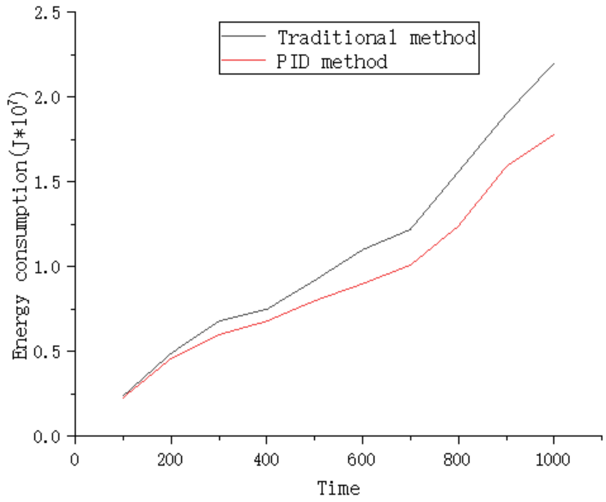

Fig.2 Energy consumption test of data center refrigeration station

The energy consumption of the data centre cooling station power saving controlled by the traditional method and the energy consumption of the data centre cooling station power saving control based on the PID control algorithm were tested and recorded. By making comparisons, the differences were observed. The specific results are shown in Figure 2. The horizontal axis is time, in h; the vertical axis represents energy consumption.

From Figure 2, it can be seen that the energy consumption of energy-saving control in data center refrigeration stations under traditional methods was higher than that of energy-saving control in data center refrigeration stations based on PID control algorithm. The difference in energy consumption between the two methods at the beginning of testing was not significant, and as time increased, the difference in energy consumption also increased. The PID control algorithm can effectively energy-saving control the refrigeration station in the data center, reducing the energy consumption of the refrigeration station. When the usage time reached 1000h, the energy consumption of the data center refrigeration station was reduced by 0.42 $*10^7$J under the PID control algorithm.

3.2 Temperature Stability Test of Data Center Refrigeration Station

The energy consumption of data center cooling stations controlled by conventional methods and the energy consumption of data center cooling stations controlled by PID-based control algorithms were tested and recorded. The experimental results were recorded and analyzed. The specific results are shown in Figure 3.

From Figure 3, it can be seen that the temperature of energy-saving control for data center refrigeration stations based on PID control algorithm was more stable, ranging from 24.9 ℃ to 26.4 ℃, while the temperature of energy-saving control for data center refrigeration stations using traditional methods was between 23 ℃ and 27 ℃. It can be seen that the PID control algorithm can ensure the temperature stability of the data center refrigeration station.

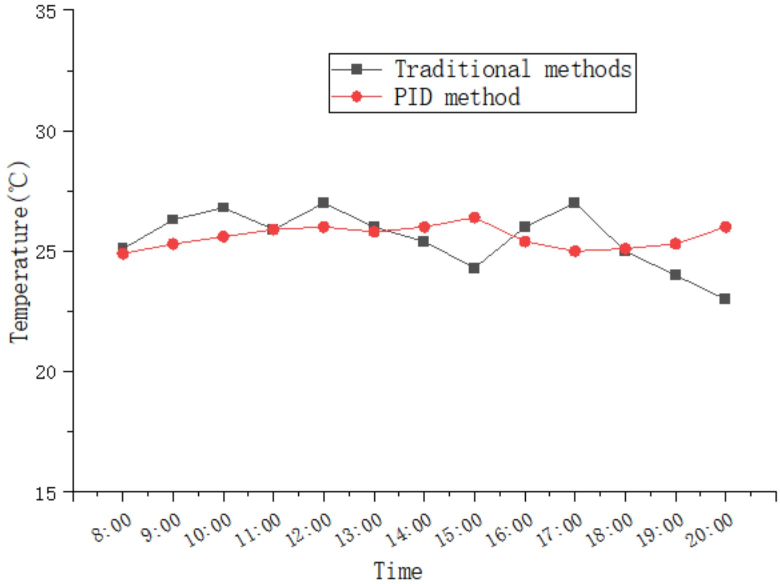

Fig.3 Temperature stability test of data center refrigeration station

4. Conclusion

In the information age, data center has become a key piece of equipment for hosting and processing large-scale data. However, the high power requirements and high carbon footprint of centre have become a global environmental and sustainability challenge. This article thoroughly studied the working principle and existing problems of data center refrigeration stations through literature review and theoretical analysis. On this basis, an energy-saving control strategy based on PID control algorithm was proposed and applied to data center refrigeration stations. The experimental results showed that the energy-saving control strategy based on PID control algorithm performs well in the data center refrigeration system. Compared with traditional fixed parameter refrigeration systems, using PID control algorithm can significantly reduce energy consumption.

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