Variable Frequency Control System for Central Air Conditioning Refrigeration System Based on PLC Technology

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Abstract: With the increasingly severe global energy crisis and environmental issues, the air conditioning industry has become more demanding in controlling electricity consumption. However, existing central air conditioning (CAC) systems generally suffer from high energy consumption. The frequency converter control system, as an advanced electrical equipment control technology, has been widely used in various types of equipment to achieve real-time automation control. However, the current frequency conversion control system still has shortcomings in accurately controlling energy consumption in various frequency bands, resulting in prominent energy waste caused by factors such as resistive loads. This article proposes a variable frequency control system for CAC refrigeration system based on programmable logic controller (PLC) technology to address the above issues. This system explores the software and hardware design as well as parameter optimization from two core perspectives: PLC program design and frequency converter control. Through careful system debugging, we have successfully achieved the green and energy-saving function of the system. This system can accurately control the energy consumption of each frequency band, effectively reducing energy waste caused by factors such as resistance load, thereby significantly improving the energy efficiency ratio of the CAC system.

1. Introduction

With the rapid development of the social economy and the significant improvement of people's living standards, people's demand for comfort in their daily living environment is increasing, and the application of air conditioning systems in modern buildings is becoming more and more widespread [1]. Whether it is a large shopping mall, office building, or high-end residential area, CAC system has become an indispensable infrastructure [2]. However, despite the excellent comfort performance of CAC systems, their operational efficiency is generally low, especially under partial load operating conditions, where energy waste is particularly prominent [3]. At present,most key energy consuming equipment such as water pumps and fans in CAC systems still use traditional power frequency operation, which cannot be dynamically adjusted in real time according to changes in environmental loads [4]. According to statistics, the actual load of CAC system is much lower than half of the design load during about 75% of the operating time, which not only leads to low energy utilization efficiency, but also increases the operating cost of the system.

In addition, traditional control methods are difficult to meet the dual demands of energy conservation and comfort in modern buildings, and there is an urgent need for a more intelligent and efficient control scheme [5]. In recent years, frequency conversion control technology has gradually become an important direction for energy-saving renovation of CAC systems due to its ability to dynamically adjust cooling capacity and air supply volume according to actual load requirements [6]. Frequency conversion technology achieves precise control of equipment such as water pumps and fans by adjusting the motor speed, significantly reducing energy consumption and improving system operating efficiency [7]. However, despite the significant energy-saving advantages of frequency conversion technology in theory, it still faces many challenges in practical applications. For example, frequency converters mainly undertake functions such as filtering,

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inversion, driving, and braking in electrical systems. These energy consuming units are prone to problems such as overcurrent, overvoltage, and overload during operation, resulting in high energy consumption risks for the frequency converter itself [8]. In addition, frequency converters also have certain limitations in control accuracy and dynamic response, making it difficult to fully meet the complex and ever-changing practical needs.

In order to overcome the above problems, PLC technology has been introduced into the field of variable frequency control. PLC technology, with its powerful data acquisition, processing, and analysis capabilities, can achieve real-time monitoring and precise control of electrical systems. By combining PLC technology with frequency converters, the shortcomings of frequency converters in energy consumption control can be effectively compensated for, thereby further improving the overall performance of the system. Specifically, PLC technology can dynamically adjust the working parameters of the frequency converter according to changes in environmental loads, ensuring that the system always operates in the optimal state. In addition, PLC technology also has strong logical analysis and environmental perception capabilities, which can monitor and diagnose equipment operation status in real time, thereby greatly improving the reliability and automation level of the system. Based on the above background, this article proposes a variable frequency control system for CAC refrigeration system based on PLC technology. This system explores the software and hardware design as well as parameter optimization from two core perspectives: PLC program design and frequency converter control.

2. CAC System Structure and Frequency Conversion Principle

2.1. CAC System Structure

With the continuous improvement of people's living standards, the application of CAC systems in modern buildings is becoming increasingly widespread, becoming an important device for improving indoor environmental comfort [9]. The CAC system mainly consists of an air conditioning unit, a water circulation system, an air conditioning fan, a cooling tower, and corresponding control systems. The various components work together to achieve efficient refrigeration functions [10]. Taking the air conditioning refrigeration process as an example, its working principle is shown in Figure 1. The core of the CAC system is the water circulation system, including the cooling water system and the chilled water system. The cooling water system consists of cooling pumps, cooling water pipelines, cooling towers, and condensers. Its main function is to dissipate the heat generated during the refrigeration process to the external environment. The chilled water circulation system is responsible for heat exchange with indoor air, absorbing indoor heat and transferring it to the cooling water system.

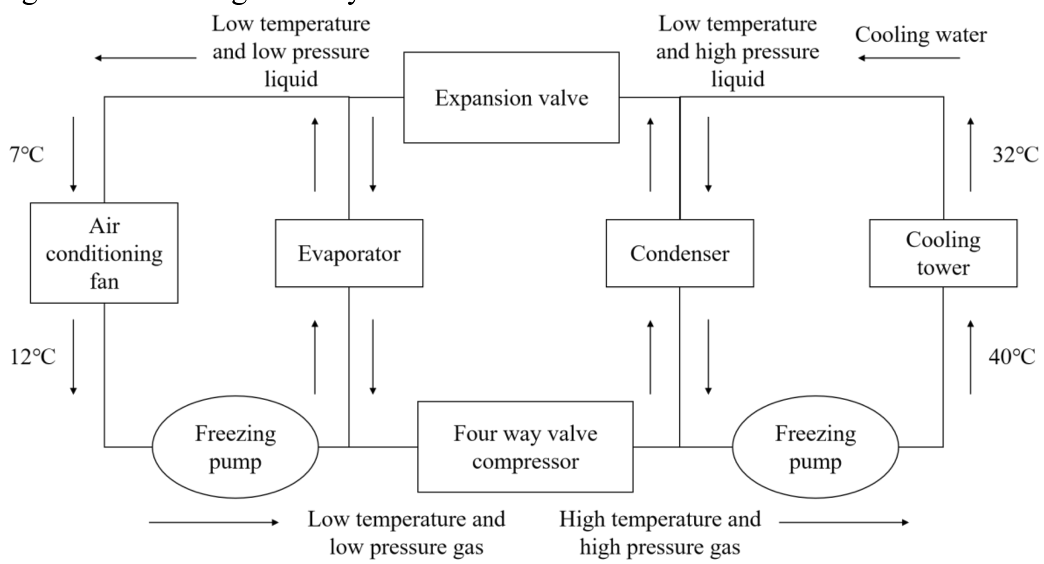

Fig.1 CAC refrigeration principle

During the refrigeration process, chilled water undergoes heat exchange with indoor air in the terminal air treatment equipment, absorbing heat and causing the temperature to rise, forming high-temperature return water. These high-temperature return water exchange heat with low-temperature refrigerant through the evaporator inside the air conditioning unit, thereby reducing the temperature and becoming low-temperature chilled water again, continuing to participate in the cycle. At the same time, the high-temperature refrigerant in the refrigeration unit exchanges heat with the low-temperature return water in the cooling water circulation system through the condenser, causing the temperature of the cooling water to rise. The heated cooling water is transported by the cooling pump to the cooling tower, where it exchanges heat with the atmosphere, lowers the temperature, and then returns to the main condenser to complete the cooling water circulation process. During this process, water serves as the heat transfer medium, responsible for absorbing and discharging heat in both the chilled water cycle and the cooling water cycle, thereby achieving continuous cooling of the CAC system.

2.2. Frequency Conversion Principle

In order to achieve variable flow operation of the water pump, the method of adjusting pipeline valves is usually adopted, and the throttle effect is used to adjust the amount of water flow. Although this method shows certain advantages compared to long-term constant speed operation, unfortunately, it did not significantly reduce the overall energy consumption of the system, but instead resulted in energy loss in the resistance of the regulating valve. In contrast, using a frequency converter to modify the operation of the water pump not only effectively avoids the electrical energy loss caused by valve regulation, but also improves the accuracy and stability of system control to a certain extent. For a closed chilled water circulation system, given that the head of the circulating water pump is not directly related to the static pressure, there is a specific relationship between the pump and the pipeline characteristic curve, which makes the system applicable to the application of similarity theorem. Before and after the frequency conversion transformation, the relationship between flow rate Q, head H, power P, and speed n satisfies formula (1):

$$\frac{Q_1}{Q_2} = \frac{n_2}{n_2}, \frac{H_1}{H_2} = \left(\frac{n_1}{n_1}\right)^2, \frac{P_1}{P_2} = \left(\frac{n_1}{n_1}\right)^3 \tag{1}$$

In this formula, Q_1, Q_2 represents the flow values of the water pump before and after frequency conversion; H_1, H_2 respectively represents the head of the water pump before and after frequency conversion; P_1, P_2 corresponds to the power of the water pump before and after frequency conversion; And n_1, n_2 respectively indicate the speed of the water pump before and after frequency conversion.

In the scenario where the cooling water circulation is an open system, due to the pipeline being connected to the atmosphere through the cooling tower, the system requires additional energy consumption to overcome the static water pressure of the cooling tower. This characteristic makes it impossible to directly apply the similarity theorem to the power calculation of the cooling water pump before and after frequency conversion. However, in terms of the CAC system studied in this article, the head generated by the height of the cooling tower is much smaller than the head H of the water pump at rated flow rate. Therefore, during the frequency conversion process of the water pump, its efficiency change is relatively small and can be ignored. Meanwhile, the proportion of cooling water loss in circulating water is also very small and can be ignored. Based on these conditions, the operating state of the chilled water pump approximately satisfies the similarity theorem. From the analysis of equation (1), we can see that there is a cubic proportional relationship between power and speed, which means that by adjusting the operating speed of the water pump, we can effectively reduce its operating power. In addition, the relationship between frequency and speed satisfies the following equation:

$$n = \frac{60f(1-s)}{p} \tag{2}$$

In the formula, n represents the speed of the water pump; f represents the operating frequency of the water pump; s stands for slip rate; p represents the number of magnetic pole pairs.

3. PLC Programming and Frequency Converter Control

3.1. PLC Program Design

PLC is a digital electronic device designed specifically for industrial automation control. Its core function is to store instructions through programmable memory and use the built-in CPU to perform logical operations, sequential control, timing, counting, and arithmetic operations, thereby achieving precise control of machines or production processes. The working process of PLC is usually divided into three stages: input sampling, user program execution, and output refresh. These three stages constitute a complete scanning cycle, and the CPU of the PLC will continuously repeat this process at a fixed scanning speed to ensure the real-time and stability of the system. Figure 2 shows the basic structural diagram of PLC. In the control of CAC system, the control mode of PLC is mainly divided into automatic control and manual control. In automatic control mode, PLC is responsible for starting various devices in the system and performing frequency conversion control on key equipment such as water pumps. By real-time monitoring of the difference between the controlled temperature and the actual temperature, PLC can use PID (proportional integral derivative) adjustment algorithm to dynamically adjust the operating status of the equipment, thereby achieving precise temperature control and energy-saving optimization.

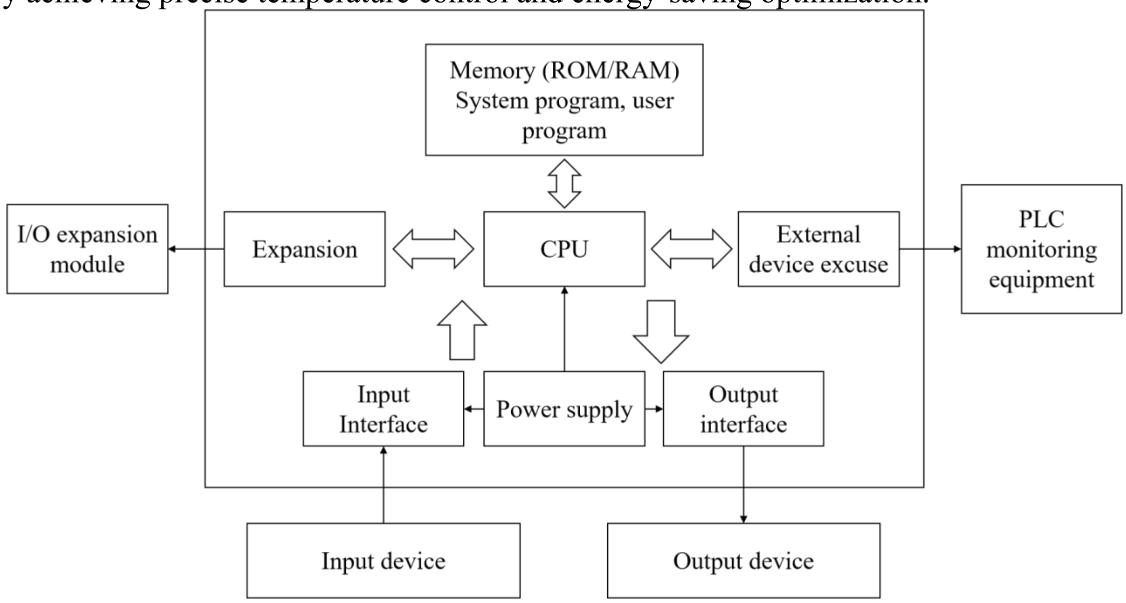

Fig.2 Basic structure of PLC

The manual control mode allows operators to directly intervene in system operation through the touch screen interface, which is suitable for special situations or system debugging stages. The PLC frequency conversion energy-saving control program of CAC water circulation system consists of multiple functional modules, including PLC main control program, touch screen operation subroutine, frequency converter subroutine, communication subroutine, and temperature sensing subroutine. Among them, the PLC main control program is the core of the entire system, responsible for coordinating the operation of various subroutines and ensuring efficient cooperation among various modules of the system. The touch screen operation subroutine provides users with a user-friendly interface, mainly including the main screen, system settings, PID parameter settings, operation mode selection, temperature display, fault alarm, and reset function interfaces. Especially the operation and monitoring screens of the chilled water pump and cooling water pump can display the real-time operating status and key parameters of the equipment, making it easy for operators to monitor and adjust.

3.2. Variable Frequency Drive Control

During the operation of the frequency converter, the input power is inverted through transistors or inverter modules to achieve precise control of the motor speed. However, this process will generate high-order harmonics in the input and output circuits. If the harmonic content exceeds the standard limit, it will not only cause interference to the power supply system, but may also affect the normal operation of load equipment and adjacent electrical equipment, leading to system operating conditions fluctuations and even shortening the service life of equipment. Therefore, effective anti harmonic interference measures must be taken when designing energy-saving control systems for PLC frequency converters to ensure the stability and reliability of the system.

Common anti-interference methods include filtering and electrical isolation. Filtering technology suppresses the propagation of harmonics by installing filters, while electrical isolation uses isolation transformers or optocouplers to block the transmission path of harmonics, thereby reducing interference to the system and other equipment. In the CAC system, the control of the water pump usually adopts two methods: segmented speed variable frequency control and PID variable frequency control. Segmented speed variable frequency control automatically switches the operating speed of the water pump based on changes in system load by pre-set multiple speed gears. This method not only has simple program design and high stability, but also effectively reduces motor losses caused by frequent speed changes during the regulation process of the water pump, thereby achieving energy-saving goals. PID variable frequency control utilizes real-time monitoring of system parameters such as temperature and pressure, and dynamically adjusts the pump speed using PID algorithm to more accurately match the load demand, further improving the energy efficiency performance of the system.

4. Conclusions

To achieve the ideal energy-saving control effect and perfectly balance the speed regulation performance and energy-saving effect of the frequency converter, designers need to use PLC technology reasonably to build a more complete energy-saving control system for the frequency converter. This article focuses on introducing a variable frequency control system for CAC refrigeration system based on PLC technology. The system revolves around two core points: PLC program design and frequency converter control, and deeply explores the software and hardware design as well as parameter optimization of the system. After meticulous system debugging, the green energy-saving function of the system has been successfully achieved. Specifically, the system can accurately control the energy consumption of each frequency band, effectively reducing energy waste caused by factors such as resistance load, and significantly improving the energy efficiency ratio of the CAC system. This frequency conversion control system based on PLC technology not only meets the practical needs of energy-saving control, but also further optimizes the operational performance of CAC, providing strong support for achieving the goal of high efficiency and energy conservation.

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