Application of PLC in Variable Frequency Constant Pressure Control System for Mine Emulsion Pump Station

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Abstract. Programmable logic controller (PLC) is an automatic control device made of microcomputer technology. It is based on sequential control, supplemented by loop adaptive, can complete logical judgment, timing, memory and numerical functions. The application of PLC in the variable frequency and constant pressure control system of mine emulsion pump station is studied. The emulsion pump station for mine is introduced. Based on the practice of energy saving, safety and protection equipment, the application of variable frequency speed regulation and constant pressure technology in emulsion pump is described. The working principle and PLC control system of emulsion pump control system are introduced by means of PLC circuit control. The experimental results show that the design of variable frequency and constant pressure control system based on PLC can greatly save energy consumption. In the variable frequency state, the average temperature of the pump body does not exceed 45°, indicating that the variable frequency constant voltage control system can improve the service life of the equipment.

Keywords: PLC, emulsion pump station, variable frequency constant pressure control

1. Introduction

At present, China is pushing forward the process of "automation" and "intelligentization" of coal mines. Mine emulsion pump provides reasonable and stable power for working face. It is of great significance and value to improve and optimize the performance of emulsion pump station control system for improving coal mining efficiency, reducing equipment loss, saving energy, reducing cost, and ensuring the safety of work surface. Therefore, the performance of emulsion pump station is very important, and it is necessary to study its control technology.

With the continuous development of computer technology, computer control technology has been well integrated into the field of industrial control and achieved good results [1]. Traditional hardware control technology is gradually replaced by software, which is a development trend [2]. The design and implementation of PLC based variable frequency and constant voltage control system for hydraulic pump station is widely used in industry due to its object-oriented programming idea and great advantages in interface processing [3].

With the continuous development of automation technology and the increasingly mature application of frequency conversion technology in various fields, a continuous pressure fluid flow
control system composed of computers, PLCs, and frequency converters has been developed. The automatic operation of the liquid volume of the control system, fast response, high efficiency, high stability, economy and energy saving have gradually replaced the traditional liquid transportation method and become an important part of the urban liquid supply [4].

Duan X proposed a novel realization of current mode frequency conversion control [5]. The system architecture has dual-loop feedback and a unique structure, with symmetrical signal paths for voltage and current signals [6]. The symmetrical structure provides practical advantages for the design of the integrated controller, so that the droop resistance can be accurately controlled [7-8]. But the complexity of the system is relatively high, resulting in inaccurate results [9].

The innovation of this paper is to realize the design of the software of the constant pressure control system. According to the system flow chart and logic diagram, the work flow of the PLC program is designed, and the PLC control program of the constant pressure liquid supply system is realized [10].

2. PLC Frequency Conversion Constant Pressure Control Method in Mine Emulsion Pump Station

2.1 Programmable Controller (PLC)

PLC is a digitally operated electronic device designed for industrial applications. Use programmable storage instruction memory to perform logic functions, sequence functions, timing, counting and digital functions, and control various types of machines or manufacturing processes through digital or proportional input and output. The design of its regional equipment must follow the principle of easy assembly, with the characteristics of an industrial control system and easy expansion. PLC has the following characteristics:

(1) High reliability

In most cases, the main prerequisite for users to choose control equipment is high reliability. In the contact relay system, due to factors such as equipment aging, electrical shock, vibration, and arcing, the reliability of the system is greatly reduced. In this system, a large number of transmission operations are completed by non-contact semiconductor circuits, and various interferences such as electromagnetic are comprehensively checked. A series of materials and software such as dust and temperature in the industrial production environment are used, and the anti-interference measures are very reliable.

(2) Strong adaptability

The product is a series of products with complete varieties and modular material structure, suitable for combination and expansion. Users can flexibly choose according to their needs to meet the inspection requirements of various system sizes and functions. The most important thing is that compared with the relay control system, the system has less wiring, and its main operation is achieved through programs. When the control function of the device needs to be changed, the workload of modifying the wiring is very small due to the modification of the program.

(3) Easy programming

PLC programming can use a proportional diagram language that is very similar to the relay circuit, intuitive and easy to understand, and is well received by field chemistry experts. In recent years, in order to make programming more convenient and simple, the object language of sequence diagrams is also called function diagram.

2.2 Emulsion Pump Station

With the rapid development of coal mine equipment and the support of some coal mines, emulsion pumping stations have also become an important part. Emulsion pumping station is the oil pressure support on the general mining surface of electrical equipment, providing comprehensive excavation or personal oil pressure support. During the working cycle of the support process, the hydraulic support must complete lifting, moving and sliding operations. The action of each hydraulic cylinder between and inside the supporting device must be continuous and intermittent. The load of each hydraulic
cylinder is also very uncertain. In this particular working mode, it is necessary to adjust the liquid flow output from the pump station to the hydraulic system to the characteristics of each system. During the intermittent period, the pump chamber needs to provide the working fluid consumed by the system leakage. The interruption time of the actual pump manufacturing process may be several minutes to several hours. At the same time, the emulsion pump station is always in a ready state to meet the fluid supply demand of the working face at any time, so the pressure is always maintained constant.

3. Design Experiment of Frequency Conversion and Constant Pressure System of Hydraulic Pump Station

3.1 System Composition of Hydraulic Pump Station

Emulsion pump station is composed of hydraulic pump, drive engine and fuel tank liquid supply system equipment. Its action principle is the motor drive oil pump rotation, the emulsion from the hydraulic pump to the hydraulic pump delivery, pressure is adjusted by the hydraulic valve through a number of valve combination.

The programmable logic controller (PLC) and frequency conversion technology are applied to the control system of emulsion pump station, which can realize adaptive closed-loop control and optimize the performance of constant pressure liquid supply significantly. The performance of emulsion pump station is very important. Emulsion pump station is the core unit of providing liquid pressure. Under the action of the control system, it supplies liquid for the hydraulic support according to the requirements of working conditions in order to support the working face. The control system structure of the emulsion pump station is shown in Figure 1.

![Figure 1. Emulsion pump station control system structure](image)

3.2 Design of Variable Frequency Constant Pressure Control System

1) Hardware environment and system structure

The control center of this design uses Siemens product S7-300 with PID module. Through a variety of external sensors, PLC can detect the system pressure, flow rate and other physical quantities. After A/D conversion, they become control signals that can be used to control the inverter start and stop motor and automatically adjust the motor speed to achieve hydraulic stability.

This design uses BPJ1 series mine explosion-proof and intrinsically safe AC inverter. The input voltage is 1140(660V), 50Hz; output voltage is 0V-1140(660V), output frequency is 0.1HZ-50Hz, and the output control power is 0-500W. Other hardware requirements include SYB-351 digital pressure transmitter, hydraulic station motor, and power control circuit. The whole variable-frequency constant-voltage system forms a set of variable-frequency pumps. The system takes PLC as the control core and the execution equipment as the converter. PLC collects pressure signals of the pressure transmitter (4-20mA) and outputs control signals of the converter (0-10V DC).

2) Scheme design

When the start button 10A pulls in, the solenoid valve of the hydraulic station will all open, and then start the emulsion pump motor to boost the pressure. At this time, PLC has received the start signal and realized the variable frequency start of the motor through the frequency converter. The system pressure in this process is between 0 and 28M Pa. Variable frequency start can avoid the direct
start of the motor to the oil pump and the hydraulic valve components caused by too much in the middle, but must ensure that the brake opened to the safety clearance within the specified time without the brake disc attached phenomenon. If the pressure does not reach the set value during the variable frequency startup process, then the system's undervoltage protection will come into play, resulting in a forced shutdown. It should also be noted that the starting between 0 and 28MPa also requires the relief valve to participate in the pressure adjustment. The system continues to boost pressure until it reaches 28MPa (its hydraulic oscillation value is plus or minus 0.2mpa). Through the integrated control and adjustment of PLC and frequency converter, the motor operates at a constant low and low frequency. When it reaches the state of constant pressure operation, overflow valve is no longer required for overflow. When the system changes and the pressure is greater than 28MPa, the integrated control and adjustment of PLC and frequency converter will keep the system pressure stable at 28MPa and provide overpressure protection for the system at the same time. When the variable frequency constant voltage control system fails to work normally, the control system can also be completely shaken off, so that the hydraulic station to restore to the previous working mode. The overflow valve continues to enter the working state to regulate the pressure of the overflow system to ensure the normal operation of the liquid supply system.

4. Analysis of PLC variable frequency and constant pressure control system in mine emulsion pump station

4.1 Application of Programmable Control System (PLC) in Industrial Control

(1) Sequence control
   This is currently the most widely used PLC field to replace the traditional relay sequence control. PLC can be used to control one machine, control a group of multiple machines, automatically control production lines, such as injection molding machines, printing machines, paper cutters, tools, mills, packaging lines, electrolyte coating lines and elevator control.

(2) Analog quantity control
   In the industrial production process, there are many constantly changing quantities, such as temperature, pressure, flow, liquid level, speed, etc., which are all proportional. In order for the planned verifier to be able to handle proportional quantities, proportional quantities should be implemented. Convert A/D and D/A conversion between digital quantity and digital quantity. All manufacturers produce programmable controllers that support converters A/D and D/A for proportional control.

(3) Motion control
   PLC can be used to control circular or linear motion. Because the control mechanism was established in the first few days, it is directly used to connect the position sensor and the actuator I/O switch unit. Nowadays, a specific action control unit is usually used. The image axis or multi-axis position control unit can drive stepping motors or servo motors. Almost all products of major PLC manufacturers in the world have motion control functions, which are widely used in various machinery, machine tools, robots and other fields.

4.2 Effect analysis of variable frequency emulsion pump station system

(1) Energy-saving effect
   This set of variable frequency modified emulsion pump was tested in underground operation. During the experiment, the data such as time, hourly power and daily power consumption under power frequency and frequency conversion operation state were recorded respectively. The data recorded in 12 days are summarized. The statistics of power consumption under power frequency and frequency conversion operation state are shown in Table 1.
Table 1. Statistics of power consumption under power frequency and frequency conversion operation state

| Date | Power frequency | Frequency conversion |
|------|-----------------|----------------------|
|      | Running time /h | Hourly power /kW·h | Daily power consumption /kW·h | Running time /h | Hourly power /kW·h | Daily power consumption /kW·h |
| 1    | 5.62            | 83.54                | 469                           | 8.9             | 68.25                | 607                           |
| 2    | 9.43            | 91.35                | 861                           | 7.55            | 80.06                | 604                           |
| 3    | 10.23           | 92.57                | 947                           | 7.63            | 56.17                | 429                           |
| 4    | 11.07           | 85.90                | 951                           | 4.50            | 87.54                | 394                           |
| 5    | 12.86           | 98.15                | 1262                          | 2.16            | 88.21                | 191                           |
| 6    | 13.18           | 98.58                | 1299                          | 1.68            | 55.75                | 94                            |
| 7    | 8.17            | 93.11                | 761                           | 5.65            | 54.31                | 307                           |
| 8    | 12.64           | 93.21                | 1178                          | 4.05            | 55.36                | 224                           |
| 9    | 6.76            | 90.07                | 609                           | 9.27            | 67.96                | 630                           |
| 10   | 8               | 94.07                | 753                           | 6.37            | 61.02                | 389                           |
| 11   | 15.02           | 101.21               | 1520                          | 1.25            | 47.73                | 60                            |
| 12   | 11.25           | 96.17                | 1082                          | 3.96            | 69.53                | 275                           |
| Total| 124.23          | 94.12                | 11692                         | 62.97           | 66.76                | 4204                          |

It can be seen from Table 1 that the power frequency and frequency conversion run for 12 days at the same time, among which the power frequency runs for 124.23 hours and the average hourly power consumption is 94.12kWh. The frequency conversion runs for 62.97 hours, and the average hourly power consumption is 66.76kWh. After using frequency conversion control, the power saving per hour is 94.12-66.76= 27.36kWh; The electricity saving rate is 27.36/94.12=29%.

The rotation speed of the pump in the emulsion pump station varies with the change of load, that is, when the working face load increases, the rotation speed of the pump increases all the way to the rated power. If the power of one pump can not meet, another pump starting; when the working face load decreases, the pump speed decreases until the minimum speed (15Hz maintained speed). In fact, most of the working surface load is low load, so the operating state of power frequency is very uneconomical and energy-consuming, energy is lost in the pump body and the pump box internal circulation. Consider from energy-saving respect so must undertake frequency conversion is reformed.

(2) Effect of life extension

The standard equipment for operating a set of emulsion pump stations at power frequency is two pumps and one tank. The instructions and operation rules require that each pump should not run for more than 2h, because the pump body temperature will exceed 70° after running for more than 2h, which is easy to burn the pump. Therefore, in actual operation, the two emulsion pumps should be rotated for 2h between each other. And in the variable frequency state because the pump is not always running at the rated speed, so the temperature of the pump body is very low. In the one-month experiment, the personnel on duty were required to record the temperature of the pump body every 1h. Now the recorded data are summarized and counted. The average temperature value of shift 3 is shown in Figure 2.

It can be seen from the data in Figure 2, the average temperature of the pump body does not exceed 45° in the variable frequency state, which fully indicates that the operation of the pump is labor-saving. At the same time, it is proved from the side that variable frequency operation can reduce the mechanical impact and loss, and prolong the service life of the equipment.
5. Conclusion
Through many times of experiments and calibration, the scheme has achieved the expected effect. The emulsion pump frequency constant pressure control system based on PLC can set the liquid supply pressure flexibly according to the actual requirements, and automatically adjust the emulsion pump speed. Therefore, the emulsion pump station is guaranteed constant pressure to stabilize the liquid supply pressure and realize the purpose of improving the liquid supply quality and saving the electric energy. The control system using PLC frequency conversion technology has many advantages over traditional control in performance, energy consumption, safety, influence on power grid and so on, with remarkable economic and environmental benefits.

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