Study on the Control System of the Phase Controlled Rectifier for Mine

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Abstract. In order to meet the requirements of different voltage rating of different electric equipment in coal mine and the requirement of voltage stabilizing for equipment use. A new type of phase control rectifier control system for mine is studied in this paper. The system has designed the control system based on the chip DSP software and the closed loop control system of the software PID. The experimental results show that the phase controlled rectifier control system can achieve a good phase shifting regulation for the rectifier output voltage, and control the output voltage of the trigger angle to meet the needs of the rated voltage of different electrical equipment, which is flexible and convenient. The software PID can adjust the closed loop according to the set value of voltage and current to meet the requirement of the rated power when the equipment is working normally. The result proves the effectiveness of the control system of the phase control rectifier, and has a good value in engineering application and popularization.

Keywords: Phase controlled rectifier, DSP, PID closed loop regulation, DC voltage detection, temperature detection, phase shift control

1. Introduction

Due to the continuous development of China’s coal industry, the continuous increase of coal production, the continuous application of high-power coal mining units and transport equipment, coal mine power supply is becoming more and more electrified. Power electronic devices such as converters have been widely used in all aspects of mine [1]. The front part of these power electronic devices basically use uncontrolled rectifier combined with charging contactor, and then use IGBT inverter to drive AC motor. The power load of power supply of coal mine has great change, frequent start and stop, and even temporary stop, which makes the power grid fluctuate relatively large. Voltage fluctuations often cause great impact on mine production, ventilation and transportation, and are very harmful to the use of electrical equipment. Sometimes, it will damage equipment and cause accidents. This requires that the phase controlled rectifier of mine has a very reliable voltage regulation performance, enabling the electrical equipment to work at a rated voltage under complex working conditions and ensuring the safe and reliable operation of electrical equipment [2]. With the continuous increase in the length of fully mechanized coal mining face and mining area, the production of coal mine is increasing. The power (capacity) of the equipment in the mining face is increasing. The transmission distance is constantly lengthening. The voltage loss of the cable line is getting bigger and bigger. The demand for the output voltage of the rectifier is getting higher and higher. This requires that the DC side output voltage of the rectifier vary according to the mining depth of the coal mine. At present, the underground power supply line system adopts the highest 10kV voltage in the country. The actual input to the mining face voltage is generally divided into 2.3kV, 3.3kV, 4.16kV, 5kV and 6kV several [3]. The power supply voltage of the
coal mine requires that the output voltage of the rectifier can be adjusted. Nowadays, the PWM rectifier control system in the market is immature in terms of high power and high voltage technology, low energy efficiency, and has the disadvantages of inconvenient installation and debugging[4]. The demand for explosion of electrical equipment is very high in coal mine, so the cost of installing flameproof input is very high. Therefore, it is necessary to develop a new type of coal mine phase controlled rectifier control system with low cost, reliable voltage stability and good phase control performance.

2. System composition and hardware circuit design

2.1. System composition
The three-phase AC input power supply is supplied to the three-phase inverter for the mining equipment through the stable DC voltage output of the phase controlled rectifier. With the increasing level of the three-phase AC input voltage, the phase controlled rectifier can automatically adjust the stable DC voltage required by the output inverter or the load. When the power load of the mine is changed greatly, the phase control rectifier can stabilize the DC voltage when the power grid fluctuates[5-8]. The designed phase control rectifier system is shown in Fig.1. It is mainly composed of 3 parts: (1) main electric route three-phase bridge full control rectifier circuit and inverter; (2) DSP digital control system; (3) various detection circuits: grid side current detection circuit, grid side voltage and DC voltage detection circuit, temperature detection circuit.

2.2. DSP digital control system
The block diagram of the DSP digital control system is shown in Figure.2. The core chip uses TMS320F28035 fixed-point DSP. By using F28035's rich peripheral interface and 12 bit high precision AD, we can accomplish all kinds of sampling signal, trigger pulse and protection state signal input in mine phase control rectifier drive control system. The DSP digital control system is the core part of the whole mining phase controlled rectifier control system [9-10]. It is mainly composed of 4 parts: DSP digital system, analog input circuit, man-machine interface circuit and thyristor drive circuit, thyristor temperature detection circuit, fault detection circuit and so on.

Fig.1. Phase controlled rectifier circuit
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DSP digital control system
TMS320F28035
Analog 
in
put
i1
i2
i3
U1
U2
U3
Udc
net 
current 
measure-
ment
net test 
voltage
AC 
voltage
drive circuit
trigger pulse
SC SW
start and stop
man-
machine 
interface

Fig. 2. Block diagram of DSP control system

(1) DSP digital system: it is composed of TMS320F28035, digital input signal of external terminal and so on. It can perform all kinds of functions, such as digital calculation, external terminal control, starting and stopping control and operation of the mine phase controlled rectifier circuit. (2) Analog input circuit: it mainly consists of network side voltage, current and DC voltage detection and conditioning circuit. The main circuit of voltage and current detection is to convert the strong signal to the weak signal for digital sampling by DSP. (3) Thyristor drive circuit: converting the trigger pulse signal from the DSP system into a pulse signal that can drive the thyristor. When the thyristor is too high or overcurrent, the fault signal is fed back to the DSP control system. (4) Man-machine interface circuit: It is mainly composed of CAN communication, upper PC display and operation keyboard. A variety of given instructions and parameters can be set by the keyboard, such as the starting and stopping of the phase controlled rectifying circuit of the mine, the given DC output voltage value and so on. It can display the various states of the phase controlled rectifying circuit of the mine and record the history of the phase control rectifying circuit of the mine.

2.3. Hardware design of various detection circuits

2.3.1. Network side current detection circuit.
The detection of network side current is very important for mine phased rectifier control system. Its value will be used as the instruction current of synchronous PI decoupling current control. The reliability and accuracy of detection is the first consideration. The sensor detection scheme is selected here. In a three-phase balance system, the line voltage is 380 V, and the maximum per phase current is not more than 400 A. Considering some margin, the selected current sensor is a three phase AC current sensor of LAC300-S model of LEM company. The initial stage of the sensor is insulated. The conversion rate is 1:4000. Measurement range 400A. It is used for three phase precision measurement of DC, AC and pulse current. The value of the rated output current is 100mA, and the voltage of the power supply is + 15V.

As shown in Fig.3, the left side of the graph is the sensor. The three phase lines of the power supply are passed through the three measurement holes respectively. The M1, M2 and M3 in the sensor are three phase measurement current output respectively. A phase current conditioning circuit is given in the diagram. Because of the three-phase balance system, the three-phase current regulating circuit is consistent. The detection values of each phase current pass through the magnetic beads (restraining high frequency interference and peak) and flow through the sampling resistance. The current signal becomes a voltage signal. Then through the TL082 operation and amplifier conditioning, the output voltage is between 0-3.3V. Finally, the output voltage is input to the AD port of DSP after the DAN217 clamping protection.
2.3.2. Network side voltage and DC voltage detection circuit.

The voltage value of the net side is used as the instruction of the synchronous PI decoupling current control, and the decoupling algorithm is realized. The line voltage rating of the test network side voltage is 380V. Therefore, the type of voltage sensor is TBV10/25 A. The primary and secondary of this type of sensor is insulated. It can be used to measure DC, AC and pulse voltage. The rated input current is 10 mA, the output current is 25 mA, and the supply voltage is 15 V. The three-phase voltage detection circuit on the net side is consistent. As shown in Fig.4, a circuit diagram for detecting the voltage of the two line voltage of the net side voltage is given. The two line voltage is connected by the input side current resistance R1 of the sensor. After the sampling resistance R2, the line voltage becomes the voltage signal. After the operation of capacitor filter and TL082 operation, the voltage signal is output to the AD port of DSP[10-15].

The value of the DC voltage is used as the external loop control feedback instruction controlled by the synchronous PI decoupling current. The function of the DC voltage which is stable in the output of the phase control rectifier is realized. The detection circuit is the same as the network side voltage detection circuit. Only the value of the input current limiting resistance R1 and the sampling resistance R2 are different.

2.3.3. Temperature detection circuit.

The driving control system of the mine phase controlled rectifier is installed in the closed electric control box of the shearer, which itself is natural cooling. The heat dissipation effect is strengthened by its tight installation on the outer wall of the water cooling system of the shearer. But at work, the temperature will rise sharply. Even if the radiator is strengthened by the shearer, the cooling effect will not be ideal if it is used for a long time. It will make the temperature too high and damage the drive control system. So it is very important to detect the temperature of the thyristor. The PT100 temperature sensor is used to detect the thyristor. As shown in Fig.5, the PT100 is in full contact with the surface of the system radiator. When the temperature of the driving control system of the phase control rectifier of the mine is changed, the resistance of PT100 also changes. The change of the resistance value can be measured by the circuit shown in Fig.5, so that the temperature of the drive control system is measured. In Fig.5, TL431 constitutes a voltage stabilizing circuit, providing a precise +5V voltage. The operational amplifier TL082 and the resistor are composed of a 200mA constant current source circuit. A constant current source is used to convert the PT100's resistance to a voltage signal. After using AD620 to adjust the signal, the signal is sent to the AD port of DSP for conversion. The temperature detection circuit will feed back the temperature of IGBT in real time, and the real-time monitoring and temperature protection will be realized by using DSP.
3. Software design

The software program of drive control system is mainly composed of main program, AD timer interrupt service routine, capture interrupt service program, CAN communication interruption program, waveform generator interrupt program and so on. The software flow chart is shown in Fig.6.

The main program mainly completes initialization variables and data settings, initialization settings of special function registers and external event management registers, interruption setting, interruption and other functions, and completes the signal sampling of external terminals. It manages the starting and stopping of the phase control converter, the reset signal of CPU, the output fault signal and so on.

The CAN interrupt service program mainly completes the communication with the operation keyboard, and sends the running state and fault information of the drive control system of the mine phase control rectifier to the display. Receive the keyboard setup command at the same time. Capture interrupt service program, which mainly completes the sampling and calculation of the phase, phase sequence and frequency of the power grid. Waveform generator interrupt service program, which mainly completes the update of the cycle register and duty ratio, the calculation of duty ratio and the generation and output of the SVPWM wave.

AD timer interrupt mainly complete the following work: (1) Sampling calculation of three phase AC current, sampling calculation of three phase AC voltage, sampling calculation of DC voltage, sampling calculation of IGBT temperature. (2) The calculation of dead zone compensation, the calculation of the cycle register value of the waveform generator, the calculation of the value of the phase accumulating, and the calculation of overload over current.(3) The calculation of the synchronous PI decoupling current control algorithm.

Fig.5. PT100 temperature detection circuit
Fig. 6. Software program for driving control system
4. Experimental research

![Fig.7](image1.jpg)

*Fig.7. The input waveform of the synchronous signal and the output waveform of the trigger pulse*

![Fig.8](image2.jpg)

*Fig.8. Output waveform with an input voltage of AC380V and a trigger angle of 30 degrees*

![Fig.9](image3.jpg)

*Fig.9. Output waveform with an input voltage of AC380V and a trigger angle of 60 degrees*
In order to verify the reliability of the control system of the mine phase controlled rectifier, the driving control system of the phase controlled rectifier is studied and applied to the underground coal mine. The main parameters of the system are: the input three-phase AC voltage of the main circuit is AC380V, the synchronous voltage of the synchronous transformer is AC20V, and Fig. 7. is the waveform diagram of synchronous input voltage signal and trigger pulse sequence.

From the waveform diagram, we can see that the driving control circuit can output reliable trigger pulses, which can effectively drive thyristor and output stable DC voltage. Fig.8-10, respectively, are the output voltage waveform of the DC side when the trigger angle are 30 degrees, 60 degrees and 90 degrees without adding filter capacitor. From the waveform chart, we can see that the phase controlled rectifier can control the output voltage well, and output the stable DC voltage needed.

5. Conclusion
In view of the characteristics of mine power supply and electrical equipment, a full digital intelligent control phase control rectifier control system is designed. The system can not only output the DC voltage of any desired setting, but also stabilize the output DC voltage, and it can be applied to the high input voltage level of the mine to adapt to the larger input power and larger load. It can meet the increasing input voltage of mining equipment with the increasing mining depth of coal mine. It has the characteristics of simple circuit, strong modularization, flexible parameter setting and good dynamic performance. It has improved the control performance, adaptability, flameproof performance and reliability of the operation of mine equipment, and has a good value in engineering application and popularization.

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