Research on Mine Frequency Converter Mutual Feedback Experimental Device

Quan-zhu ZHANG, Chang-guo JING and Yong-hong DENG

Institute of Information and Control Technology, North China Institute of Science and Technology, Yanjiao 065201, China

*Corresponding author

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Abstract. Aiming at the problems that are difficult to realize in the test, troubleshooting and maintenance of high-power inverter performance and function in mining, especially the difficulty of power experiment, a high-power experimental device is proposed. The hardware circuit of the system is given based on TMS320F28335. The software implementation scheme and circuit structure adopt vector control strategy to realize closed-loop control of speed and torque. Field experiment debugging verified the feasibility and correctness of the mutual feedback experimental device, which can be promoted and applied in the coal mining industry.

Introduction

Due to the rapid development of China's coal mining industry, some high-power inverters for mining are also being applied to the mining process. Although the speed of mining is accelerated, the high-power inverter itself brings a lot of difficulties to mining trouble. For example, the detection and maintenance of these high-power inverters during use are a big problem. Previously, there were many methods for detecting such high-power inverters, such as ①Dynamic test [1]. The so-called dynamic detection is a step-by-step detection, for example: first check whether the circuit connection is correct; when it is determined that the circuit connection is no problem, power on other parts, and use the elimination method to determine the cause of the failure. ②Current detection method [2]. The principle is to detect the change of the current of the inverter to determine whether the inverter has a fault or other problems.③Voltage detection method [3]. The phase voltage, the line voltage, and the like are compared with the difference in normal operation for judgment. ④Expert system method [4]. Experts in the industry use their knowledge reserves to use experience to diagnose and judge. ⑤Neural network fault diagnosis method [5, 6]. By measuring the DC output voltage waveform under each type of fault state, fault codes corresponding to different fault types can be obtained, and the obtained fault code training is the neural network to realize the fault diagnosis of the three-phase rectifier. ⑥Fault tree fault diagnosis method [7]. After the system fails, the operator or maintenance personnel input the discovered fault phenomenon into the computer according to the prompts of the knowledge base. The expert system compares them step by step, and promptly gives the maintenance personnel a fault judgment similar to the field fault phenomenon. Summarizing all the previous detection methods, you can clearly see a lot of deficiencies. ①②③④⑤these four methods need to use external motors, which are difficult to achieve for high-power inverters, costly, large investment, and not universal; ⑥⑦these two methods require a large knowledge reserve, which is difficult guarantee the accuracy of detection and fault diagnosis. In response to these problems, a system that is economical and practical and accurate is proposed. The system uses the relationship of speed, torque and current to control the current by controlling the phase angle of the voltage difference. It not only reduces costs, but also has universality, improves mining conditions and saves mining economy.
System Composition and Hardware Circuit Design

System Components

The system is mainly composed of DSP controller TMS320F28335, rectification, inverter circuit and corresponding current and voltage detection circuit. After the grid voltage is rectified, the inverter is used for speed control, and the energy is fed back in the DC measurement. The inverter uses insulated gate bipolar transistors (IGBT); the DSP generates 6 high-speed pulses to control one inverter, and the total requires 12 pulses. The entire structure of the system is shown in Figure 1.

DSP Control System

DSP control system shown in Figure 2, the core chip of the system uses TMS30F28335 fixed-point DSP, TMS320F28335 has a rich peripheral human-machine interface, 12-bit high-precision on-chip AD, AC current, AC voltage, DC voltage, temperature required for design Others can be well tested, and the required PWM pulses are also provided.

The DSP control system is the core part of the overall design and consists of many peripheral circuits. The utility model comprises an alternating current detecting circuit, an alternating current voltage detecting circuit, an IGBT driving circuit, a human-machine interface circuit and an external terminal. The external terminals control the system to run and stop during the design. The AC current and AC voltage detection circuit is mainly used to cooperate with DSP sampling to convert the strong electric signal in the circuit into a weak electric signal suitable for the DSP, which can also protect the DSP chip. The IGBT driver is the control core point, and if the driver has a problem, the circuit cannot work. Its function is to convert the PWM signal from the DSP into a pulse signal that can drive the IGBT, and detect whether the IGBT is running normally and feed back to the DSP control system. The man-machine interface circuit is mainly composed of a CAN communication circuit, a host PC display circuit and an operation keyboard, and the purpose is to study the design parameters.

Hardware Circuit Design

IGBT Drive Circuit. In the market, IGBTs are driven a lot, and suitable drivers can be used for different circuits. This design takes into account the power of the inverter and other factors, and drives optocoupler PC929 and PC923 in combination. PC923 and PC929 chips are single-pulse driver chips for small and medium-capacity IGBTs, which are often used in pairs. The internal structure of PC929 is shown in Figure 3. The PWM pulse signal enters from the 2nd pin and the 3rd pin. In order to ensure the normal use of the drive, the signal of the 3rd pin should be higher than the signal of the 2nd pin, ensuring the internal the diode is conducting. The internal structure of PC923 and PC929 are basically the same, so the roles of the two are basically the same. The
difference is that there is a short circuit protection circuit inside the PC929, and the PC923 does not have this function. Because the PC929 has internal short-circuit protection, it is generally used as an upper arm and the PC923 is used as a lower arm.

![Figure 3. PC929 Driver Internal Structure.](image1)

The driving current of PC923 and PC929 is at most 0.4A, and it is impossible to directly drive the power IGBT. It is necessary to post-drive the output drive pulse after the push-pull circuit is driven to drive the IGBT. Figure 4 shows the drive circuit of one phase, and the other two phases are exactly the same.

![Figure 4. Drive Circuit.](image2)

**AC Current Sampling Circuit**

The detection of the output current of the inverters 1 and 2 is very important for the mutual feedback experimental device. The value will be used as the vector control command current. The reliability and accuracy of the detection are the primary considerations. The sensor detection scheme is used here. Considering the typical power of 400KW, in the three-phase balanced system, the line voltage is 1140V, and the maximum current per phase is not more than 300A. Considering some margin, the current sensor selected is the three-phase alternating current model of Nanjing Token Company. The sensor is primary and secondary insulated with a resolution of 1000:1 and a measuring range of 300A for three-phase precision measurement of DC, AC and pulse current. Its rated output current is 100mA, and the power supply voltage is ±15V.

The schematic diagram is shown in Figure 5. The left side is the sensor. The three-phase lines of the power supply pass through the measurement holes respectively. The OUTPUT signals in the sensors in the figure are the three-phase measurement current outputs, giving one of the phases. The current conditioning circuit is a three-phase current balancing circuit because it is a three-phase balancing system. The output current detection value of each phase passes through the magnetic beads (suppressing high-frequency interference and spikes) and then flows through the sampling resistor, so that the current signal becomes a voltage signal, and then is conditioned by the TL082 op

![Figure 5. AC Current Sampling Circuit.](image3)
amp, so that the output voltage is between 0-3.3V, and finally after the DAN217 clamp protection, enter the AD port of the DSP.

![AC current sampling circuit diagram](image)

**Figure 5. AC current sampling circuit.**

**AC Voltage and DC Voltage Detection Circuit**

The inverter 1 and 2 output voltage values are used as instructions for the vector control algorithm. According to the detected output line voltage rating of 1140V, the voltage sensor of TBV10/25A is selected. This type of sensor is insulated from primary and secondary. It can be used to measure DC, AC and pulse voltage. The rated input current is 10mA and the output current is 25mA. The power supply voltage is ±15V. The output three-phase voltage detection circuit is identical, as shown in Figure 6, the detection circuit diagram of the output voltage two-wire voltage is given. The two-wire voltage is connected to the current-limiting resistor R1 of the sensor input, and becomes a voltage signal after passing through the sampling resistor R2, and then filtered by the capacitor and then input into the AD port of the DSP by the TL082 operational amplifier.

The value of the DC voltage is used as a feedback command of the SVPWM control to achieve a stable output of the mutual feedback experiment. The detection circuit is the same as the output AC voltage detection circuit except that the values of the input current limiting resistor R1 and the sampling resistor R2 are different.

![AC and DC voltage detection circuit diagram](image)

**Figure 6. AC and DC voltage detection circuit.**

**Temperature Detection Circuit**

The inverter of the mutual feedback test bench mainly relies on the air cooling system to enhance the heat dissipation effect. However, when working, the temperature will rise sharply. If it is used for a long time, the cooling effect will be unsatisfactory, and the temperature will be too high, thus damaging the inverter. Therefore, the detection of its IGBT temperature is very important. Temperature sensor choose PT100, as shown in Figure 7, PT100 is in full contact with the surface
of the system radiator. When the temperature of the inverter system changes, the resistance of PT100 also changes. The circuit shown in Figure 7 can be used to measure the resistance. The value changes to measure the temperature of the mutual feedback test bench. In Figure 7, TL431 constitutes a voltage regulator circuit, providing accurate +5V voltage, operational amplifier TL082 and resistor to form a 200mA constant current source circuit, using the constant current source to convert the resistance value of PT100 into a voltage signal, and then using AD620 to condition the signal, and then the signal is sent to the AD port of the DSP for conversion. The entire temperature detection circuit will feedback the temperature of the inverter IGBT in real time, and real-time monitoring the temperature and protection can be realized by using the DSP.

![Figure 7. PT100 temperature detection circuit.](image)

**Algorithm Implementation**

Figure 8 is a block diagram of the vector control algorithm for the mine inverter mutual feedback test bench. A DSP control system simultaneously controls two inverters, one inverter controls the speed, other inverter controls the torque, the speed \( \omega \) and the torque \( T \) respectively. For the outer loop control of the two inverters, the speed and torque without static control can be realized. The three-phase voltage and the three-phase current value outputted by the inverter are detected, and the actual operating frequency of the inverter is predicted, and the current changes on the inductor are calculated through three separate current PI controllers. The current inner loop control realizes the direct current control of the output side inductor current waveform of the experimental bench and the voltage phase of the two inverters for quickly tracking the reference current and realizing the control of current and power. Finally, the actual value of the midpoint voltage of the IGBT bridge arm of the two inverters is calculated, and then the trigger pulse of the control switch is obtained by the space vector pulse width modulation SVPWM [8] algorithm.
When the mutual feedback test bench is working, the frequency converter 1 controls the speed of the mutual feedback test bench, and the frequency converter 2 controls the torque. The algorithm phasor diagram is shown in Figure 9. The three-phase voltage output $(u_A, v_A, w_A)$ from the inverter 1, the combined space voltage vector $u_s$; the three-phase voltage output $(u_B, v_B, w_B)$ from the inverter 2, the combined space voltage vector $u_{s_2}$, and the $\delta$ angle are the phase differences of the space voltage vector, $u_s$ are the voltage vectors on the inductor. Adjusting the $\delta$ angle can adjust the $u_s$. If the $u_s$ more larger, the current on the inductor more larger, thus adjusting the output and input power of the inverters 1 and 2. Thereby, the full load experiment of the mine frequency converter and the load experiment under different torques can be realized.

**Analysis of Experimental Results**

For the above-mentioned mine frequency converter mutual feedback experimental device, a reduced scale experimental platform was built. The inverter 1 and the inverter 2 were 2.2 kW and the inductance was 4.5 mH. Figure 9 (a) shows the phase voltage waveform of the inverter 1 output, 50V / div, Figure 9 (b) shows the phase voltage waveform of the inverter 2 output, 50V / div. As can be seen from the figure, the system runs stably.
Summary
The design of the study used a less component and lower cost scheme to build a test rig, which realized the testing of the mine high-power inverter, and carried out a proportional reduction experiment, demonstrating the feasibility of the experimental platform. It also has the characteristics of simple circuit, strong modularity and flexible parameter setting. The energy utilization efficiency is improved, and the cost is saved, and the engineering application promotion value is well in the project. Applying this technology to coal mine work has achieved economic, environmental protection and energy saving, with good economic and social benefits.

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