A mine digital integrated protector with harmonic detection and analysis function

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Abstract. Aiming at the protection problems and harmonic detection problems of motor circuit, lighting signal circuit in coal mine, a mine digital comprehensive protector based on STM32 is designed. The protector can realize the protection and harmonic detection of motor circuit, lighting circuit and signal circuit in coal mine, and use windowed interpolation fast Fourier algorithm to calculate and analyze harmonic. The protector has the functions of under voltage, over-voltage, overload, short circuit, three-phase unbalance, open phase, leakage locking, insulation danger indication, over temperature, under temperature, wind power and gas locking, harmonic analysis, local storage, remote control and other functions. The experimental results show that the system design scheme is feasible and effective.

1. Introduction

According to the "special provisions of the State Council on the prevention of coal mine production safety accidents" (State Council Order No. 446) and other laws and regulations, the original JDB motor comprehensive protector used in underground mine is made of discrete components, without protection status indication, no protection parameter adjustment function and poor anti-interference performance, so it needs to be banned and replaced by digital motor comprehensive protector [1-2].

With the improvement of coal modernization level, a large number of high-power and high-performance switching devices are widely used in the mine. These devices improve the coal mine production efficiency to a certain extent, but also bring serious harmonic problems to the coal mine power grid [3]. The harmonic problem leads to the increase of production cost of coal mine enterprises, which is also a threat to the safety production of enterprises [4]. Therefore, it is particularly important to detect and control the harmonic of coal mine power supply and distribution network [5]. However, the current power quality detector for power grid harmonic detection generally has the disadvantage of high cost.

In view of the above problems, this paper designs a low-cost digital mine integrated protector by using single-chip microcomputer as the main control chip. The protector not only improves the discrete components of traditional mine protector into digital circuit, but also integrates the functions of mine electromagnetic starter and lighting signal comprehensive protector, and has the function of harmonic detection and analysis, which reduces the volume of equipment and the cost of production, operation and maintenance.
2. System design

2.1. System hardware design
The hardware circuit design block diagram of the system is shown in Figure 1. The hardware design of the integrated protector adopts STM32F103VET6 as the main control chip. The system is mainly composed of data acquisition, human-computer interaction, switch input, relay output, data storage, 485 communication and power supply.

![Integrated protector design block diagram.](image)

The input voltage of the protector is 36V AC. After rectifying, the power management chip classifies the voltage to provide different levels of DC voltage for each part of the system. When the system is powered down, the backup battery supplies power to the main control chip to ensure the normal operation of the real-time clock (RTC).

Data acquisition includes voltage acquisition, current acquisition, leakage resistance acquisition, temperature acquisition, etc. It is used to collect voltage value, current value, leakage resistance value of motor circuit, lighting circuit and signal circuit, as well as motor shell temperature. After the acquisition, the data is sent to the 12 bit ADC channel of STM32 for analog-to-digital conversion processing. The switch input part is used to control the start and stop of motor circuit, lighting circuit and signal circuit, receives the feedback information from underground coal mine, and uses photoelectric coupler to isolate it, so as to filter out the noise signal on the switch value, prevent the switch from misoperation, and prevent high voltage from entering the single chip microcomputer.

The relay output is used to control the start and stop of motor circuit, lighting circuit and signal circuit. Human computer interaction includes keys, LCD display, status indicator, 485 communication and so on. The data storage part includes flash storage and local SD card storage. Flash stores important system parameter information, local SD card stores system working parameters, system operation status, equipment real-time detection record, equipment fault record, etc.

2.2. System software design
The software design flow chart of integrated protector is shown in Figure 2. It mainly includes power on initialization part, key display part, data acquisition part, data processing part, harmonic analysis part, RTC part, motor start stop and protection logic, storage part, 485 communication part and so on.

After the system is powered on for initialization of each module, read the system operating parameters in the local SD card and flash. If the system is powered on for the first time, write the initial working parameters. At the same time, the data of current, voltage, insulation leakage resistance and temperature are collected continuously. The data collected by ADC is processed by filtering, integrating and Fourier transform, and harmonic analysis is carried out, the processed data is sent to the liquid crystal display and store them. The system judges whether the motor circuit, lighting circuit and signal circuit need to be started and stopped according to the switch input, and the current value, voltage value, leakage resistance value, temperature value of each circuit processed by single chip microcomputer, and the wind power and gas locking signals fed back from underground mine are used as the basis to determine whether protection is needed. It also detects whether the key display, 485 communication and other functions are triggered for managers to check and control the working state.
of the system, modify the working parameters of the system, and query the real-time detection information and fault information of the system.

Figure 2. General protection device software design flow chart.

2.3. Harmonic detection algorithm

Figure 3. Harmonic analysis flow chart.
The flow chart of harmonic analysis algorithm is shown in Figure 3. Aiming at the problem of harmonic analysis in coal mine, this paper adopts interpolation windowed function fast Fourier transform algorithm [6]. In order to further eliminate the fence effect and spectrum leakage phenomenon, the equal phase angle difference is used for data sampling to ensure the accuracy of spectrum analysis results. 64 points are collected in each cycle, and 256 points are collected in 4 cycles for each harmonic analysis, so as to obtain sampling data with the same waveform as far as possible [7]. Then, Hanning window function is used to optimize the sampling data, and then FFT basis 4 algorithm is carried out to reduce spectrum aliasing and spectrum leakage [8]. The total harmonic distortion (THD) and each harmonic content are obtained from the frequency spectrum after FFT transform.

3. Experiment and result analysis

The application scenarios of mine digital integrated protector are as follows: it is used with various types of electromagnetic starters (including reversible starters) with AC 50 Hz voltage levels of 380V, 660V, 1140V and the maximum current of 120A, and the mining lighting system of single-phase 127V and three-phase 380V. According to this application scenario, experiments are carried out in the mine laboratory to test the detection accuracy, protection function and harmonic analysis of the system.

Figure 4 shows the linear fitting curve of input voltage sampling. The grid side voltage is 1140V, and the input voltage is adjustable. The system is powered by 1140V to 36V transformer. It can be seen that the voltage acquisition quantity has a high linear fit with the actual voltage value. The system sets the input voltage lower than 85% of the rated voltage for under voltage protection, and 15% higher than the rated voltage for over-voltage protection. Through the experiment, the function of voltage protection is normal.

Figure 5 shows the linear fitting curve of the system leakage resistance value sampling, and the leakage resistance value is sampled in sections according to different ranges. The system sets different rated leakage resistance values according to different voltage levels. Among them, the rated leakage resistance value of lighting circuit is set as 4KΩ, the rated leakage resistance value of main circuit is 7KΩ at 380V voltage level, 22KΩ at 660V voltage level and 40KΩ at 1140V voltage level. After testing, the linearity of each sampling range is very high, and all voltage levels and lighting circuits of the main circuit can be locked normally.

Figure 6 shows the linear fitting curve of current sampling. The grid side current is sent to the system through the current transformer. It can be seen that the linear fitting degree of the current sampling value and the input current value is high. The system sets the ratio of input current and rated current as overload multiple. When the overload multiple is between 1.5 and 8.0, the system will
protect according to the inverse time curve. When the overload multiple is greater than 8.0, the short-circuit protection will be carried out. Figure 7 shows the fitting curve of inverse time protection of the system. It can be seen that the action time of overload protection is based on the inverse time limit curve, and the short circuit protection function is normal.

![Current sampling linear fit curve](image1)

![Inverse time protection fit curve](image2)

Figure 6. Current sampling linear fit curve.  
Figure 7. Inverse time protection fit curve.

Figure 8 shows the harmonic measurement and analysis diagram of the system. It can be seen that the system can detect the odd harmonics of 3rd, 5th, 7th, 11th and 13th in the power grid, and then feed back the harmonic analysis results to the management personnel to formulate the harmonic control scheme. In order to test the accuracy of harmonic parameter analysis, the power quality detector is connected to detect and analyze the harmonic of power grid, and the measurement data of each power parameter measured by both are recorded. The harmonic measurement and analysis data of the two schemes are shown in Table 1. In the table: the actual value is the harmonic detection and analysis using the power quality detector, and the experimental value is the harmonic detection and analysis using the system, and the harmonic value represents the percentage of harmonic relative to the fundamental wave. It can be seen from table 1 that the system has some errors compared with the high-precision power quality detector, and the error can meet the requirements of relevant national standards.

![Harmonic measurement analysis chart](image3)

Figure 8. Harmonic measurement analysis chart.
Table 1. Measured values of harmonic analysis.

| Harmonic number | Harmonic value (%) | Harmonic number | Harmonic value (%) | Harmonic number | Harmonic value (%) |
|-----------------|-------------------|-----------------|-------------------|-----------------|-------------------|
| Actual Experiment | Actual Experiment | Actual Experiment | Actual Experiment | Actual Experiment | Actual Experiment |
| 1 36V | 36V | 2 0.023 | 0.1723 | 3 0.128 | 0.2631 |
| 4 0.031 | 0.0452 | 5 0.203 | 0.3715 | 6 0.021 | 0.0681 |
| 7 0.194 | 0.3328 | 8 0.013 | 0.0332 | 9 0.122 | 0.1703 |
| 10 0.015 | 0.04106 | 11 0.157 | 0.2517 | 12 0.013 | 0.0309 |
| 13 0.214 | 0.2814 | 14 0.013 | 0.0252 | 15 0.082 | 0.0799 |
| 16 0.009 | 0.0175 | 17 0.052 | 0.1125 | 18 0.004 | 0.0377 |
| 19 0.051 | 0.1061 | 20 0.005 | 0.0181 |

The working parameters of the system are modified through the key display function. After power failure, the system is powered on again to view the modified working parameters. The work is saved successfully. The work record before the system power down can be queried. The storage functions of the local memory card and internal flash of the system are normal. After the system is powered on, the system is remotely controlled by 485 communication module, the working state of the system is checked, the working parameters of the system are modified, the real-time detection information and fault record of the system are inquired, and the 485 communication function is normal.

4. Conclusion
This paper designs a kind of digital motor comprehensive protector used in coal mine. Through the experimental test, the protector can accurately sample the voltage, current, leakage resistance value, temperature and other signals of motor circuit, lighting circuit and signal circuit. The protection functions of under voltage, over-voltage, three-phase imbalance, phase loss, inverse time limit, short circuit, leakage, wind power locking, gas locking, over temperature and under temperature have passed the test, and harmonic detection, harmonic analysis, key display, storage, 485 communication and other functions are normal. The experimental results show that the system has perfect functions and can accurately measure and analyze the grid voltage, current, leakage resistance and power quality. The measurement accuracy and protection response time meet the design requirements.

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