Design of a Selective Leakage Protection System for Coal Mine Load Center

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Abstract. Leakage protection is one of the three major protections in coal mines and is a crucial safeguard for the safety of underground workers. Based on an analysis of the current state of selective leakage protection systems in coal mine load centers, this paper designs a leakage fault protection system for coal mine load centers using a combination of an additional DC power supply method and zero-crossing triggering method, thereby improving the reliability of leakage protection in coal mine load centers.

Keywords: Coal mine; Load center; Selectivity; Leakage protection.

1. Introduction

With the rapid development of comprehensive mechanized mining technology in coal mines, the increasing extension distance of underground power supply networks has led to higher demands for the reliability and safety of underground electrical systems. Due to the humid and harsh production environment underground, leakage faults frequently occur in low-voltage power supply systems. If these faults are not addressed promptly, they pose significant safety hazards, such as potential coal dust explosions, gas explosions, or premature ignition of detonators, which threaten safe production and directly endanger national property and the personal safety of underground workers. Leakage protection, along with overcurrent protection and grounding protection, ranks among the three major safeguards ensuring safe power supply in coal mines and is an important measure to prevent electric shock. Selective leakage protection refers to the ability to selectively issue fault signals or disconnect power from faulty branch circuits when a leakage fault occurs in the grid while allowing non-faulty sections to continue operating. Currently, most selective leakage protection systems in coal mine load centers utilize protection technologies based on zero-sequence current magnitude and direction. This type of protection can struggle to meet selective protection requirements in radial power supply networks when one branch’s length is significantly greater than that of others, potentially leading to failure to operate correctly and failing to achieve effective protective outcomes.

2. Leakage Protection System

The selective leakage protection system for coal mine load centers is centered around a Digital Signal Processor shown in Figure 1 and mainly consists of the DSP, zero-sequence signal acquisition circuit, signal processing circuit, insulation resistance detection circuit, execution unit, operation unit, display unit, and CAN communication unit. The zero-sequence signal acquisition circuit collects zero-sequence voltage and zero-sequence current signals, with its output connected to the input of the signal processing circuit. The output of the signal processing circuit is connected to the signal capture unit of the DSP; the output of the insulation resistance testing circuit is connected to the analog signal input of the DSP. The execution unit consists of a leakage relay and a tripping device, with the control signal input of the execution unit connected to the signal output of the DSP. The operation unit serves as an external control command input unit, with its output connected to the signal input of the DSP.

The driving input of the display unit is connected to the signal output of the DSP; The input terminal of the CAN communication unit is connected to the CAN module of the DSP.

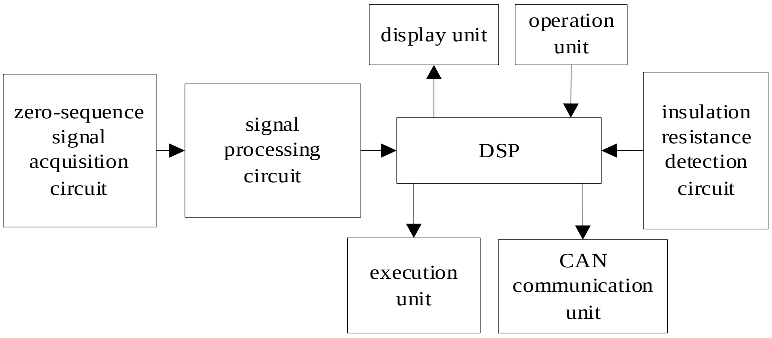


Figure 1. The selective leakage protection system for coal mine load centers

DSP

The insulation resistance detection circuit is shown in Figure 2. It employs an additional DC power supply in a three-phase power grid. The DSP detects changes in three-phase ground current "I" in real time to determine variations in three-phase ground insulation resistance. The detection circuit sequentially includes: positive terminal of DC power supply, resistor "R3", ground, grid insulation resistance, three-phase grid, three-phase reactor L, resistor R1, resistor R2, and negative terminal of DC power supply. The formula for calculating current I is as follows:

$$I = \frac{U_1}{R_{(L)}/3 + R_1 + R_2 + R_3 + R_s + r_{\sum}}$$

Where R_L represents the DC resistance of each phase coil in the three-phase reactor; R_S represents grounding resistance; and $r_{\sum}$ represents total insulation resistance from the three-phase grid to ground. In this formula, only $r_{\sum}$ is a variable ($r_{\sum}$ = r/3), allowing us to reflect the insulation condition of the grid based on changes in current "I". Based on actual operating conditions of the grid, a safety value for insulation resistance is set. When the detected insulation resistance exceeds this safety value, it indicates that a leakage fault has occurred. Subsequently, specific faulty branches are identified based on feedback signals from zero-crossing triggering methods.

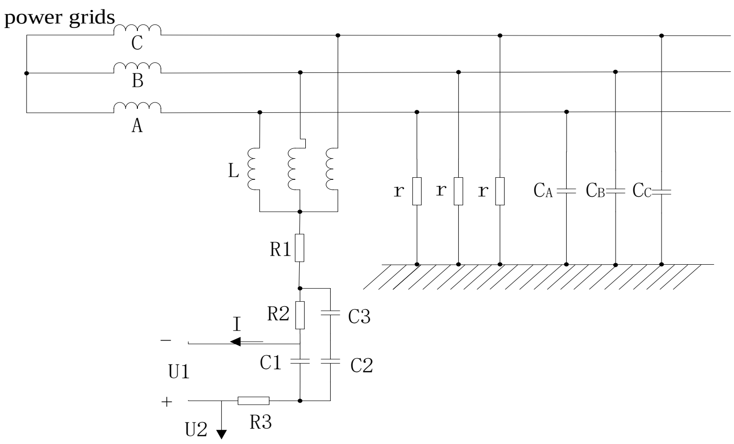


Figure 2. Circuit diagram of insulation resistance detection

The zero-sequence signal acquisition and signal processing circuit are shown in Figure 3. Utilizing the capture function of the DSP, zero-crossing points of zero-sequence voltage and zero-sequence current are captured each time. The captured signals are synchronously sampled using an analog-to-digital converter (ADC). After being isolated by an optocoupler (EL814) and shaped by a Schmitt trigger (74HC37), as well as processed through a resistor-capacitor phase-shifting circuit and an inverter (74LS19), the signals are fed back to the ADC of the DSP. The DSP then performs calculations on the signals to implement leakage protection using the zero-crossing triggering method. The original signals of zero-sequence voltage and zero-sequence current are sent to the signal capture pin of the DSP after being isolated by the optocoupler, shaped by the Schmitt trigger circuit, and phase-shifted through resistors and capacitors. Assuming that the zero-crossing point of the zero-sequence voltage is captured at time T1 and the zero-crossing point of the zero-sequence current is captured at time T2, if $0.005 \le T2-T1 \le 0.01$, it indicates that the zero-sequence current signal lags behind the zero-sequence voltage signal by 90° to 180°. This allows for determining specific branch leakage faults.

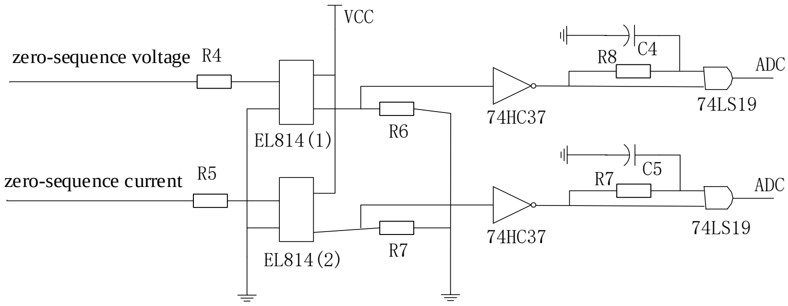
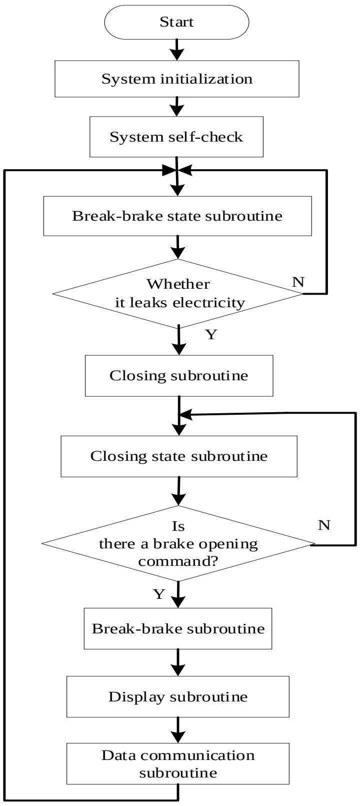


Figure 3. Circuit diagram of zero sequence signal acquisition and signal processing

The selective leakage protection system for coal mine load centers employs a structured programming design method, dividing the entire system program into several independent subprograms. Each subprogram is compiled and debugged separately, and finally, the subprograms are linked together to form an organic whole. The software flowchart of the selective leakage protection system for coal mine load centers, as well as the insulation resistance detection subprogram, is shown in Figures 4 and 5. According to the technical requirements of the protection system, the software program includes the main program, insulation resistance detection subprogram, and zero-sequence signal detection subprogram, among others.



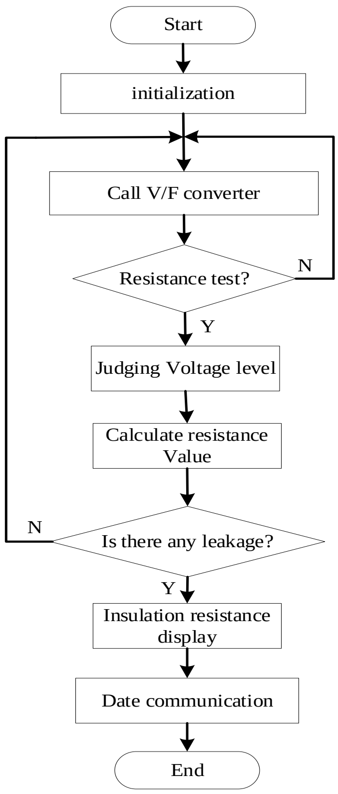


Figure 4. Flow chart of the selective leakage protection system for coal mine load centers

Figure 5. Insulation resistance detection subroutine

3. Conclusion

The leakage protection system implemented at the main power supply switch of the coal mine power grid employs the principle of an additional DC power supply. For the leakage protection at each branch's power supply switch, a zero-crossing triggering method is utilized. Additionally, robust CAN bus technology is adopted to facilitate data communication between the branch power supply switches and the main power supply switch. This enhances the safety of equipment in the coal mine load center and provides technical assurance for the safety of personnel working underground in the coal mine.

References

[1] W. Yuanyuan, Z. Xiangjun and S. S. Choi, "Ground fault protection scheme using leakage current in ineffectively earthed power systems," 2007 International Power Engineering Conference (IPEC 2007), Singapore, 2007, pp. 488-493

[2] G. Hong, S. Zhu, H. Huang and X. Wei, "Emergency Treatment in Case of Electric Leakage Protection Device Failure," 2022 International Conference on Information Technology, Communication Ecosystem and Management (ITCEM), Bangkok, Thailand, 2022, pp. 126-129

[3] C. Pochet, H. Jiang and D. A. Hall, "Ultra-Low Leakage ESD Protection Achieving 10.5 fA Leakage," 2021 IEEE International Symposium on Circuits and Systems (ISCAS), Daegu, Korea, 2021, pp. 1-5

[4] Y. Wei, Z. Yanxu, H. Kangtao, T. Niang, L. Guobang and H. Mingxin, "Development of a New Type of Leakage Current Protection Device for Distribution Network," 2023 5th International Conference on Smart Power & Internet Energy Systems (SPIES), Shenyang, China, 2023, pp. 64-69

[5] Y. Yang and P. Zhang, "A Novel Over-Temperature Protection Technique Based on Leakage Current for IGBT Modules," IECON 2020 The 46th Annual Conference of the IEEE Industrial Electronics Society, Singapore, 2020, pp. 3025-3030

[6] Xiaoling Yang and Zhan Li, "Design and simulation of FIR digital filter of High-Voltage Network leakage protection in underground mine," 2010 International Conference on Computer Application and System Modeling (ICCASM 2010), Taiyuan, 2010, pp. V8-84-V8-88

[7] Zhuang Wei and Mu Longhua, "CPS based relay protection system for underground coalmine distribution networks," 2010 International Conference on Power System Technology, Hangzhou, 2010, pp. 1-6

[8] Y. Liu, T. Yu, S. Gao, J. Lu, S. You and D. Huang, "Development of a leakage current monitoring system of iced insulators base on fiber optic transmission," 2009 IEEE 9th International Conference on the Properties and Applications of Dielectric Materials, Harbin, China, 2009, pp. 1038-1042