Design of the Disconnection Fault Detection System for Low Voltage Cable in Power System

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Abstract. The paper proposes a designed scheme for the fault detection system of low voltage cable breakage in power system. By analyzing the characteristics of low voltage power line communication channel, establishing the channel characteristic model and comparing the measurement data with the simulation model, the author summarizes the impedance characteristics, noise characteristics and attenuation characteristics. It can be concluded that the suitable frequency range for communication is between 120kHz and 20kHz. The signal modulation method is studied, that the spread spectrum modulation is a preferred method. It also shows good results in the simulation. The object testing is done. The device and test method selected by author can be used to realize the early warning function of the power system low-voltage cable disconnection fault.

1. Introduction
Now days, the application of transmission cable is gradually increasing, widely application and of high value [1]. However, cable breakage caused by construction, natural disasters and man-made stealing occurs frequently, which not only seriously affects power supply stability, damages important units such as factories, hospitals, schools, and various monitoring equipment are not functioning properly, but also causing huge economic losses [2].

Therefore, the paper proposes a cable disconnection alarm system based on power line carrier communication detection and GSM wireless alarm. It monitors the cable status in real time. It will immediately send an alarm message to the mobile phone when finding the disconnected line. The staff can take measures to restore power supply and reduce losses in time.

2. Carrier communication channel characteristics analysis
The channel characteristics determines the stability and reliability of carrier communication[3]. Therefore, it is necessary to accurately grasp the channel characteristics, find the specific frequency, test a way of carrier signal modulation method and design a stable and reliable carrier communication device. Here gives the research.

2.1 The impedance characteristics
The impedance characteristic is the impedance of the power line input port. When the impedance matches the impedance of the carrier transmitter output port, the maximum coupling power can be obtained [4].

In order to verify the correctness of the law of change of the field calculation results, the impedance measurement circuit shown in figure 1 is used to measure the power line input port impedance [5]. The
measurement results and linear fitting curve are shown in figure 2. The measurement results are basically consistent with the simulated impedance trend.

![Figure 1. Impedance measurement circuit](image1)

**Figure 1.** Impedance measurement circuit

**Figure 2.** Impedance measurement

### 2.2 Attenuation characteristics

The attenuation characteristic determines the transmission distance of the carrier signal, and the attenuation characteristics of different frequency segments are quite different. Therefore, grasping the attenuation characteristics of the channel is beneficial to determining the carrier signal frequency [6].

#### 2.2.1 Multipath attenuation curve

The multipath transmission model is shown in equation (1). Applying this channel model and selecting suitable parameters as shown in Table 1. The multipath attenuation frequency characteristic curves shown in figure 3 and figure 4 can be obtained.

\[
H(f) = \sum_{i=1}^{N} g_i \cdot e^{-a_i f + a_i f d_i} \cdot e^{-j 4 \pi f d_i / c_0}
\]

(1)

#### Table 1. Multipath model parameters

| Attenuation parameter | Path parameter | Table 1. Multipath model parameters |
|-----------------------|----------------|-----------------------------------|
| \(k=1\)               | \(a_0=0\)      | \(a_1=7.8 \times 10^{-10}\)      |
| \(i\)                 | \(g_i\)        | \(d/m\)                          |
| 1                     | 0.67           | 200                               |
| 2                     | 0.32           | 249                               |
| 3                     | 0.65           | 156                               |
| 4                     | -0.18          | 123                               |

#### 2.2.2 Attenuation characteristics measurement

In order to verify the correctness of the simulation analysis, the paper uses the measurement circuit shown in figure 5 to measure the attenuation characteristics in the laboratory environment [7].

The measurement circuit measures three sets of socket interfaces in the laboratory environment, and the distance between each of them is about 10m. The measurement data is drawn, and one certain set of data is selected for fitting. The result is shown in figure 6.

![Figure 3. Two path attenuation curves](image2)

**Figure 3.** Two path attenuation curves

![Figure 4. Four path attenuation curves](image3)

**Figure 4.** Four path attenuation curves
2.3 Noise characteristics

Through long-term actual measurement, the paper captures a large number of noise waveforms and classifies the noise according to the waveform characteristics [8]. The waveforms in the measurement results are shown in figure 7, figure 8, and figure 9 representatively.

The above figures are the instantaneous signal waveform captured by the oscilloscope for a long term. In the low frequency band, the noise intensity gradually increases, and the noise fluctuation in the frequency range of 100 kHz to 200 kHz is relatively stable, and the noise amplitude fluctuates greatly after 200 kHz. Therefore, it shows that 100kHz-200kHz is more suitable for carrier communication.

3 Carrier communication modulation mode selection

The paper uses specific channel model above and simulation tool to simulate the anti-interference performance of different communication modulation modes. The results show that the spread spectrum modulation has better anti-interference performance and multipath fading resistance. The simulation model and simulation results of the spread spectrum modulation are shown in figure 10 and figure 11.
4 The structure of monitoring system

According to the analysis results of the above channel characteristics, the paper designs a carrier communication system with a communication frequency of 120 kHz, with an output impedance of 4 Ω and spread spectrum modulation.

4.1 Monitoring system hardware design

The principle block diagram of the monitoring system is shown in figure 12. The polling mode is used. If the communication fails, the cable is disconnected and the GSM alarm is activated.

The structure block diagrams of the monitoring main station and detector are shown in figure 13 and figure 14. The signal is received by the coupled port from the power line, after passing through the primary filtering and the frequency selective amplification. It enters the main control chip, and the frequency selective and amplifier circuits are shown in figure 15. The passband of the frequency selective amplifier circuit is shown in figure 16.

The simulation results show that the passband of the frequency selective amplifier circuit is just the carrier communication frequency band, which has well filtering and anti-interference effect.
Figure 15. Frequency selective amplifier circuit

Figure 16. The simulation results of the frequency selective amplifier circuit

4.2 Monitoring system software design

The software part of the monitoring system mainly consists of three parts: carrier signal transmission, carrier signal reception and GSM alarm program. The monitoring system main program block diagram is shown in figure 17.

The main program is responsible for completing the system initialization, including setting the dog feed time length, ALU operation mode (8-bit/16-bit), carrier communication configuration, serial communication configuration, timer interrupt configuration, interrupt level configuration, and interrupt enable configuration.

The carrier transmission program is called by the main program, and is responsible for transmitting the data in the register to the carrier. The encoding and spread spectrum modulation of the signal are done by the internal hardware of the controller, and outputs the square wave signal of 120 kHz.

The carrier receiving program judges the received data bit by bit, then sets the register, so that the carrier chip changes into the carrier transmitting mood. The GSM alarm program is shown in figure 18, which is called by the main program when the cable is disconnected, and sends an alarm message to the staff.

Figure 17. Monitoring system main program block diagram

Figure 18. GSM alarm program block diagram

5 Monitoring system debugging and analysis of test results

5.1 System debugging

The carrier signal output is shown in figure 19 that the 120kHz square wave signal outputted by the main control chip. The second stage of the signal passes through the power amplifier circuit, then the
LC series circuit. Finally enters the power line through the coupling port. The signal waveform is shown in figure 20, which is an approximately sinusoidal signal of 120 kHz.

The carrier signal receiving process mainly passes through several stages of coupling port, primary filtering, frequency selective amplification and ceramic filtering. The waveform of the received signal that finally enters the main control chip is shown in figure 21.

![Carrierg signal output waveform](image1)

![The power line waveform after coupling](image2)

![The signal waveform passed through the ceramic filter](image3)

After debugging, the carrier signal entering the main control chip is a 120 kHz sine wave signal, which is demodulated by the internal hardware of the main control chip, and is interpreted by the carrier receiving program to judge the state of the cable.

5.2 Analysis of test results
The main function of the monitoring system designed by the paper is to detect the cable breakage and send the alarm information when the disconnection is found. Therefore, the fault detection function of the monitoring system is tested in the laboratory environment. The two sockets are about 10 meters apart, which are used to simulate the disconnection monitoring of the 10-meter cable. After the system is started, the wires are artificially destroyed to simulate cable breakage, test the wire break detection and alarm function. The test results are shown in Table 2.

Table 2 shows the test results of the monitoring system alarm function. The test results show that the monitoring system can accurately judge the cable disconnection and send out the alarm message in time, but occasionally a false alarm will occur when the cable is not disconnected.

| Test time     | False alarm numbers | Alarm times/test times |
|---------------|----------------------|------------------------|
| 10:00-12:00   | 1                    | 10/10                  |
| 15:00-17:00   | 0                    | 10/10                  |
| 20:00-22:00   | 2                    | 10/10                  |

6 Conclusion
Based on the analysis of carrier communication channel characteristics, the paper determines the appropriate carrier communication frequency, carrier output impedance and carrier signal modulation method. Based on the theoretical research, the overall scheme of the monitoring system is designed and the hardware system and software design are completed. Finally, in the simulation test of the monitoring system in the laboratory environment, the results show that the monitoring system can accurately detect the cable breakage and send the alarm message in time. In the case of the channel interference, several false alarms message would send when the cable is not break. This situation would not occur in actual use, so the software system needs to be optimized, and the carrier signal should be allowed to have a certain bit error rate or fault tolerance. In the following part of the research, the disconnection fault detection system for low voltage cable in power system may be applied commercialize.
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