POTDR based Power Communication Optical Cable Anti External Force Damage Monitoring System

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Abstract. The traditional system has low recognition accuracy for the vibration signal of optical cable damaged by external force. Therefore, a power communication optical cable anti external force monitoring system based on potdr is designed. In terms of hardware, the modular structure of the system is constructed, the potdr distributed optical fiber sensor and power supply circuit are designed, and the vibration signal of the optical cable is collected. In the aspect of software, optical fiber communication transmits vibration signal, denoises and filters the signal, extracts the state characteristics of optical cable, and monitors whether external force damage occurs. The experimental results show that, compared with the conventional system, the designed system improves the identification accuracy of the vibration signal of the optical cable damaged by external force, and ensures the operation and maintenance management level of the optical cabl.

1. Introduction
Power communication optical cable belongs to underground concealed equipment. With the needs of construction, large machinery will continue and frequently construct around the optical cable, which will have a great impact on the power communication optical cable, and even lead to major accidents such as surface collapse\cite{1}. Therefore, the design of power communication optical cable anti external force damage monitoring system is applied to the operation and maintenance of power pipeline, which provides reference for the monitoring and control of power pipeline. It is of great significance to provide support for repair and maintenance, provide strong guarantee for the safe operation of optical cable, and improve the safe operation level of power pipeline.

With the popularization and application of computer technology, a microcomputer multi-functional insulation on-line monitoring system has emerged \cite{2}. The system takes computer processing technology as the core, combines with wireless communication technology, sensing technology, digital waveform acquisition and processing technology, and realizes more parameters on-line monitoring, with large amount of on-line monitoring information and fast processing speed. It can display, store, print, transmit and cross line alarm the monitoring parameters in real time, and realize the automation of optical cable anti damage monitoring, which represents the development direction of today’s online monitoring \cite{3}.

Domestic optical cable on-line monitoring technology has also made great progress. By using the anti external force video monitoring technology, the optical cable anti external force damage monitoring system with complete function is designed to realize the optical cable insulation monitoring, mechanical monitoring, line environment monitoring, etc., effectively solve the problem of long-distance data transmission, and improve the operation safety level of existing optical cable \cite{4}.

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On the basis of the above theory, the power communication cable anti external force monitoring system based on POTDR is designed. POTDR fully distributed vibration sensor is a typical fully distributed optical fiber sensor, which has the characteristics of distributed, long-distance, real-time and vibration sensitivity, and can be used for fully distributed monitoring of long-distance and vibration along the power communication optical cable.

2. Design of power communication optical cable anti external force monitoring system based on POTDR

2.1. System hardware design

2.1.1. Construction of optical cable anti external force monitoring system structure

The modular design concept is adopted to construct the structure of optical cable anti external force damage monitoring system. The optical cable anti external force damage monitoring system monitors and warns the optical cable external force damage in an all-weather way. When the external force damage is detected, the front end will send out a voice warning in time. With the help of wireless communication, the video data of the external force damage will be transmitted to the back-end monitoring and Analysis Center in real time. At the same time, it will be sent to the set monitoring personnel's handheld device in the form of SMS to prompt the monitoring personnel to pay attention to the alarm area to reduce the impact of external force damage on the optical cable.

Through the microprocessor, the video difference analysis of the sampled data is processed, the collected results are packaged and stored, and the alarm data of the external force damage of the optical cable is generated, so as to realize the docking of the background data. Thus, the optical cable alarm prompt is sent to the front-end sound device for sound alarm. Through the sustainable power supply, the system can carry out all-round uninterrupted real-time monitoring of the optical cable, providing a reference for the monitoring personnel to pay attention to the alarm area to reduce the impact of external force damage on the optical cable.

2.1.2. Design of POTDR distributed optical fiber sensor

The POTDR distributed optical fiber sensor is designed to collect optical fiber vibration signal. POTDR fiber sensor uses distributed feedback laser as the light source, the laser model is hua826, the linewidth is 500 kHz, the output power is 10mW, the working wavelength is 1550nm, with constant temperature and constant current control, has high wavelength and power stability, and has internal modulation function [5]. The light pulse emitted from the laser enters the polarizer after amplification and filtering, and is injected into the fiber to be tested through the circulator. When the backscattered light in the fiber returns to the incident place through the circulator, it is sent to the detector after passing a PBS, and the data acquisition card is used to process and display the returned signal [6]. The POTDR signal is very weak, which requires a high noise coefficient of the amplifier. Therefore, the same direction pumping mode with the lowest noise coefficient is adopted, the EDFA amplifier is built by itself, and the isolator at the input end of the amplifier is used to eliminate the possible interference caused by the back propagation of the spontaneous emission of the upper amplifier. The isolator at the output end is used to protect the monitoring system from the interference of the reverse reflection of the lower section Filter the noise of the amplifier and improve the signal-to-noise ratio of the system. The length of the erbium-doped fiber of the filter is 11.5 m, the wavelength of the pump source is 980 nm, and the maximum output power is 320 MW. The fiber Bragg grating with the same wavelength as the hua826 laser is used [7]. The change of polarization state in optical fiber is closely related to birefringence phenomenon in optical fiber. Only the lowest order mode is transmitted in single-mode optical fiber. For ideal single-mode optical fiber, it is actually composed of two orthogonal polarization modes with the same propagation constant [8]. In view of this phenomenon, the two
orthogonal modes are coupled, and the polarization state of light wave changes in the process of propagation. When the optical cable is damaged by external force, it will cause disturbance, ensure that the optical fiber has obvious anisotropy, generate extrinsic birefringence, and change the polarization state of transmission light [9]. The evolution information of polarization state of the optical cable damaged by external force is included in the back scattering in Rayleigh scattering light signal [10]. So far, the design of POTDR distributed optical fiber sensor is completed.

2.1.3. Design of power supply circuit for optical fiber sensor
Using the combination of solar energy and battery, the power supply circuit of optical fiber sensor is designed. According to the power consumption of the system, regional sunshine condition and battery standby time, the power control management module can realize the functions of voltage monitoring, low-voltage protection, over-current protection, automatic sleep and intelligent power management, so that the normal working days without sunshine of the monitoring system can be greater than 30 days. The optimized power supply circuit is shown in Figure 1:

![Optimized power supply circuit of optical fiber sensor](image)

After the output voltage of the solar cell is stabilized by the conversion module, the battery pack is divided and charged at the same time to make the battery pack store energy. When there is no sunshine at night, the battery releases energy for the work of optical fiber sensor, and the control module detects the capacity of each battery to realize overcharge and over discharge protection. So far, the design of the power supply circuit of the optical fiber sensor is completed, and the hardware design of the system is realized.

2.2. System software design

2.2.1. Preprocessing optical cable vibration signal
The vibration signal of optical fiber is preprocessed to realize the de-noising and filtering of optical fiber signal. Considering that in the long-term monitoring process of the system, most of the collected signals are safety signals and relatively few non safety vibration signals, the signal processing program should have the function of distinguishing and cutting the non safety vibration signals from the safety signals, so that the subsequent algorithm only needs to process the non safety signals. The monitoring system needs to compress or delete the collected original signal, so that the later signal processing and classification can meet the requirements of real-time system, and reduce the loss of useful information as far as possible to ensure the effectiveness of classification and recognition algorithm. Therefore, in
the signal preprocessing stage, in order to compress the original data and observe the unsafe vibration signal, the system should carry out simple band-pass filtering on the data.

Considering that the speech signal is also a vibration signal in essence, the system uses endpoint detection technology to distinguish the vibration signal segment and segment the vibration signal segment. The FIR digital band-pass filter is selected to preliminarily de noise the signal. The frequency band is 50 ~ 350Hz, and the data sampling rate of the system is 20kHz. The higher sampling rate can provide enough information for the vibration source localization algorithm, which can be used for the accurate positioning of the external force damage of the optical cable, greatly reducing the amount of data and improving the speed of vibration signal recognition. Since the effective signal of optical cable vibration is concentrated below 320Hz, the sampling processing below 750Hz can meet the positioning sampling.

2.2.2. State characteristics of monitoring optical cable
The state characteristics of optical cable vibration signal are extracted to prevent the optical cable from being damaged by external force. Taking a batch of real data as training samples, the signal characteristics of the training data are compared, and the time-frequency characteristics of the signal are analyzed. The higher the main frequency of the signal is, the higher the corresponding zero crossing number is. There is a linear relationship between them. The calculation formula of zero crossing $A$ is as follows:

$$A = \frac{1}{2} \sum_{i=1}^{n} \left[ \text{sgn} \left[ x(n) - B \right] - \text{sgn} \left[ x(n - 1) - B \right] \right]$$  \hspace{1cm} (1)

In the formula, $n$ is the length of data segment, $x(n)$ is the time series of optical cable vibration signal, and $B$ is the set zero crossing threshold. The vibration events around the optical cable are summarized and divided into short-term events and continuous events with long duration. When the short-term event occurs, the interval between the vibration segments is long, and each segment is relatively independent. So far, the monitoring of optical cable status characteristics is completed to determine whether the optical cable is damaged by external force, the system software design is realized, and the design of power communication optical cable anti external force damage monitoring system based on POTDR is completed.

3. Experiment
In order to test the effectiveness of the system, the following two groups of conventional systems are compared.

3.1. Experimental preparation
A certain power communication optical cable is selected as the test object, and the starting point 275 m and the ending point 4132 m are selected as the test points. The standard vibration source is used to simulate the vibration signal of the optical cable damaged by external force. Three groups of systems collect the vibration signal and its position of the optical cable, and judge the status of the optical cable through the vibration signal. The frequency domain of the detection signal is shown in Figure 2:
The spectrum characteristic of the simulated vibration signal is obvious, which contains 48
However, there are many interference signals. The vibration signals collected along the line are
accompanied by a lot of background noise, such as high-frequency noise, AC frequency noise, low-
frequency geological vibration noise, Gaussian white noise and so on. Such signals can not be directly
classified and identified, so it is necessary to de noise the signals.

3.2. Experimental result
During the mechanical construction on the optical cable site, the three groups of systems found and
alerted the construction hidden danger points in the background. At the same time, they sent the
warning SMS to the monitoring personnel. According to the warning level, the monitoring personnel
confirmed and stopped the construction hidden danger that might damage the normal operation of the
optical cable. The signal classification features extracted by the design method meet the following two
points: different types of signals have obvious differences in the performance of the features; the same
kind of signals have little differences in the performance of the features. The accuracy of three groups
of systems to identify the vibration signal of optical cable damaged by external force is shown in
Table 1:

| Construction machinery | Vertical distance of optical cable (m) | Identification accuracy of design system (%) | Recognition accuracy of conventional system 1 (%) | Recognition accuracy of conventional system 2 (%) |
|------------------------|--------------------------------------|------------------------------------------|--------------------------------------------|--------------------------------------------|
| Piling machine         | 5                                    | 98.29                                    | 95.28                                       | 93.17                                       |
|                        | 10                                   | 98.31                                    | 95.64                                       | 94.03                                       |
|                        | 15                                   | 99.93                                    | 95.21                                       | 94.86                                       |
|                        | 20                                   | 99.28                                    | 94.83                                       | 93.47                                       |
| Pipe threading operation | 5                                    | 98.92                                    | 95.59                                       | 93.54                                       |
|                        | 10                                   | 99.49                                    | 94.75                                       | 94.28                                       |
|                        | 15                                   | 99.21                                    | 94.69                                       | 93.95                                       |
|                        | 20                                   | 98.93                                    | 95.29                                       | 93.15                                       |
| Excavating machinery   | 5                                    | 98.65                                    | 94.17                                       | 93.62                                       |
|                        | 10                                   | 99.93                                    | 95.96                                       | 94.84                                       |
|                        | 15                                   | 98.29                                    | 94.53                                       | 93.29                                       |
|                        | 20                                   | 99.75                                    | 94.84                                       | 94.31                                       |
It can be seen from the above table that, for different construction machinery, the accuracy of the designed system to identify the vibration signal caused by the external force damage of the optical cable is higher than that of the two groups of conventional systems, which improves the accuracy of identifying the external force damage event of the optical cable, and fully ensures the operation and maintenance management level of the optical cable.

4. Conclusion

The design system gives full play to the technical advantages of POTDR optical fiber sensor, improves the identification accuracy of optical cable external force damage vibration signal, and divides the early warning level according to the identification results. However, there are still some deficiencies in this research. In the future research, the monitoring system and the central database server will be set up in a LAN, and the standard communication protocol which is convenient for system expansion will be used to facilitate the background to understand and master the real-time situation of the optical cable.

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