Two Modes Power Optical Fiber Network Monitoring with Protective Optical Path and Fault Self-Recovery

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Abstract. The optical fiber communication network of city power system has the characteristics of dense network, complex laying environment, and the interruption of communication is high cost. Two modes optical fiber network monitoring solution with protective optical path and fault self-recovery is discussed to ensure the reliable work of the optical fiber network. For optical fiber line that lacks core resource, the monitoring mode with protective optical path and fault self-recovery is designed to monitor working core, and the problem of waste fiber core and interruption of working core can be solved. For optical line that plenty of core resource, the monitoring mode is designed to monitor non-working core. The monitoring mode switch method is proposed, and each optical fiber can select one mode independently to adapt different demands. An optical power prediction model is proposed based on an improved Elman neural network. As result, scientific maintenance plan can be made in terms of trend analysis of optical fiber line to reduce maintenance cost. Finally, using experimental core and real optical fiber line in power system, the testing result of the monitoring solution is analyzed to illustrate the effect of the solution.

1. The first section in your paper

1.1. Optical fiber and its monitoring technology for optical fiber

With superiority of high bandwidth, low loss, built convenience and stability, optical fiber network has been widely used in communication area, such as the telecommunication industry, electric power industry, and application of fiber sensing [1]. By 2017, the length of optical fiber cable is 36 millions kilometres in China. The total length of power fiber cable is 1.5 million kilometres [2]. The 11 thousands kilometres backbone optical fiber network has been built for communication, scheduling, transmission, office business and video & audio meeting in Jilin Electric Power Company [3]. First of all, the optical fiber cable network is built along with electrical power network. Once one optical fiber line fails, the interruption will affect the safe operation of power enterprises. Secondly, the low loss can make it use for backbone communication with long distance between two substations.

Since the long distance transmission of optical fiber network, it has the characteristics of complicated environment, dense network and large fault influence. As a result, the breakage will cause
high cost of maintenance. To ensure the stability of power communication operation, it is necessary to research monitoring technology for optical fiber network [4].

As the traditional monitoring mode, optical time domain reflectometer is used to localize the fault position when received a no-light alarm. The off-line monitoring method is proposed for monitoring redundant core. The optical power meter is used to monitor optical lines online for on-line monitoring method. However, the core of line is wasted or the mode cannot be changed for different demand.

The weight of risk index is discussed for the comprehensive risk evaluation of power communication network [5]. The prediction methods have been researched and the product model is proposed for load forecasting based on decomposition technique in time series. The short-term wind speed prediction based on support vector machine in the power system is given as an review [6,7]. However, the status of optical fiber line has not been discussed.

1.2. Motivation on two modes optical fiber network monitoring solution
There are several problems of existing monitoring systems should be solved. Firstly, either the monitoring mode of working or spare core is used as the single work mode. The low sharing degree of components within the monitoring system leads to the cost of instrument is high. The fault line cannot timely switch to other lines, which caused the long time interruption of communication. Two modes monitoring solution should be designed to meet various demands, and protective optical path is used to realize fault self-recovery and ensure high levels of availability of communication. And the monitoring data is used for trend analysis for making maintenance plan to decrease fault rate.

2. Monitoring solution design

2.1. Structure design of two modes optical fiber network monitoring solution
The structure of two modes optical fiber network monitoring solution is shown as figure 1. There are \( n \) monitoring units with same structure, and each unit has two working modes, that is, monitoring mode for working core, monitoring mode for non-working (spare) core. Each unit can select one mode independently, and the mode can be changed freely. And monitoring unit \( i \) comprises monitoring sub-unit \( i_1 \) of send side and monitoring sub-unit \( i_2 \) of receive side, where \( 1 \leq i \leq n \). And sub-unit of send side includes WDM, optical switch of 2-path, sub-unit of receive side includes of WDM, three optical switches of 2-path and optical splitter. All \( n \) units use optical switch module of send side, controller&&processer unit, OTDR, two optical switches of n-path, optical alarm module, data acquisition module, non-working core monitoring module, optical power monitoring module, optical switch module of receive side, and application server and data server together. On the basis of guaranteeing functions, the sharing degree of components is improved to reduce the solution cost.

With electrical interface, \( n \) units, optical switch module of receive side, optical power monitoring module, non-working core monitoring module, data acquisition module and optical alarm module are controlled by controller&&&processer respectively. The controller&&&processer communicates with the optical switch module of send side and server by using information bus interface. The optical switch 1, switch 2, switch 3 and switch 4 are the \( 1 \times 2 \) optical switch, and the optical switch 6 and switch 7 are the \( 1 \times n \) optical switch, that is, the optical switch of \( n \)-path. And the optical splitter is a \( 1 \times 2 \) optical splitter. WDM 1 and WDM 2 are optical demultiplexer and multiplexer respectively.

2.2. Working process of the monitoring solution

2.2.1. Monitoring of working optical fiber core. As shown in figure1, the application server controls optical power monitoring module realize the online monitoring of \( n \) optical lines through optical switch 7 of \( n \)-path and optical splitter, and the communication of working core will not be affected. The monitoring process of working core monitoring mode is as follows. With data from optical terminal, the working core connects WDM and the switch 1. Then the optical point \( a \) of the switch 1 and optical point \( e \) of the switch 2 are selected to connect with protective core, the optical point \( h \) of
the switch 3 and optical point \( j \) of the switch 4 are selected to connect with optical splitter. The original communication optical is divided into communication optical and monitoring optical, and the optical point \( j \) of the switch 4 is selected to connect with optical splitter for divided optical transmission. The optical power monitoring module is connected to optical splitter through the switch 7, and the optical power value is collected by data acquisition module from optical power monitoring module, and the state of core 1 is monitored online.

Figure 1. Structure design of two modes optical fiber network monitoring solution.

When optical power of core 1 is abnormal, optical alarm module gives alarm and uploads the alarm information to the server. When receive optical alarms under the monitoring mode for the working core, the working core 1 will be detected by using optical detecting module of receive side. And OTDR is started to detect possible fault of optical line 1, the optical point a1 is selected by the switch 6, and the detecting optical is injected into the core through WDM 2 (multiplexer). Then the detecting optical is removed by WDM 1 (demultiplexer) for protecting the optical source.

With data acquisition module, detected data is uploaded to the server. Then optical switch module of send side controls the switch 6 reselect the optical point that corresponds the non-working core, and OTDR is used to monitor non-working core again. The optical switch module of receive side controls the switch 1 select point \( b \) and the optical switch module of send side controls the switch 2 select point \( e \), faulty working core can be replaced by protective optical path, fault self-recovery is realized.

2.2.2. Monitoring of non-working optical fiber core. With switch 6, non-working monitoring module can control OTDR to detect non-working core at regular intervals. The monitoring process is as follows. The optical switch module of send side and optical switch module of receive side controls the optical switch 1 and the optical switch 2 respectively to select the optical point \( b \) and the optical point \( f \), and OTDR connects with the WDM 2 through the switch 6, which selects optical path a1. And the switch 3 and the switch 4 selects optical point \( g \) and point \( i \) respectively. As a result, the testing optical of OTDR can be injected into the non-working core, and non-working core is monitored.

The monitoring data is collected by data acquisition module, and then obtained curve of monitoring data should be compared with the standard curve of the core. And then alarm will be given by the optical alarm module for abnormal difference, and then fault can be localized at application server.

2.2.3. Monitoring of non-working optical fiber core. In terms of monitoring mode of fiber core, the optical switch module of send side controls switch 1, and the optical switch module of receive side controls switch 2, switch 3, switch 4, switch 6, switch 7, the mode of each monitoring unit can change into another mode. On one side, the working core monitoring should be changed into the spare core monitoring to meet the accuracy of monitoring demands. On the other side, the non-working core
monitoring should be changed into the working core monitoring to save core resource.

To save the cost of solution, OTDR is also shared for monitoring of non-working cores and detecting of working cores. If there are more than two working cores have abnormal optical power value, optical detecting module controls optical switch 6 connect the corresponding optical path, these warned work fiber lines can be detected by OTDR in turn. Similarly, if there are more than two non-working cores, non-working core monitoring module controls the switch 6 connect the corresponding optical path, and the corresponding optical path can be monitored by OTDR in turn.

3. Monitoring solution development

3.1. Low level development of the monitoring solution
The balance of performance and cost is considered, the controller& processer unit, optical switch module of send side, optical switch module of receive side, non-working core monitoring module, optical power monitoring module, optical detecting module, data acquisition module, optical alarm module can design using the technology of single chip microcomputer and chip. For easy maintenance, all optical components and units should be integrated into an independent printed circuit board. And a TCP/IP protocol switch module is used and the standard RJ45 Ethernet is implemented as the single communication port to communicate with application server. To meet power supply industry standards of power telecommunication room, the power supply of -48V DC and 220V AC is designed uniformly for the solution. To decrease the optical loss of the solution, the optical paths among units, modules and components of optical switches, optical splitters, optical power meters and OTDR are connected by bare core.

The hardware programming is designed based on the single chip microcomputer and chip as the tie to integrate the controller& processer, optical components, module and units, including optical components of the optical switches, optical power meter and OTDR and modules of the optical switch module of send side, optical switch module of receive side, non-working core monitoring module, optical power monitoring module, optical detecting module, data acquisition module, optical alarm module and units of monitoring. With the circuit and optical path, the controller& processer can control units, modules and components. C programming is used for the soft-core modules, and all basic functions are packaged as the programming interface.

3.2. Platform development of the monitoring solution
The control communication and data transmission between the application server and data server and the controller& processer is realized. C# programming and visual studio platform is used based on TCP/IP protocol. Logical functions of two modes monitoring, modes switching, fault detecting and fault self-recovery are designed and developed firstly based on the programming interface. As a result, all operations of monitoring could be completed on the software platform. And SQL Server database is designed for saving monitoring and detecting data, fault information into the data server.

n fiber cores are selected and the mode parameter of each fiber line is set respectively, and the mode can be switched independently. Optical fiber network management module is designed, the information of lines will be managed to improve the efficiency and accuracy of monitoring and detecting. Electronic map of optical fiber network is used for convenience of alarm information display and most importantly for accurate fault location.

For working core, the monitoring data could be displayed in the platform in real time, for example -8.35dB in the normal range. With the alarm information from the optical alarm module, the alarm will be displayed, and the detecting operation should be delivered to the controller& processer. When detection data of one working optical fiber is uploaded by the detecting module to the application and data server, the fault reason is analysed immediately using detecting curve and the information of the fiber line. The parameters of wavelength and length of working core is used in the process of detection. Then the fault diagnosis conclusion is obtained in the platform for the user. For non-working core, the periodical detection is realized through the controller& processer. The curve of monitoring data
could be displayed in the platform. With the alarm information from the optical alarm module, the detection curve and event list could be displayed.

4. Optical power forecast and trend analysis
Except for the breakage of optical fiber line, all potential faults will seriously affect the reliability and available of power system. The historical monitoring data of optical fiber line at the data server can be used for optical power value forecast. The corresponding predictive optical power value curve between 26 January and 3 February of one fiber line is shown as figure 2. The rising tendency is obtained with the short-term prediction, and the optical power increases after periodical fluctuation.

An optical power prediction model is proposed based on an improved Elman neural network[8,9]. The internal feedback mechanism of the neural network improved and additional momentum and variable learning rate algorithms are introduced. As a result, the learning ability of the model is improved. At the same time, it is easy for the neural network to fall into local minimum value when using the traditional gradient descent method for weight training. In addition, a firefly algorithm with improved variable step size factor is proposed to avoid falling into local minimum value and apply to the weight optimization of each layer of the Elman model. Using the prediction of the optical power of the power optical fiber line, the status and trend of optical fiber line can be obtained by the trend analysis for scientifically making maintenance plan.

5. Testing result of the solution
The efficiency of the solution is tested by using the tail core in the laboratory and the real fiber cable. 300m tail core is used as the working core, the send side and the receive side are connected by this core. A laser light source is used at the send side. When the source is removed from the fiber core, the alarm is given by the platform and detection is started. Monitoring reflected optical power value curve of tail core is obtained, which is shown as figure 3. The curve has an obvious falling edge, which is the disconnecting position, that is, the tail of fiber core. The user can localize the position of curve with the cursor. When the fiber core is removed from the send side, the optical power is below the abnormal threshold. Then this disconnecting is detected, the detection curve is shown as figure 4. The reason of fault is obvious, and there are noise data after the rapid and obvious falling.

One 13.5km working core is selected from Jilin Company. When the send side is disconnected, it will reduce optical power below the threshold. For city optical cable network, the fault threshold of optical power should be less than the empirical value of -18dBm. As the normal state of working core, the dynamic range of the working core should be a little fluctuation. When the core removed from the laser light source at the send side, there is an obvious falling edge in the end point of fiber core, as shown in the figure 5. To obtain normal features of curve of optical fiber line, the falling edge of head side of curve and rising edge of tail side of curve is extracted. The position of events of breakpoint and breakage in the line is consistent with the falling edge or rising edge of curve, the typical falling and
rising edges are corresponding to events of start point and end point respectively. With landmark information of cable joint box and fusion splice in the line, the accurate breakpoint and breakage event can be diagnosed. And the position of these events can be located accurately by using the cursor.

Figure 4. Detection reflected optical power value curve of reflected fault tail fiber core.

Figure 5. Detection reflected optical power value curve of reflected fault tail fiber core.

6. Conclusion
For one optical fiber line of city power system, two monitoring modes are designed in this paper. The on-line monitoring mode for working core is designed, and the matching protective optical path and fault self-recovery is designed to solve great impact of faults on power operation. The off-line monitoring mode for non-working core is designed. And two modes can be switched freely. Using the monitoring data, the prediction of optical power is obtained to make maintenance plan as early as possible. The testing of the solution is given by using experimental core and real optical fiber line.

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