Research on Substation Safety Online Monitoring Based on Fiber Bragg Grating Sensor

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Abstract. This article successfully applied fiber bragg grating sensors to multi-parameter online monitoring of various objects such as substation equipment and important structures, where using various types of sensors including static level, displacement meter, inclinometer and strain gauge to remotely monitor the safety status of substation equipment and important structures in real time. It is conducive to safe and stable operation of substations. The results show that the FBG sensor can realize the automatic and real-time measurement of multi-physical quantities in the substation safety monitoring. This technology provides data support for the substation disaster prevention and reduction, and has important practical application value.

1. Introduction

As an integral part of the entire transmission and transformation system, the substation bears an important role of inheritance and development. With the development of science and technology, the substation is developing in the direction of unattended substation. However, safety issues of substation have raised higher requirements. Notably, some substation projects have caused deformation disasters such as surface subsidence or tilted facilities due to the combined effects of various factors such as inadequate soil replacement, poor drainage and geological disasters in the previous construction. As a result, they are directly threatening the safe and stable operation of substation equipment \cite{1}. Therefore, carrying out safety monitoring during the operation of the substation is conducive to preventing disasters, minimizing the possibility of adverse consequences caused by them. And it can provide an important guarantee for the safe operation of the substation.

Considering the complex structure of the substation, traditional monitoring equipment is affected by electromagnetic field interference, which makes it difficult to achieve the desired monitoring effect. Otherwise, the long monitoring time, limited observation period and frequency of manual monitoring cannot achieve real-time monitoring and early warning. More specifically, substation is in a live state where there are safety risks in site operation of monitoring personnel \cite{2}. With the development and application of information surveying and mapping, sensors, network communication and other technologies, the safety monitoring technology for large-scale projects has developed rapidly. The most representative monitoring method is fiber bragg grating sensor monitoring, which is used in substations. The advantages of deformation monitoring are obvious, mainly including the following advantages: 1) strong electromagnetic interference resistance and good electrical insulation; 2) easy to
implement distributed monitoring, multiple gratings can be written in one fiber, which can be prepared multiple or even hundreds of grating detection points; 3) high sensitivity, fast response time and high accuracy; 4) The sensor has simple structure, light weight, small volume and changeable shape. It can monitor a wide range of objects and can measure settlement, tilt, strain, etc [3, 4].

Based on this, this paper carried out the research of multi-parameter online monitoring research on the application of fiber bragg grating sensors to various objects such as substation equipment and important structures.

2. FBG sensor monitoring principle and online monitoring system architecture

2.1. Principle of fiber grating sensing

Fiber Bragg Grating (FBG) sensing technology is a kind of optical fiber sensing technology, which transmits light waves as carrier waves to the sensor device through incident light. Some characteristic variables of the light waves are modulated by physical quantities in the sensor, and the light waves containing the modulated information pass through the output fiber. Then it is transmitted to the photoelectric conversion part, and the size and state of the measured physical quantity are obtained after demodulation. The core sensor element is FBG, and its basic structure is shown in Figure 1(a), which is mainly composed of three parts: cladding, fiber core and fiber Bragg grating [5, 6].

![Figure 1. (a) Structure of fiber Bragg grating; (b) Principle of Spectral Propagation of Fiber Bragg Grating](image)

The light emitted by the broadband light source is transmitted to the FBG through the optical fiber. The light that meets the bragg condition will be reflected back, and the other light will pass through. According to the theory of fiber bragg grating coupling model, the central wavelength expression of FBG can be expressed by formula (1):

$$\lambda_B = 2n_{\text{eff}} \Lambda$$

(1)

It can be seen from formula (1) that the effective refractive index and period of FBG are the decisive factors that lead to the change of the center wavelength [6, 7]. Therefore, any external measured parameters (temperature, vibration, strain, etc.) will change the FBG effective refractive index and period, thus cause the FBG center wavelength to drift (Fig.1 (b)):

$$\frac{\Delta \lambda_B}{\lambda_B} = (\alpha + \xi) \Delta T + (1 - p_r) \xi$$

(2)
In the formula, $P_e$ is the effective elasto-optic coefficient, $\alpha$ is the linear thermal expansion coefficient of the optical fiber, $\xi$ is the thermo-optic coefficient of the optical fiber, $\Delta T$ is the temperature change, and $\varepsilon$ is the axial strain of the optical fiber. By measuring the drift of the center wavelength, the changes in temperature, vibration, strain, etc. can be reversed [6, 8, 9].

2.2. Online monitoring system

This paper employs online monitoring system of FBG sensors to monitor the safety of substation. It is mainly composed of the monitoring system consisting of sensing and demodulation subsystem, data transmission subsystem, data management and display subsystem system [11, 12], as shown in Figure 2:(1) Sensing and demodulation subsystem: Use front-end sensing equipment to monitor various characteristic information of object status, and perform data demodulation and control processing; (2) Network transmission subsystem: It is transmitted to the data processing center through the sensor network for subsequent data processing and presentation. (3) Data management and display subsystem: To realize transmission data storage and data processing, visualization and control of monitoring sampling.

![Figure 2. Overall structure of online monitoring system](image)

The above-mentioned three systems cooperate and cooperate to perform a series of steps of demodulation, acquisition, processing and analysis of the fiber grating sensor signal to realize online monitoring of physical quantities such as settlement, displacement, inclination and strain of the monitored object. Multi-channel fiber grating demodulator is used to collect sensor signals, and TCP/IP protocol is used to collect each channel of fiber grating demodulator. After peak detection and temperature compensation, the spectral data of the sensor is converted to the physical quantity corresponding to each monitoring point according to the calibration data of the sensor, and the data collection and processing of the fiber grating sensor system are better achieved.

3. Case study of Substation online monitoring

3.1. Area of study

In this paper, a Chinese substation under the influence of deformation disasters was selected as the research object. This substation is about 3300m above sea level and is backed by mountains. Due to the large temperature difference of the area, the soil is soft and the subsidence has occurred. Uneven settlement caused problems such as building cracks and equipment deviation.
A total of 100 sets of sensors were installed in this case, including 25 sets of static level and 20 sets of displacement displacement meter, 15 sets of inclinometer and 40 sets of strain gauge. This article only selects typical monitoring points (a 220kV tower) to analyze the monitoring results of various sensors. The corresponding monitoring time span is from April 15, 2019 to July 3, 2019.

3.2. Results

(1) Monitoring data of static level

In this case, the monitoring data of three static levels placed in human-shaped frame 1 ~ 3 of the 220kV area are selected for display. The result unit is mm, and a positive value indicates settlement. The monitoring results show that the monitored objects tower RG1 and tower RG3 are relatively stable during the monitoring period, the cumulative settlement is less than 1mm, and the settlement of RG2 tower is greater than 2mm.

![Figure 3. static level derived deformation at selected points](image)

(2) Monitoring data of displacement meter

In this case, the monitoring data of three displacement meters placed in the tower bracket 1 ~ 3 of the 220kV area are selected for statistical analysis. The results are in mm, with positive tension and negative compression. The displacement meters installed on the support is used to monitor the uneven settlement of the support foundation and surrounding fill. The ZJ3 monitoring result is tensile, which indicates that the surrounding fill has a sinking greater than 5 mm compared with the support foundation.

![Figure 4. displacement meter derived deformation at selected points](image)

(3) Inclinometer monitoring data

In this case, the monitoring data of three inclinometers placed in the human-shaped frame 1 ~ 3 of the 220kV area are selected for statistical analysis. The test selects the monitoring axis of the 220kV tower b equipment in the substation to be perpendicular to the frame plane, and the monitoring axis of
the structure is perpendicular to the installation plane of the measuring point. Positive and negative indicate the direction of tilt, change from positive to negative surface tilt direction, and vice versa. The inclinometer data is as follows: the unit is °, which is a single-axis inclinometer (only one axis is monitored). The monitoring results show that tower RG2 and tower RG3 are relatively stable during the monitoring period, and tower RG1 has a maximum tilt of about 0.5 degrees.

Figure 5. Inclinometer derived inclination at selected points

(4) Monitoring data of strain gauge
The strain gauge data is as follows: the unit of strain is με (1 × 10⁻⁶), positive values indicate tensile strain, and negative values indicate compressive strain. A selected of 6 strain monitoring devices were installed in the 220kV area human-shaped frame. According to the monitoring results and on-site observations, the monitored objects exhibit stability cycle change phenomena during the trial operation.

Figure 6. strain gauge derived strain at selected points

4. Conclusion
In this paper, a substation is used as the monitoring object, and a series of FBG sensor hardware devices are designed and installed. The FBG demodulator is used to collect the sensor signals, and the physical quantity corresponding to each monitoring point is converted according to the sensor calibration data. Send to the monitoring center server, and finally realize the online monitoring system of the substation. The results prove that the FBG sensor can automate and real-time measure the basic information of multiple physical quantities in the substation safety monitoring. It can provide data support for the substation disaster prevention and reduction, and ensure the safe and stable operation of the equipment.

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