Measurement of optical signal state of polarization in OPGW under lightning strike condition

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Abstract: We monitored the polarization state of the power grid Optical Ground Wire (OPGW) cable for three months in 100G-OTN system and unprecedented detected the maximum state of polarization (SOP) rotation speed of 43Mrad/s.

1. Introduction

Optical ground wire cables which integrate the function of fiber-optic communication and lightning protection, have been widely used in power utilities. However, as a kind of aerial link exposed to a dynamic environment, the state of polarization of the transmitted optical signal in the fiber is expected to change due to climatic conditions like wind or lightning strikes. The lightning induced strong electromagnetic field can lead to very fast SOP rotation resulting to transmission interruption of 100G-OTN(Optical Transport Network) equipment [1,2].

At present, some studies on the SOP transient in OPGW have been carried out in the laboratory. The results show that the SOP transient is mainly caused by the Faraday effect [3]. At the same time, the speed of SOP transient depends on the size of lightning current and the length of OPGW [4,5]. The SOP transient monitored can reach 7.727Mrad/s. The other part is mainly conducted in actual environments, and according to the measurement results, the SOP transient can reach 5.1Mrad/s by now [6]. On this basis, we monitored the polarization state of the actual OPGW for three months in lightning prone areas and detected the maximum SOP rotation speed up to 43Mrad/s.

2. Experimental investigation

2.1. Experimental setup

We conduct a 3-month experiment on the 500kV transmission line OPGW with the highest lightning frequency in the coastal areas of China, including DieLing, WuYi and JiangMen where are the most severe lightning strike areas in China from Fig.1(a). Firstly, we measured the polarization changes of the optical signal passing through this section of OPGW. Secondly, we monitored the single wave circuit error rate in power grid with 100G-OTN system. Thirdly, we used a lightning monitoring system to real-time monitor lightning strikes within a 2-kilometer range of this section of OPGW and statistically analyzed the measurement data Comparison and analysis. The experimental setup is shown in Fig. 1.

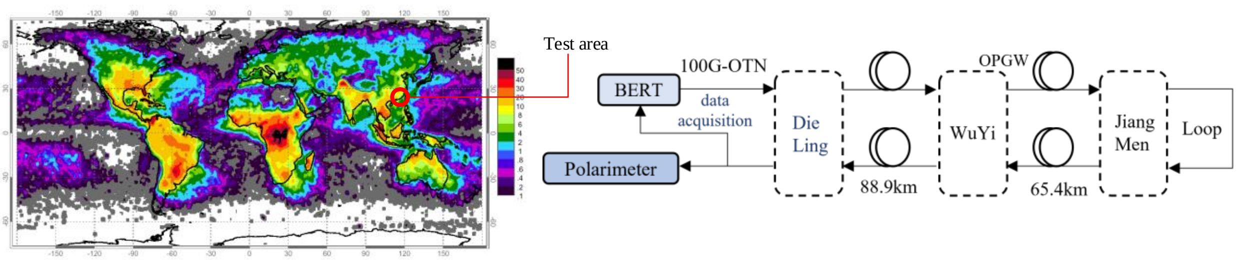

Fig. 1. (a)World Lightning Strike Distribution Map (Lightning strikes with colors above the right marker are more severe) [7] (b)Experimental setup

The polarized light source is a 10G unmodulated signal generated by the SDH/OTN analyzer EXFO FTBx-88200NGE. BERT represents both the transmitter of the optical signal and the receiver after the signal is looped back. The analyzer measures the quality of channel operation 24 hours a day and records the number of code errors and outages. The polarimeter uses the Novoptel PM1000, which samples the Stokes vector at a rate of 125MHz. The maximum SOP angle change of light measured on the Poincare sphere is π, so the maximum speed of change in the SOP measured by the polarimeter is 78.5Mrad/s. To avoid interference caused by changes in SOP due to non-lightning factors throughout the recording process, we set thresholds for the polarimeter. Data only can be recorded when the rate of change of the SOP exceeds 1.5Mrad/s [6]. The sampling interval is 40ns, and the total recording time of a single lightning strike is 40.880μs. The data signal received by power station A is sent back to the headquarters computer terminal through the MSTP special line. During the whole process, we recorded the lightning current size data within the 2km diameter of the cable where the OPGW cable carrying OTN is located through the lightning strike detection system.

2.2. Experimental results

The polarimeter measuring instrument recorded a total of 131 groups of data with SOP transients change of more than 1.5Mrad/s during the three-month measurement period. We divided SOP rotation speed into 14 gears and plotted it in Fig. 2.

From Fig.2(a), we can see that the SOP rotation speed caused by lightning is mainly concentrated between 2Mrad/s and 3Mrad/s, accounting for 26.7% of the total recording times, and the maximum SOP rotation speed even exceeds 40Mrad/s.

During a 3-month test, the lightning monitoring system detected a total of 5175 lightning strikes within a radius of 2 kilometers of OPGW, as shown in Fig. 2(b). The magnitude of lightning current is mainly concentrated between 10-30kA, accounting for 72.79% of the entire recording frequency. The probability of lightning current exceeding 100kA is extremely low, and the maximum lightning current we have monitored can reach 379.3kA.

From Fig.2, the trend of the magnitude change of lightning current and SOP rotation speed is approximately consistent, which also indicates that the magnitude of SOP rotation speed is closely related to the magnitude of lightning current.

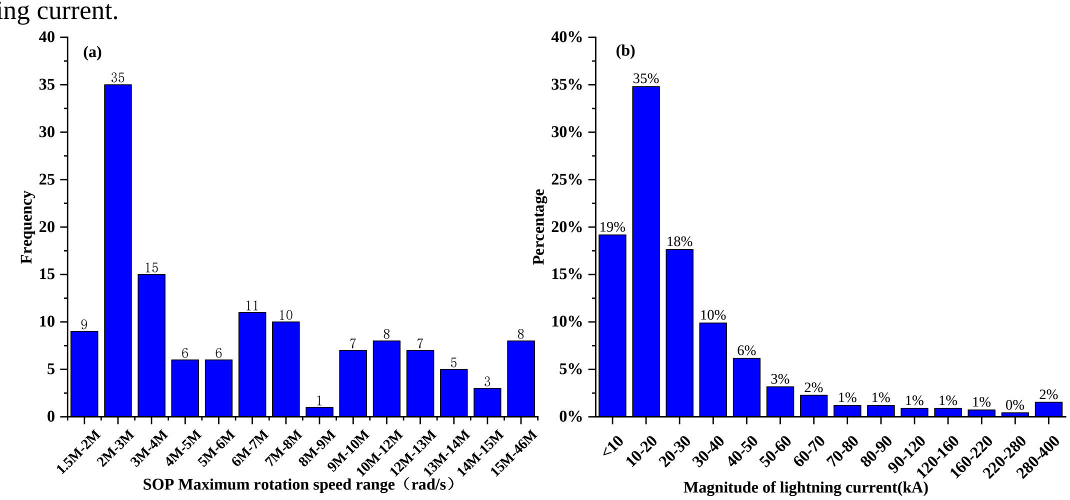

Fig. 2. (a) SOP maximum rotation speed distribution diagram (b)Lightning current size distribution diagram

We made a more detailed analysis of this recorded data with SOP rotation speed of 43Mrad/s, which is divided into three aspects:

(1) Degree of polarization

The degree of polarization reflects the proportion of the total intensity of the fully polarized light:

$$DOP = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0^2} \tag{1}$$

Where S_1, S_2, S_3, and S_0 respectively represent the Stokes vectors of the signal. We put the three parameters S_1-S_2-S_3 collected by the polarimeter and S_0 into Eq. (1) to obtain the curve of polarization degree change with time during the sampling time. As can be seen from Fig. 3(a), the variation range of its polarization degree DOP is not large, fluctuating between 0.99994 and 0.99995, and the main reason for the fluctuation may be caused by external noise during data acquisition. Therefore, we can think that the polarization degree of the signal light is unchanged under the entire lightning strike and the signal light is still fully polarized.

(2) Stokes vector curve with time

As can be seen from Fig. 3(b), when there is no lightning action, the three Stokes vectors change relatively slowly before 23μs, and under lightning, the three Stokes vectors change rapidly with time between 23 and 40μs.

(3) Rotation rate curve with time

Since the sampling interval of the polarimeter is 40ns, we use Eq. (2) to represent the size of RSOP and obtain the curve of SOP rotation speed change with time at each moment.

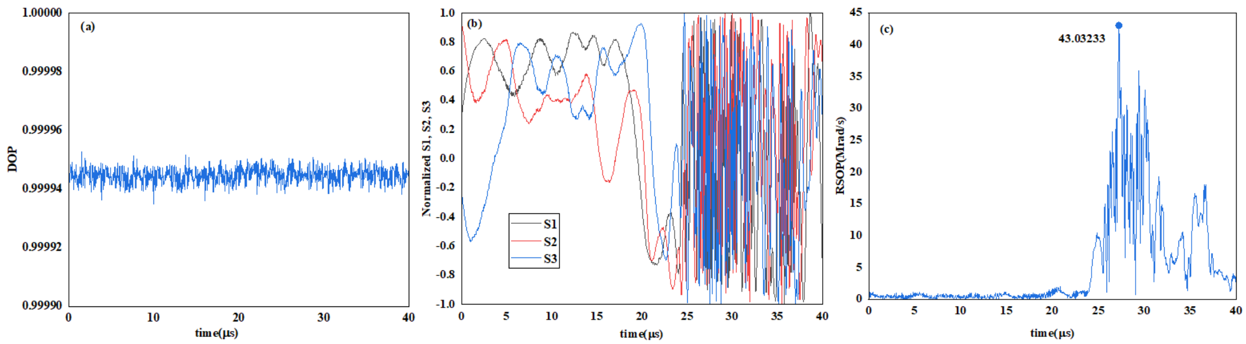

Fig. 3. Result analysis. (a) Polarization degree over time curve. (b) Stokes vector curve with time. (c) Rotation rate curve with time.

$$RSOP = \frac{\arcsin\left(\sqrt{\left(S_1(t+\Delta T)-S_1(t)\right)^2+\left(S_2(t+\Delta T)-S_2(t)\right)^2+\left(S_3(t+\Delta T)-S_3(t)\right)^2}\right)}{\Delta T} \tag{2}$$

Where ΔT is the sampling time. As can be seen in Fig. 3(c), when there is no lightning strike between 0 and 23μs, the rotation speed is basically in the range of 0-1Mrad/s; while there is lightning strike between 23 and 40μs, the rotation speed of SOP rises sharply and form multiple peaks among which the highest peak can reach 43Mrad/s. For the occurrence of multiple peaks, we believe that it may be caused by lightning striking back several times in a very short time.

3. Conclusions

We monitored actual power OPGW cables in thunderstorm-prone areas for three months and recorded the signals SOP change in the OPGW and found that the maximum SOP change rate can even reach 43Mrad/s. This provides a reference for existing OTN networks, for power grid communication systems, the algorithm's tolerance for SOP change rate may need to reach 40Mrad/s to achieve total uninterrupted communication in some lightning prone areas.

4. Acknowledgement

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5. References

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