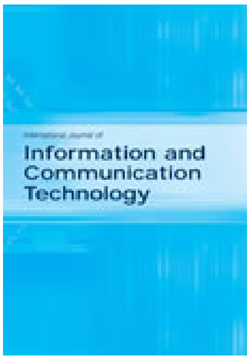

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Technique for monitoring and recovering of the polarisation state in OPGW with influencing factors analysis

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Abstract: OPGW is widely employed in China's electric-power optical communication system. It has been frequently reported that the optical transport network carried by OPGW encountered system failures due to the extreme environment, such as strong wind and lightning. To investigate this issue, this article derives a theoretical model that describes the rotation of state of polarisation (RSOP) of the optical signal inside OPGW and builds a simulation system together with conventional model of RSOP. Simulation results obtained with various sets of system parameters show that the lightning would be a major source of system outage, due to the ultra fast RSOP. Finally, suggestions are given in the aspects of receiver algorithms and system design to resolve or suppress the issues caused by the mechanical force and lightning.

Keywords: optical communication system; power line; state of polarisation; SOP; lightning strike.

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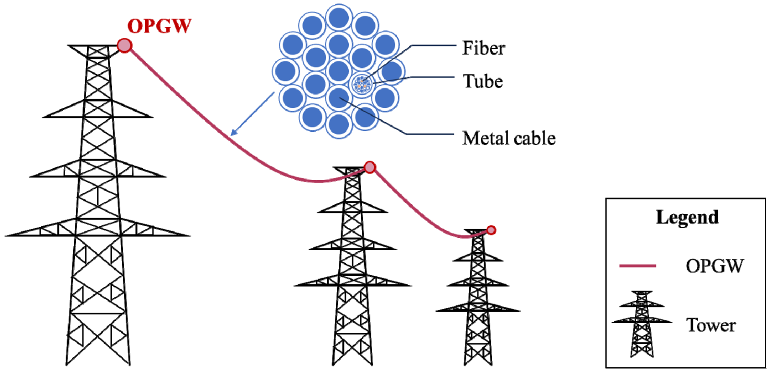
1 Introduction

Optical fibre composite overhead ground wire (OPGW) grounds the high-voltage transmission lines and enables high-capacity optical communications simultaneously. It has been widely adopted in power communication systems globally owing to its high reliability, high practicability, and ease of maintenance. Furthermore, OPGW cables, with their high strength and relatively safe and reliable operation, are highly suitable for installation on newly constructed lines. In recent years, with the increasing demand for communication, the number of fibre cores and the length of optical fibres in OPGW have continued to increase. For instance, the latest *Technical Guidelines for Planning and Designing Power Communication Network* issued by the State Grid Corporation of China stipulates that OPGW cables must be synchronously constructed in newly built overhead transmission lines of 110 kV and below, as well as 220 kV and above, with each cable having no less than 48/72 cores, respectively (Yao et al., 2023). Evidently, OPGW has gradually become the primary transmission medium for China's power backbone communication network.

To accommodate the demand for communication rates, China's power grid companies commonly choose the optical transport network (OTN) solution for newly constructed OPGW lines. Compared to the synchronous digital hierarchy (SDH) technology used in early power optical transmission communication networks, the OTN solution employs novel coherent optical communication technology and significantly enhances channel capacity through in-phase/quadrature multiplexing and polarisation multiplexing techniques. Driven by OTN technology, the mainstream communication rate carried by OPGW optical cables in China has reached 100 Gbps and is evolving towards 400 Gbps (Xu et al., 2020). However, during actual operations, both domestic and international power communication operators have repeatedly observed service interruptions in OTN systems caused by sudden changes in the polarisation state within OPGW cables (Krummrich et al., 2016; Chen et al., 2022; Charlton et al., 2017) due to lightning strikes. This indicates that polarisation variations within OPGW have become one of the key factors severely affecting the reliability of power communication systems.

Figure 1 OPGW and its typical structure in high-voltage power line (see online version for colours)



In this paper, we first make clear the mechanism of vibrate and lightning-induced changes in the state of polarisation (SOP) of optical fibre signals. Combining industry standards with observed data from existing networks, it delves into the effects of different types of wind-induced vibrations on the optical polarisation state. It points out that current optical transmission equipment can track polarisation rotations caused by wind-induced vibrations but cannot yet track severe polarisation rotations caused by lightning under extreme conditions. Based on this, a precise model is established for the temporal evolution of polarisation state rotations caused by lightning effects on optical signals. Using this model, numerical simulation is conducted to investigate the impact of lightning current on the signal polarisation state under different lightning parameters. Finally, to address the issue of rapid polarisation rotations that severely constrain the reliability of existing networks, practical suggestions are proposed from the perspectives of receiver algorithms and system design.

2 SOP in OPGW

The traditional power optical communication system carried within OPGW cables utilises SDH technology, which is based on intensity modulation/direct detection (IM/DD) of optical signals. Since optical intensity signals are insensitive to polarisation states and SDH systems have relatively low communication rates (generally below 10 Gbps), severe changes in the polarisation state of optical signals caused by various effects have insignificant impacts on SDH system performance, failing to attract sufficient attention. Nevertheless, the spectral efficiency of IM/DD system is very limited, as it only modulate information onto single dimension, i.e., the intensity of the light. It is also sensitive to fibre chromatic dispersion and polarisation mode dispersion (PMD), limiting its maximum transmission distance and line rate. In recent years, with the growing demand for communication rates, mainstream power communication networks have gradually upgraded to OTN systems based on coherent optical communication technology. The transmitters of OTN systems not only achieve amplitude and phase multiplexing but polarisation multiplexing, enabling a significant increase in communication rates. Digital signal processing techniques are performed at the receiver to compensate for the linear distortion introduced by the fibre channel and transceiver, such as laser phase noise, fibre CD, PMD, equalisation of channel response, demodulation and decoding. Moreover, the tracking and recovering the SOP enables the decoding of different information from the two orthogonal polarisation states. Although this polarisation tracking algorithm equips the coherent optical receiver the capability of tolerating against random polarisation rotation in the fibre, there is a maximum of this capability and severe polarisation state changes can even lead to failure in polarisation tracking algorithms, resulting in communication failures.

The speed of polarisation state changes in optical fibres is characterised by the angle of change per second. Table 1 shows the rates of polarisation state changes in different scenarios. For laboratory and deeply buried cables, the external environment is relatively stable, resulting in slow polarisation changes. Conversely, the polarisation state of optical signals in OPGW is highly susceptible to changes in environmental temperature, wind forces, temperature gradients, and current variations. Among these, environmental temperature and temperature gradients are long-term effects that cause relatively slow polarisation changes in optical signals. Under the influence of alternating currents, the optical polarisation state in OPGW exhibits a periodic change (50~60 Hz) that follows the frequency of alternating current (Leeson et al., 2009). These effects do not lead to rapid changes in the polarisation state within the optical cable, and their impact on fibre-optic communication systems is generally negligible.

Wind-induced vibration refers to the vibration phenomenon that occurs in OPGW cables due to the influence of wind-disturbed airflow contributed by the cross-sectional shape, fluid properties and directions, flow direction, and velocity. Common wind-induced vibrations in OPGW include Karman vortex street vibration and galloping vibration. The former is relatively mild and is also known as aeolian vibration. It is usually caused by a process known as vortex shedding and has proven to be responsible for the 'singing vibration' of suspended telephone or power lines. While, the latter, also known as 'dancing vibration', often occurs during colder winter months, especially when combined with ice accumulation on the cables. These vibrations can result in large amplitudes and easily lead to severe rotations in the polarisation state.

Table 1 Changing rate of SOP in various typical scenarios

Application scenario	*SOP rotation rate*	*RSOP compensation capability*
Fibre spool in laboratory	Hundreds of kilo-rad/s	8 mega-rad/s
Deeply buried fibre cable	Tens of kilo-rad/s	
OPGW	Up to tens of mega-rad/s	

Lightning is a weather phenomenon with high voltage, strong current, and tremendous energy, and it is a cause of damage to various systems. It happens almost everywhere in the world and has becomes the origin of a lot of failures in fibre-optic communication link as reported by the service providers. As shown in Figure 1, OPGW is typically installed at the highest point of the transmission line, serving as a lightning conductor to protect the transmission line from damage caused by lightning. A typical OPGW consists of metal strands and optical cables. The outer metal strands are used to divert lightning strikes to the ground, while the optical cables are wrapped in helical metal wires and protected by stainless steel tubes that are tightly adhered to the cables. When a lightning strike occurs, the changing current generates a magnetic field along the fibre direction, which, under the Faraday effect, dramatically alters the polarisation state of the optical signal. Meanwhile, considering the considerable length of the aerial OPGW cable, the rotation of polarisation state caused by the wind is non-negligible.

Therefore, analysing the impact of wind-induced vibration and lightning strikes on the polarisation state and transmission system of OPGW links, and researching corresponding solutions, is of crucial practical significance for improving the reliability of power communication systems. In this paper, we first review the basis concepts related to the polarisation rotation in the optical fibre and its effect on the optical signals. The various behaviours of polarisation rotation caused by wind and lightning strike are discussed. Numerical simulations are performed to investigate the rotation speed of polarisation state caused by lightning. Finally, we try to provide a couple of useful guidance to the power-line optical communication system based on OPGW. Both system level and algorithm level solutions are discussed.

3 Concepts related to the SOP of an optical signal

3.1 States of polarisation of optical signals

Light is an electromagnetic wave composed of mutually orthogonal electric and magnetic fields. The polarisation of light waves is generally defined by the direction of oscillation of its electric field. To describe the polarisation of light, we can project the electric field of light onto two mutually orthogonal directions. The polarisation state is defined as a set of amplitude ratios and phase differences between the light's vibrations in these two orthogonal polarisation directions. These two reference orthogonal polarisation directions are typically defined as the *x*-axis and *y*-axis. In polarisation multiplexing systems, the multiplexed optical field is typically represented by a 2 × 1 one-dimensional vector, namely $E = (Ex, Ey)$. Here, Ex and Ey represent the optical fields on the *x*-axis and *y*-axis, respectively, which are mutually orthogonal in polarisation directions. Therefore, they can be used to modulate different information, increasing the channel capacity.

3.2 Modelling of polarisation rotation

Standard single-mode fibres widely used in optical communication systems possess birefringence, which causes the polarisation of optical signals to rotate after transmission through the fibre. The Jones matrix is generally employed to describe the effect of optical fibres or other optical devices on the polarisation state of optical signals. The Jones matrix expression for a single-mode fibre is defined by

$$J = \begin{pmatrix} \cos\frac{\theta}{2} e^{j\frac{\varphi}{2}} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} e^{-j\frac{\varphi}{2}} \end{pmatrix} \tag{1}$$

where θ is rotation angle and φ is the phase difference between two orthogonal polarisation states. Assume an input SOP of $[E_{in,x}\ E_{in,y}]$, the output SOP is

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = J \begin{pmatrix} E_{in,x} \\ E_{in,y} \end{pmatrix} = \begin{pmatrix} \cos\frac{\theta}{2} e^{j\frac{\varphi}{2}} E_{in,x} - \sin\frac{\theta}{2} E_{in,y} \\ \sin\frac{\theta}{2} E_{in,x} + \cos\frac{\theta}{2} e^{-j\frac{\varphi}{2}} E_{in,y} \end{pmatrix} \tag{2}$$

Thus, the SOP rotation results in the mix of signals in each polarisation. The SOP can also be defined in the Stokes space, which is given by

$$s = \begin{bmatrix} |E_x|^2 - |E_y|^2 \\ 2\,\mathrm{Re}\{E_x E_y^*\} \\ 2\,\mathrm{Im}\{E_x E_y^*\} \end{bmatrix} \tag{3}$$

where Re{} and Im{} stands for the real and imaginary part of a complex number. Equations (2) and (3) is linked by

$$R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{4}$$

Here, R is the rotation matrix defined in the Stokes space, and it is equivalent to the equation (2), which is defined in the Jones space.

3.3 Wind-induced SOP rotation

The primary mechanism for the change in the polarisation state of optical signals in OPGW cables caused by wind-induced vibrations is the additional birefringence effect in the fibre due to vibrations. The vibrations generated by wind or other external forces cause bending in the fibre, altering the refractive index in specific directions within the fibre. This leads to an additional birefringence effect, finally resulting in a change in the polarisation state of light within the fibre (Leeson et al., 2009; Zhao et al., 2021; Wuttke et al., 2003).

For Karman vortex street vibrations, they primarily stem from the influence of relatively weak airflows such as gentle winds. The amplitude of these vibrations is generally within 2 to 3 times the diameter of the cable. These vibrations are typically simulated by applying mechanical vibrations to the cable. Experimental studies have shown that when the wind speed ranges from 3.6 to 25.2 km/h, the vibration frequencies caused by wind-induced vibrations are between 10 and 80 Hz (Zhao et al., 2021). Earlier observations indicate that under similar wind speeds, the rate of polarisation state change due to Karman vortex street vibrations is between 0.09 and 0.26 Hz (Wuttke et al., 2003). Therefore, the impact of Karman vortex vibrations on fibre polarisation is relatively weak.

Galloping vibrations, especially in OPGW cables with regular, non-circular cross-sections formed by ice accumulation, can lead to low-frequency but large-amplitude mechanical vibrations under wind excitation. The amplitude of these vibrations can reach 5 to 300 times the diameter of the cable, resulting in rapid polarisation rotation. In laboratory conditions, galloping vibrations are typically simulated using a dance-like motion. Experimental measurements have shown that the maximum polarisation angle rotation speed caused by galloping oscillations is 7.293 krad/s (Zhao et al., 2021).

Based on the typical capabilities of tracking the polarisation state rotation for commercial OTN equipment under laboratory conditions, the polarisation tracking capabilities of mainstream commercial OTN equipment in recent years are above 3 Mrad/s. Therefore, polarisation state rotations caused by wind can be adaptively compensated by the digital signal processing algorithms in the communication line-cards theoretically, and they are no longer a critical factor limiting the stability of newly constructed power communication systems (Chen et al., 2022). This motivates us to investigate other sources of the rotation of SOP, such as lightning strikes, and we will discuss this issue in the following section.

4 Modelling and simulation of optical polarisation change caused by lightning strikes

As shown in the inset of Figure 1, the structure of the OPGW cable indicates that when lightning strikes near the OPGW cable, a pulsed impact lightning current appears in the metal strands of the outer layer of the cable. The amplitude of this current can reach up to 105 amperes (A), with a duration typically ranging from tens to hundreds of microseconds. The varying large current within the metal strands generates a strong magnetic field along the direction of the cable (McCann, 1944). Under the Faraday rotation effect, this magnetic field causes significant rotation of the polarisation state of the optical signal (Gorbatov et al., 2022; Pittalà et al., 2018; Gorbatov et al., 2023; Hu et al., 2023). Meanwhile, this rotation varies with the change of the current in the lightning strike and interplays with the PMD effect in optical fibre (Sokolov, 2008). Therefore, the rotation speed is as fast as the lightning, which makes the tracking of SOP in the receiver-side signal processing module highly important.

There have been numerous reports in the literature on the drastic changes in polarisation state caused by lightning strikes. For example, through continuous observations lasting half a year during the summer in a lightning-prone area in North America, the maximum rotation speed of the polarisation angle caused by lightning strikes was measured to be 5.1 Mrad/s (Charlton et al., 2017). In the monitoring of the China Southern Power Grid, a maximum polarisation angle rotation speed of 29.3 Mrad/s has been measured (Chen et al., 2022). Considering the mainstream polarisation tracking levels of OTN service line cards from multi-vendors, the drastic polarisation rotation caused by lightning strikes still poses a challenge to the normal operation of current power-line optical communication networks.

4.1 Model of SOP rotation caused by lightning strikes

It is of paramount importance to accurately emulate the polarisation fluctuations caused by lightning strikes. Here we utilise a method introduced by Noe and Koch (2018). It has shown that the relationship between the polarisation rotation angle θ caused by lightning and the current I in the OPGW is as follows (Krummrich et al., 2016):

$$\theta = \frac{1}{2} V \mu_0 I \tag{5}$$

where V represents the Verdet constant; μ_0 is the magnetic permeability in vacuum, generally taken as 1.2566 × 10^{-6} H/m. The Verdet constant is in the unit of rad/(T·m), and it quantifies the response of Faraday effect of each material at given wavelength and temperature. Clearly, the polarisation angle is proportional to the Verdet of one certain material. Therefore, the polarisation rotation angle caused by lightning strikes is only related to the current flowing through the OPGW and is independent of the distance to the lightning strike point, as the influence of the distance is reflected in the current, I. Similar model is also proposed in Zhao et al. (2021).

First, we need to model the characteristics of the lighting current. In literature, the lightning current is generally described using the Heidler et al. (1999) model. According to the *Technical Guidelines for Lightning Protection of Overhead Transmission Lines (Q-CSG11077002-2018, China)*, it is recommended that the Heilder model parameters for the lightning current waveform are 2.6/50 μs, which means the wavefront duration is 2.6 μs and the wave tail duration is 50 μs. The definition of the Heilder model is given in equation (6).

$$I(t) = \frac{I_0}{\eta} \frac{(t/\tau_1)^n}{1+(t/\tau_1)^n} e^{-t/\tau_2} \tag{6}$$

where I_0 represents the maximum lightning current, η is the correction coefficient, and τ_1 and τ_2 are the time constants that determine the durations of the wavefront and wave tail, respectively.

By substituting equation (6) into equation (5), we can obtain the value of the polarisation rotation angle caused by the lightning strike. Since the lightning strike only causes rotation of the polarisation angle and does not affect the phase difference between the two polarisation states, the polarisation rotation matrices caused by the lightning strike in the Jones space and the Stokes space are respectively as follows:

$$J_{雷} = \begin{pmatrix} \cos\frac{\theta_{lightening}}{2} & -\sin\frac{\theta_{lightening}}{2} \\ \sin\frac{\theta_{lightening}}{2} & \cos\frac{\theta_{lightening}}{2} \end{pmatrix} \tag{7}$$

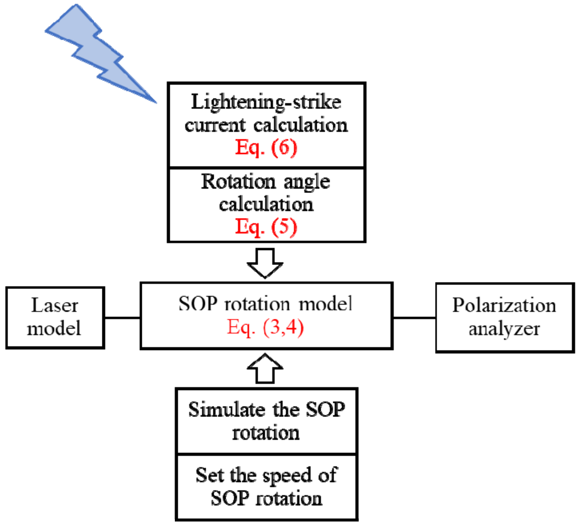
$$R_{雷} = \begin{pmatrix} \cos\theta_{lightening} & -\sin\theta_{lightening} & 0 \\ \sin\theta_{lightening} & \cos\theta_{lightening} & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{8}$$

where $\theta_{lightning}$ is the angle of SOP rotation caused by lightning strike.

4.2 Simulation of lightning-induced SOP rotation in OPGW

Numerical simulation is performed following the procedures as illustrated in Figure 2. A simple laser model which assumes a constant amplitude and a single optical frequency (193.4 THz). The phase noise of the laser is not considered here to eliminate any phase effect and focus on the lightning-induced polarisation rotation only. A standard polarisation analyser which converts the optical field in Jones space to three Stokes dimensions and plots the variation of s_1, s_2, and s_3 values for analysis.

Figure 2 Schematic diagram of the simulation system of lightning-strike-induced SOP rotation (see online version for colours)



Firstly, based on the Heilder model, we simulated four different lightning currents with random rise and fall times for the wavefront and wave tail over the entire time window. The resulting phase waveforms are shown in Figure 3(a). The parameters of the four lightning waveforms are presented in Table 2. Various ratios of $\tau 1/\tau 2$ are considered to emulate different scenarios of the practical lightning strikes. Measuring the characteristics of the lightning strikes is necessary if more accurate result is expected. A couple of methods for the lightning measurement have been reported in Han et al. (2023), Leal et al. (2018) and Rubinstein et al. (2009).

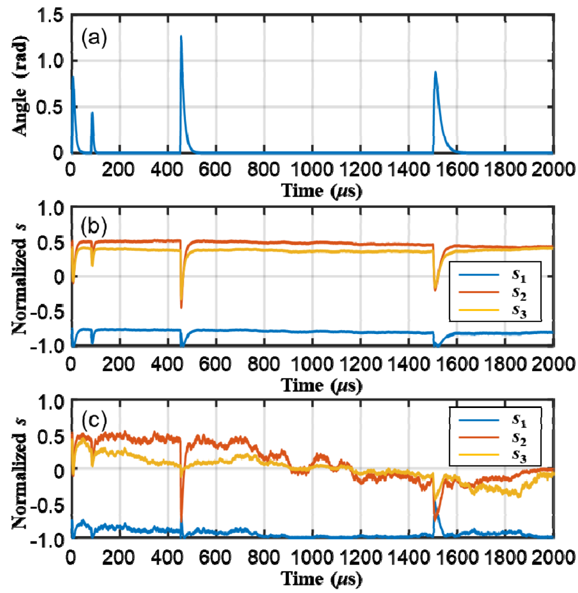
Table 2 Parameters of lightning current waveforms

Waveform no.	τ_1 *(μs)*	τ_2 *(μs)*
1	2	8
2	3	4
3	1	12
4	5	50

Secondly, for the conventional non-lightning-induced polarisation changes, we set the rates of change for the polarisation angle and phase difference to 50 krad/s and 500 krad/s, respectively. By combining these with the lightning-induced polarisation angle rotation, we calculated the final polarisation states, represented by normalised Stokes parameters, as shown in Figures 3(b) and 3(c).

When the conventional polarisation rotation angular velocity is 50 krad/s, the polarisation state remains relatively stable within the 2 ms time window. Lightning strikes cause rapid polarisation changes that gradually stabilise as the lightning current dissipates. When the conventional polarisation rotation angular velocity is increased to 500 krad/s, the polarisation state exhibits a random wandering trend. Although the magnitude of the polarisation state rotation caused by lightning is comparable to that of the conventional polarisation rotation, it can still be clearly identified.

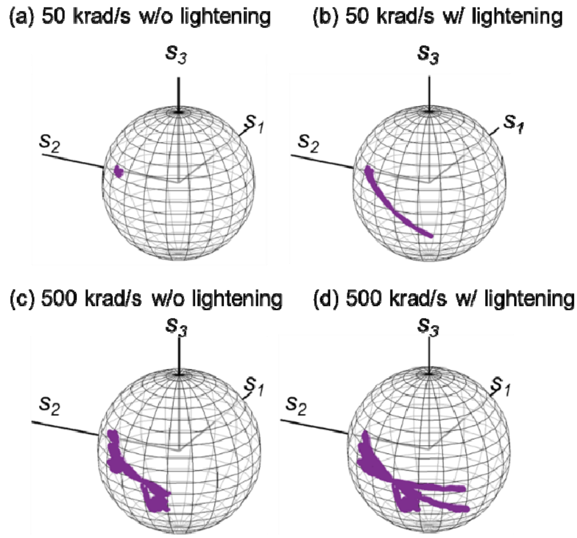
Figure 3 Simulation results of optical polarisation rotation in OPGW induced by lightning, (a) polarisation angle rotation caused by lightning current (b) evolution of optical polarisation state (s parameters) over time with a base polarisation rotation angular velocity of 50 krad/s (c) evolution of optical polarisation state (s parameters) over time with a base polarisation rotation angular velocity of 500 krad/s (see online version for colours)



Finally, we compared the impact of lightning-induced polarisation rotation on the polarisation state of the normal link on the Poincaré sphere, as shown in Figure 4. The Poincaré sphere is a commonly used representation of the polarisation state, visually displaying the normalised stokes parameters on a three-dimensional sphere. Each point in the Poincaré sphere represents one specific SOP. For example, the point in the equator indicts the linear polarisation, the north and south poles are the circular polarisation, while other points represent the elliptical polarisations. The simulation results reveal that the rapid polarisation rotation caused by lightning results in rapid changes in the polarisation state of the optical signal within a very short time.

Based on the above theoretical analysis and simulation results, it can be concluded that lightning strikes have a significant impact on the performance of coherent optical communication systems carried on OPGW lines. The rapid rotation of the optical polarisation state due to the Faraday effect is difficult to track successfully using current algorithms. However, using algorithms with faster polarisation tracking speeds inevitably increases the complexity of the receiver, this has been demonstrated in the Kalman filter approach (Liang et al., 2023). Even, the computational cost of its simplified algorithm is still significant (Huo et al., 2022). The solution to the problems caused by lightning strikes thus cannot rely on simply improving the efficiency of algorithms only. A more comprehensive solution which covers simultaneous hardware and software levels is mandatory, and this will be discussed in the next section.

Figure 4 Poincaré sphere representation of polarisation state changes under different simulation parameters, (a) base polarisation change rate of 50 krad/s, no lightning (b) base polarisation change rate of 50 krad/s, with lightning (c) base polarisation change rate of 500 krad/s, no lightning (d) base polarisation change rate of 500 krad/s, with lightning (see online version for colours)



5 Potential solutions

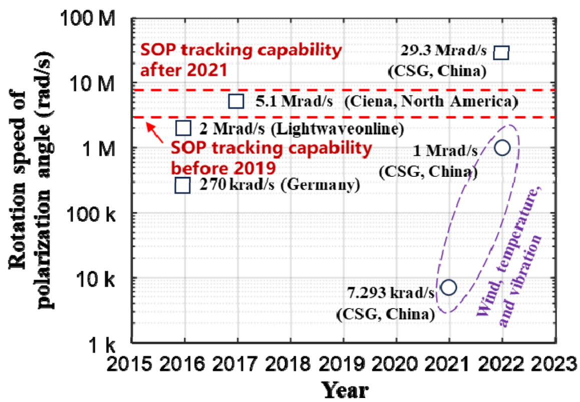
Although lightning strikes can cause rapid rotation of optical polarisation in OPGW and pose a significant challenge to the tracking speed of receiver algorithms, lightning striking OPGW is a low-probability event. According to the Design Code for Overvoltage Protection and Insulation Coordination of AC Electrical Installations (GB/T 50064-2014) and Overvoltage Protection and Insulation Coordination of AC Electrical Installations (DL/T 620-1997), the lightning current and its probability in most regions of China (excluding the northwest) can be estimated using equation (9).

$$\log_{10} P = -I / 88 \tag{9}$$

where I represents the lightning current intensity in kA, and P represents the probability corresponding to the lightning current intensity. Based on the model and simulation results presented in this paper, the polarisation angle rotation will exceed 5 Mrad/s only when the lightning current intensity exceeds 300 kA. However, according to equation (9), the probability of a lightning current intensity exceeding 300 kA is only 0.04%. Therefore, it needs to be carefully considered at the system planning level whether it is necessary to increase the complexity, cost, and power consumption of the receiver algorithm to cope with high-speed polarisation rotation.

In addition, with the continuous advancements in communication technology, the polarisation tracking capabilities of current optical communication line cards have been significantly enhanced. As shown in Figure 5, prior to 2019, the polarisation tracking capabilities of line cards were below 3 Mrad/s, whereas cards manufactured after 2021 can achieve a polarisation tracking capability of 8 Mrad/s. However, there is still a gap between this performance and the reported maximum speed of polarisation rotation caused by lightning strikes.

Figure 5 Statistics of polarisation angle rotation speeds inside OPGW reported in literature (see online version for colours)



Drawing from the simulation results above, the solution of issues related to lightning strikes can be approached from the following directions.

Direction 1: receiver algorithm level

a It is necessary to enhance the polarisation recovery algorithm's polarisation tracking capabilities while minimising the hardware complexity of the algorithm. The approach based on Kalman filtering is a good start but further cutting down the required computation is necessary.

b The use of polarisation recovery algorithms assisted by preamble sequences can improve the speed of polarisation recovery with lower hardware complexity, but comes with a compromise in net information rate. This is worth considering in the scenario when preambles are utilised for other purpose.

c Employing elastic adaptive optical receivers, which leverage perception information provided by the network control layer, can enable a switch to high-polarisation-tracking-capability algorithms during weather conditions with a high probability of lightning strikes. This approach enhances system reliability while reducing average power consumption and operational costs, but requires flexible transceivers as well as new optical network feature to support this application.

Direction 2: system design level

a The selection of novel optical fibres and cables is crucial. These new cables exhibit excellent isotropy, low PMD, and high tolerance to polarisation-related impairments. Recent deployment of G.654E fibre in power-line communication link has shown its superior performance (Xu et al., 2020).

b Optimising the design of OPGW cables to reduce the intensity of the magnetic field in the same direction as the fibre can suppress the degree of SOP rotation.

c Reducing the length of OPGW cables in areas prone to lightning strikes can enhance relevant tolerances.

d Employing forward error correction coding with better performance can improve the overall optical signal-to-noise ratio margin of the system, thereby increasing tolerance to performance losses caused by rapid polarisation rotation due to lightning strikes.

e Increasing the application of distributive sensing and monitoring applications can efficiently and accurately trigger polarisation compensation. This is foreseeable with the integration of communication and sensing, which is a on-going trend in the future fibre-optic and power-line communication system.

6 Conclusions

This paper comprehensively analyses the impact of two natural phenomena, namely, wind-induced vibration and lightning strikes, on the changes in the optical polarisation state within OPGW cables. Regarding wind-induced vibration, its maximum polarisation rotation speed falls within the safe tolerance of mainstream optical communication receiver polarisation tracking algorithms, thus it is no longer a critical factor limiting the performance of current power communication systems based on digital coherent optical communication technology. As for lightning strikes, we have established a model linking lightning currents to changes in fibre polarisation angles. By combining this model with conventional optical polarisation models in fibres, the evolution of the optical signal polarisation state in OPGW over time is simulated and analysed under different lightning parameters and typical polarisation rotation angular velocities. Finally, this paper proposes several feasible suggestions from the perspectives of receiver algorithms and system design, aiming to mitigate the impact of wind-induced vibration and lightning strikes on the performance of power optical transmission systems. The simulation models and preliminary results established in this paper can provide references and guidance for the design of power optical communication systems, thus possessing certain practical significance. The signal processing techniques related to the polarisation issue in coherent optical communication systems need further development to track the ultra fast rotation of the polarisation state. This requires the algorithm design from the device manufacturer and careful system design from the network operator, being a long-term goal for the development of OPGW-based optical communication systems.

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