Research status of optical fiber voltage transformer

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Abstract. Optical fiber voltage transformer (OVT) has the advantages of good insulation, bandwidth, and small size, and has good development prospects and application requirements. Through combing and analysis, the article summarizes the development and changes in the past ten years from the four parts of sensing probe, sensing fiber, optical information extraction and light source according to the basic principles of the OVT measurement system, analyzes the potential development direction, and finally discusses the main problems encountered in the current OVT research, and some suggestions have been put forward.

1. Introduction

As the main component of the contemporary energy system, the power system has been developing faster and faster in recent years. Its transmission capacity is getting larger and higher and the transmission voltage level is getting higher and higher. Traditionally, electromagnetic and capacitive mutual inductance are used to measure the voltage of the power system. Due to the large volume and complicated insulation, it is more and more difficult to meet the actual measurement requirements. Optical voltage transducer (optical voltage transducer, OVT) relies on optical media to sense voltage, while using optical fiber to transmit signals, it can effectively measure AC and DC voltage, and can also sense instantaneous pulse voltage, impulse voltage, etc., with good insulation performance, large measurement range, high measurement accuracy, convenient remote control and remote measurement, easy to miniaturize, intelligent, etc., has broad application prospects, and is the current key research direction of power system voltage measurement[1-2].

The research on OVT has a history of nearly 60 years, and the key voltage information optical sensitivity principle can even be traced back to the 19th century. The stability and accuracy of the early OVT are relatively poor, and most of them have only conducted principle experiments in the laboratory. With the rapid development of electronic technology in the 1980s, OVT began to carry out some practical cases, and set off a wave of research enthusiasm around the world, France’s ALSTHOM company, Sweden’s ABB company, Canada’s Nxtphase company, Japan’s Toshiba, China Electric Power Research Institute, Beijing University of Aeronautics and Astronautics, Tsinghua University, and State Grid Corporation of China have invested a lot of manpower and material resources in OVT-related research, some of which are already in power grids. The network operation has achieved good results.

In recent years, with the development of optoelectronic science and quantum computer technology and the improvement of manufacturing processes in the industrial sector, there have been many new advances and directions in the research of OVT[3-4]. The applied new OVT is sorted and classified according to technical methods, and introduced to readers from 5 aspects of the features of OVT functional components and the current problems.
2. OVT sensor probe
At present, OVT can be divided into the following three categories according to the measurement principle on which the sensor probe is based.

2.1. OVT based on electro-optical effect
The electro-optic effect refers to a phenomenon in which the material's refractive index changes significantly under the action of an external electric field[5]. The traditional theory believes that the electro-optic effect only exists in crystalline materials, but the latest research has shown that polarized polymers and fused silica glass materials can also produce electro-optic effects[6]. The relationship between the electro-optic effect caused by the applied electric field and the change in the refractive index of the crystal can be expressed as:

\[ n - n_0 = aE_m + bE_m^2 \]  

Among them, \( n_0 \) represents the refractive index of the material when the applied electric field \( E_m \) tends to zero. The electro-optic effect caused by the first term \( aE_m \) is called the linear electro-optic effect (Pockels effect). The electro-optic effect caused by \( aE_m^2 \) is called the secondary electro-optic effect (Kerr effect). Among them, the Pockels effect generally exists in crystals without a symmetry center. Although the Kerr effect is widespread, the secondary electro-optic effect is generally small, so it is not widely used as an OVT sensing measurement.

The OVT based on the electro-optical effect generally depends on the intensity of the electric field induced by the sensitive crystal, so that the measured voltage can be obtained according to the position relationship between the electrode and the sensitive crystal[7]. In practical applications, according to the measured voltage and the crystal withstand voltage characteristics, the full-voltage type in which the electrode is directly contacted with the sensitive crystal can be used, or the capacitance/resistance voltage division and the non-capacitance voltage division process can be used to achieve voltage sensitivity.

![Structure of OVT sensor head based on Pockels effect](image)

Figure 1. Structure of OVT sensor head based on Pockels effect

There are generally three types of sensitive crystals: KDP type, LiNbO₃ type and BGO type. Among them, BGO (bismuth germanate) is a cubic crystal with no natural linear birefringence and circular birefringence. It is transparent to light with a wavelength in the range of 350nm~4μm, the temperature stability is good, there is no pyroelectric effect, the half-wave voltage is high, and the large-volume crystals with excellent optical quality can be easily obtained, so more applications are obtained[8-12]. In the specific light information sensitive modulation method, according to the relationship between the direction of the applied electric field and the direction of light passing through the crystal, it can be divided into horizontal modulation (the direction of the applied electric field and the light passing direction are perpendicular to each other) and longitudinal modulation, as shown in Figure 1.
2.2. OVT based on inverse piezoelectric effect

Under the action of an electric field, piezoelectric materials will produce strain in a linear relationship with the intensity of the electric field in certain directions. This phenomenon is called the inverse piezoelectric effect, also known as the electrostrictive effect[13]. OVT based on the inverse piezoelectric effect generally converts the deformation of the piezoelectric material caused by the inverse piezoelectric effect into a sensitive modulation of optical information, and finally obtains the voltage value to be measured by detecting the optical information. Piezoelectric ceramics (PZT) is a typical piezoelectric material with the characteristics of hard texture and stable chemical properties. In an applied electric field, the relationship between its strain and electric field is expressed as follows:

$$\Delta L = dE + ME^2$$  \hspace{1cm} (2)

$ME^2$ represents the inverse piezoelectric effect, $\Delta L$ represents the strain, $E$ represents the electric field (V/m), and $M$ represents the inverse piezoelectric effect coefficient.

Piezoelectric ceramic-based OVT generally modulates the strain into optical information by modulating the strain into a change in the center wavelength of the grating, or by cooperating with an FP interferometer[14]. Figure 2 is a schematic diagram of a typical OVT sensor head based on the inverse piezoelectric effect of the F-P interferometer. The interferometer passes through the middle. The strain of the piezoelectric ceramic can change the length of the Fabry-Perot cavity, resulting in a change in wavelength. Realize the measurement of voltage.

![Figure 2. Principle structure diagram of OVT based on inverse piezoelectric effect](image)

2.3. OVT based on electro-optical rotation effect

The electro-optical rotation effect refers to the phenomenon that the polarization plane of light waves in some optical crystals rotate correspondingly under the action of an external electric field. If the rotation angle caused by it is proportional to the intensity of the applied electric field, it is called the linear electro-optical rotation effect. The electro-optical rotation effect is similar to the Faraday magneto-optical rotation effect. The latter has been widely used in optical current transformers. The difference between the two phenomena is that the Faraday effect is non-reciprocal, while the electro-optical rotation effect is reciprocal. That is, when the sensitive light wave passes through the crystal twice, the Faraday effect will double, and the electro-optical rotation effect will cancel out[15].

![Figure 3. Optical voltage sensor unit based on crystal electro rotation effect](image)

It is worth noting that the BGO crystal, which is widely used in the linear electro-optical effect, has a small electro-optical rotation coefficient. Therefore, the OVT based on the electro-optical effect generally uses lead molybdate (PbMoO4) and sodium bismuth molybdate (NaBi(MoO4))2. These two
kinds of uniaxial crystals with considerable linear electro-optical rotation effect. The OVT developed by Beijing University of Aeronautics and Astronautics using domestic lead molybdate crystals measured 50-5000 V power frequency voltage, and the resultant non-linear error was less than 0.2%[16].

3. Sensing fiber

Sensing fiber is an important part of OVT, which is responsible for maintaining and transmitting sensitive optical information to the rear for data extraction processing. However, it should be noted that when the external temperature and other environmental factors change, the optical fiber itself will be affected by thermal expansion and thermo-optical effects, which will lead to changes in its structure and performance. The sensing optical fiber mainly transmits the polarization state and wavelength etc. will also be affected, thereby affecting the measurement results of the entire measurement system, resulting in unstable output results.

Common sensing fibers include single-mode fiber, multi-mode fiber, polarization-maintaining fiber, and photonic crystal fiber. Single-mode fiber is a fiber in which only the fundamental mode can propagate within the cut-off wavelength. On the contrary, a fiber that can propagate multiple modes is called a multimode fiber. Single-mode fiber is a relatively common sensor fiber, but ordinary fiber is difficult to achieve absolute symmetry due to the limitation of manufacturing technology, and it is also affected by factors such as mechanical stress in practical applications, resulting in birefringence, leading to light polarization. It is disturbed during transmission in the sensing fiber, so that the optical information obtained by the OVT, which is sensitive to the polarization state, is lost.

Polarization maintaining fiber (PMF) is designed to artificially introduce high birefringence into the fiber through a special structure design. Commercially used polarization maintaining fibers include panda fiber, bow tie fiber, and elliptical clad fiber. The polarization-maintaining fiber artificially introduces two mutually perpendicular and opposite strains during preparation, resulting in light waves having different propagation speeds in the two polarization modes, that is, there is a phenomenon of fast axis and slow axis. This allows if the polarization of the input light is consistent with the fast and slow axis of the polarization-maintaining light, the polarization state will not change during the transmission process.

Photonic crystal fiber (PCF) has artificially designed periodic air holes. Compared with general single-mode fibers, it has the advantages of high birefringence, high nonlinearity, large mode field area, unlimited single-mode transmission, and high design flexibility[17]. Interferometric OVT uses light interference to obtain light-sensitive information. In order to obtain better interference effects, this type of OVT usually requires the same optical transmission mode and polarization state. Generally, the higher the birefringence of the fiber, the better its ability to maintain polarization, and the periodic structure of the PCF pores can easily obtain high birefringence through artificial design, so it is very suitable for interferometric OVT.

Figure 4. Sectional view of Panda polarization maintaining fiber and photonic crystal fiber
4. Optical information extraction
The voltage-optical information obtained through the sensing of the sensor probe needs to be interpreted in the OVT measurement system. Currently, there are three main methods for obtaining optical information:

4.1. Based on phase interferometry
The electro-optical effect will cause the change of the refractive index of the sensitive material in the sensor head, but the change of the refractive index is difficult to be directly measured. Therefore, in practice, the change in refractive index is usually measured indirectly by detecting the change in the phase difference of the two polarization components of the polarized light after passing through the sensitive crystal. For materials with electro-optical effects, the applied voltage when the electro-optical phase delay is exactly half a wavelength \( V \) by longitudinal modulation is called half-wave voltage \( V_{\pi} \), assuming that the applied voltage on the sensitive material is \( V = V_0 \sin(\omega t + \phi) \). Add a \( \lambda/4 \) wave plate on the optical path, by adjusting the angle between the electro-optic crystal spindle, polarizer polarization axis, and analyzer polarization axis, the phase change in the electro-optic crystal can be modulated into light intensity change. According to the optical theory of the correlation matrix, the relationship between the output light intensity \( I_0 \) and the input light intensity \( I_i \) and the applied voltage \( V \) can be obtained as Equation 3

\[
I_0 = \frac{1}{2} I_i [1 + \sin(\frac{2\pi V}{V_{\pi}})]
\]  

(3)

By detecting the change of the output light intensity, the voltage value applied to the sensitive material in the sensor head can be derived. When the phase difference in the electro-optic crystal is \( \delta < 1 \), a first-order approximation is made to Equation 3, and the approximate linear expression is Equation 4:

\[
I_0 = \frac{I_i}{2} [1 + \frac{2\pi V}{V_{\pi}}]
\]  

(4)

This approximately linear relationship can greatly simplify signal modulation and demodulation, and OVT based on phase interferometry is based on this theory. In order to effectively convert the phase conversion into light intensity changes, the interferometers used in interference mainly include the following types:

4.1.1. The Michelson interferometer is generally composed of two circuits: a sensing arm and a reference arm. The light signal emitted by the light source is divided into two light beams evenly through the coupler (split ratio 5:5), and enters the sensing arm and the reference arm respectively. The reference arm is finally reflected back to the coupler by the reflector. Because there is an optical path difference between the light beam passing through the sensing arm and the light of the reference arm, light interference occurs at the coupler, which is measured by the photodetector.

![Figure 5. Optical path structure of Michelson interferometric optical fiber sensor](image)

4.1.2. The Mach-Zehnder interferometer is basically similar to the Michelson interferometer. Both use the same light source to split two beams of light for measurement. The main difference is that it uses two couplers to measure transmitted light instead of reflected light. The interferometer reduces the
noise of the light source because there is little light reflected back to the light source. At the same time, the MZ interferometer has a smaller volume, stable performance, and a wider range of applications.

Figure 6. Optical path structure of Mach-Zehnder interference optical fiber sensor

4.1.3. Fabry-Perot (Fabry-Perot) interferometer, the light emitted by the light source enters the optical fiber after passing through the coupler, and is reflected twice by the two mirrors M1 and M2, and finally interferes at the coupler. Voltage sensitivity is the change in the optical path difference between the two mirrors to achieve voltage measurement. The F-P interferometer is simple in structure, easy to package and easy to manufacture.

Figure 7. Optical path structure of Fabry-Perot interference optical fiber sensor

4.1.4. After the light source of the Sagnac interferometer passes through the integrated optical device such as the coupler or Y-waveguide, the light beam enters the circular optical circuit, and the two light beams meet and interfere again in the forward and reverse propagation. The single loop characteristic of Sagnac interferometer makes it have the characteristics of good stability, compact structure and strong anti-interference ability. It has been widely used in fiber optic gyroscopes. Figure 7 is a typical fiber optic gyroscope optical path structure diagram. Fiber-optic voltage and current transformers based on Sagnac interferometers are also currently research hotspots[18-19].

Figure 8. Optical path structure of Sagnac interferometer in fiber optic gyroscope

In addition, new research shows that the nonlinear optical interferometer can effectively amplify the optical signal in the beam splitting process without amplifying the noise of the incident light, so that the phase sensitivity of the interference signal is greatly improved, and the sensitivity limit can exceed the standard Quantum limit is currently an emerging direction of OVT based on phase interferometry[20].

The current limitations of OVT based on phase interferometry mainly include: measurement nonlinearity; optical power correlation of measurement results due to light source fluctuations, transmission loss, fiber aging, etc.; temperature drift issues[21], etc., which need to be studied in subsequent studies. Make a breakthrough.
4.2. Based on light wavelength change measurement

The wavelength modulation sensor usually changes the wavelength of the transmitted light according to the optical transmittance of the fiber grating, the SPR effect, the photoacoustic spectrum and the characteristics of the fluorescent material, and then detects the change in the wavelength to determine the measurement parameter. This type of sensor has good anti-interference, good repeatability and high stability, and the sensor head has a simple structure, which makes it easy to build various optical fiber sensor networks.

OVT based on light wavelength change measurement is generally measured by fiber grating. In the measurement, OVT uses the fiber grating as the optical path carrier, through the connected piezoelectric ceramics or other materials that produce the inverse piezoelectric effect, the stress of the fiber grating is changed through the sensitive voltage, so that the center wavelength of the grating is shifted. The center wavelength changes to achieve voltage measurement[22]. In order to eliminate the interference of the ambient temperature in the measurement, a reference chirped grating can generally be used for temperature compensation, thereby eliminating the influence of the ambient temperature. However, this kind of secondary sensing using PZT combined with fiber grating has an extra layer of conversion compared to primary sensing, so it will introduce more errors and affect system accuracy.

![Figure 9. Optical path structure for measuring OVT based on light wavelength change](image)

4.3. Direct linear measurement

In phase-based interferometry, since only one-way analyzer can be performed and Marius's law is nonlinear, it is generally only possible to approximate a linear sine function to measure the small-angle electro-optic phase delay. At the same time, the measurement results have a strong optical power correlation, and the measurement results will be seriously affected due to factors such as temperature changes and stress birefringence in the outside world and the sensor system. Of course, by adding a closed-loop feedback link during measurement and using optical phase modulation devices such as Y-waveguides, the measurement results can be locked in the linear region and the measurement range can be increased, thereby improving the above-mentioned problems. However, a research team represented by Fuzhou University has proposed a measurement method that uses condensing displacement. This new optical information acquisition method can achieve direct linear measurement of optical phase information.

![Figure 10. Optical path structure for direct linear measurement of OVT based on condensing displacement](image)

It uses a specially designed radial polarization grating that can modulate the phase delay angle change generated by the sensitive crystal into a synchronous rotation change corresponding to the ring light spot. The ring light spot is then converted into a stripe light spot by the image converter, and finally through the alignment The measurement of the change of the center position of the light spot dark stripes indirectly realizes the linear measurement of the voltage[23]. By analyzing this detection
mode, it can be found that the measurement result is linearly related to the sensitive phase change, and there is no linear approximation; secondly, in this measurement mode, the measurement result has nothing to do with the optical power and is not affected by the light source power. The influence of fluctuation and optical path transmission loss. However, this scheme is still in the laboratory stage, and there are many optical circuits and circuit devices, and the composition is complicated. Prototype products for practical applications have not yet been produced.

5. Light source system
In the OVT system, the light source is responsible for providing the basis of the entire measurement system—light waves, which are the source of the measurement light path. However, as the external temperature changes, due to the working principle of the light source itself, its optical power and wavelength may be affected and changed. For OVT, the change of optical power will cause the output light intensity to change, and the deviation of the center wavelength will interfere with the phase difference and half-wave voltage in the electro-optic effect, which will have a great impact on the OVT measurement results[24]. Therefore, in the OVT system, the stability of the light source is very important. In practical applications, a specific light source control circuit is generally designed according to the light source used to realize the temperature control of the light source chip, so as to achieve the goal of constant output light power[25]. As shown in Figure 11, it is a structure diagram of SLD light source temperature control and constant current circuit control. Generally, the control accuracy of 0.1°C can meet most practical applications.

![Figure 11. SLD light source temperature control and constant current circuit control structure diagram](image)

The light source used in OVT generally needs to select the appropriate light source input and output power, structure size, stability, spectral characteristics, coherence and coupling difficulty according to the measurement principle, signal modulation method, system sensitivity, resolution and measurement accuracy, etc. The light source used in OVT has two types: coherent light source and incoherent light source.

5.1. Coherent light source
Coherent light sources are mainly lasers as light sources. According to different laser media, they can be divided into solid lasers, gas lasers, liquid lasers, semiconductor laser diodes (LD) and fiber lasers. The coherent light source produces a high-brightness laser with good monochromaticity, directivity, and coherence. In the polarization fiber voltage transformer, because of the high stability requirements for the output optical power, output wavelength and polarization state of optical information, many of these OVTs use laser light sources. However, during the use of laser light sources such as LD light sources, the stability of the optical power will fluctuate due to the increase in the internal temperature of the laser, and the stability is poor. In practical applications, continuous attention and adjustment of the light source temperature are required to ensure measurement accuracy. Of course, some new types of lasers such as pneumatic lasers, single-atom lasers, free electron lasers, color center lasers, X-ray lasers, etc. have shown better results in the laboratory, but they have not yet been researched and applied in OVT.
5.2. Incoherent light source
Incoherent light sources mainly include thermal light sources, gas discharge light sources, light emitting diodes (LED) and super luminescent diodes (SLD), among which SLD light sources are incoherent light sources between LED light sources and LD light sources. When the driving current is the same, the output power of the SLD is generally lower than that of the LD. Because the spontaneous radiation is amplified only once through the waveguide and does not form a laser cavity, the output is a broadband light source; the total output power of the LED may be higher, but because of the emission angle Large, low power density, it is difficult to couple to a single-mode fiber, and the amplified spontaneous emission process of the SLD light source will narrow the spectrum, so that the light emitted by it has a narrow active layer equivalent to a laser diode, which is very suitable for transmission through the fiber Therefore, it has been widely used in fiber optic gyroscopes and fiber optic current and voltage sensors.

LD, LED and SLD light sources are all used as semiconductor light sources, and their typical output spectrum and half-spectrum width are shown in Figure 12.

OVT usually contains multiple optical components, which can cause backscattering and backreflection in the optical path, leading to more stray parasitic interference and forming false signals. Broadband light sources such as SLD can significantly reduce backscatter and reflection on the optical path, thereby reducing parasitic interference.

6. Current problems
With the development of materials science, optics and electricity related research, OVT research has also undergone new changes in many aspects and perspectives, but at the same time, it still faces some key issues that need to be resolved.

6.1. Temperature stability
Because many measurement links in the OVT measurement system are sensitive to temperature, such as the temperature-induced birefringence of the optical fiber-the change of the external temperature environment will change the thermal stress distribution of the optical fiber material; the temperature stability of the light source-the temperature of the light source when it is working The change will cause the center wavelength of the incident spectrum to be biased; the sensitive crystal also has a serious temperature stability problem. The temperature change will produce a temperature-induced birefringence effect on the electro-optic crystal in the sensitive optical path of the high-voltage side, making the phase difference information generated by the system include In addition to the effective phase difference caused by the Pockel's effect, there is also a phase difference caused by parasitic effects, which affects the sensor's working state and measurement accuracy[26]. At the same time, the general OVT working environment temperature changes relatively large, it is difficult to maintain a constant temperature and stable measurement conditions, which will cause the temperature to form a large error interference to the system measurement.

In terms of solutions for temperature stability, in addition to material and technical improvements for individual links, such as the use of low-temperature-sensitive sensing fibers, sensing crystals, or temperature self-adjusting light sources, there is also a part in the measurement system The above
improvement, using the reference sensing terminal of the same environment to offset the temperature interference, or adding a prepared reference voltage source to the measurement system to form a self-calibrating system[27-28], these methods have achieved certain results and are worth continuing Research and promotion.

6.2. Measurement accuracy
Generally, when interferometric OVT realizes optical voltage information extraction, it generally converts sensitive voltage information into optical power for indirect measurement. Due to the characteristics of the trigonometric function curve, this method is first of all non-linear in the basic principle, which is accurate The reading voltage caused interference. Secondly, most OVTs are relatively susceptible to fluctuations in the light source's optical power, and ensuring a constant and stable light source's optical power requires a significant price. At the same time, there are measurement errors and temperature drift caused by the linear birefringence of optical components used in the optical path; in addition, the manufacturing process of optical components is demanding, and in actual production, the manufacturing errors of polarizers and other components will cause polarization of light. The crosstalk between these will affect the measurement accuracy of the system[29-30].

The solution to the measurement accuracy generally adopts methods such as improving the manufacturing accuracy of various components, reducing noise, compensating for temperature drift and linear birefringence. Although these methods have certain effects, the accuracy is limited and it is difficult to meet the actual measurement accuracy requirements. The closed-loop feedback adjustment by setting the system has a very good effect on improving the accuracy and improving the error. Here introduces a kind of double closed loop control system, its measuring range has good linearity and high reliability, and its control system block diagram is shown in Figure 13.

The first closed loop: phase position zero. The main working principle is: the interference light intensity is the cosine function of the phase difference between the two birefringent beams caused by the Pockels effect. The sensitivity is low at small voltages, and it is difficult to detect with ordinary methods. Through modulation and demodulation, the optical operating point is designed as a ±π/2 square wave using digital superposition processing, and the maximum sensitivity is obtained due to feedback adjustment, and then the signal output by the detector is reversed according to the polarity of the modulation wave Get the voltage to be measured.

Figure 13. Block diagram of double closed loop control system

The first closed loop is mainly to zero the phase position. The main working principle is: the interference light intensity is the cosine function of the phase difference between the two birefringent beams caused by the Pockels effect. The sensitivity is low at small voltages, and it is difficult to detect with ordinary methods. Through modulation and demodulation, the optical operating point is designed as a ±π/2 square wave using digital superposition processing, and the maximum sensitivity is obtained due to feedback adjustment, and then the signal output by the detector is reversed according to the polarity of the modulation wave Get the voltage to be measured.
The second closed loop is to reset the modulated wave. Its working principle is: the long-term slow drift of the optical device will affect the long-term stability of the measurement system. The automatic tracking technology is adopted for the phase modulator to ensure that the optical path of the measuring device is at the same working point for a long time. Long-term stability of the system.

6.3. Crystal polarization problem
At present, all OVTs used in experiments are AC measurement OVTs, and DC measurement OVT research has basically stagnated. This is because in optical DC voltage sensors, electro-optic crystals are prone to polarization under the action of a DC electric field, which destroys its own measurement characteristics. Figure 14 shows a schematic diagram of the polarization phenomenon of an electro-optic crystal. When the crystal is not polarized, the internal electric field $E_0$ of the crystal is equal to the electric field $E_0$ to be measured. When the crystal is polarized, the positive and negative charges in the crystal material are separated, resulting in a couple. The polarizer, the polarized charge will form a polarized electric field $E_i$ inside the crystal. The electric field direction is opposite to the external electric field. At this time, the electric field inside the crystal $E_{a}=E_0-E_i$, and as $E_i$ increases gradually, so offset the electric field $E_0$ to be measured. When the external electric field exceeds the coercive field of the crystal, the domain structure inside the crystal will start to invert the polarization. The above phenomenon will have a great impact on the electrical performance of the electro-optic crystal, which is the main reason for the electrical breakdown of the crystal, and it is also the main technical bottleneck for the practical application of optical DC voltage sensors.

For optical DC voltage sensors, solving the problem of crystal polarization can start from two aspects. One is to improve the current more mature optical measurement scheme based on the crystal Pockels effect, such as the use of electro-optical rotation effect, designing a reciprocal optical path, and measuring the voltage to be measured by detecting the rotation angle of the incident light; the second is tracking materials science. With the development of the manufacturing process, new electro-optical sensitive crystals have been discovered or developed to resist or weaken the polarization effect of the crystal. For example, the LiNbO$_3$ sensitive crystal independently developed by the China Aerospace Electronics Technology Research Institute, its crystal is extremely The delay time can currently reach 10 minutes.

7. Conclusion
With the development of economy and society, power systems have become more and more important, and OVT is the main development trend of power system voltage measurement. This is of great significance to the development and construction of the country's powerful smart grid and the ubiquitous power Internet of Things. However, the research results of OVT have not been satisfactory and have not yet met the conditions for wide application. Therefore, we need to pay attention to the development trend of related disciplines, introduce new theories, new methods and new materials in time, and conduct extensive research and application practices, as soon as possible to provide a reliable, stable and accurate OVT for the power industry.
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