Analysis of the detection method of insulators deterioration based on optical electric field sensors

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Abstract. With the acceleration of uh-voltage transmission project construction, transmission lines are becoming increasingly important to maintain the safe and stable operation of the power grid, and insulators are essential components of mechanical support and electrical connection in transmission lines. However, due to long-term environmental impact, insulators exposed deteriorate year by year. Therefore, it is necessary to detect the faulty insulator in advance, and to carry out the test in the operating state of the insulator string to identify and replace the faulty insulator string in time. However, the current method of detecting insulators in actual engineering is greatly affected by the environment, the test result is not accurate enough, the predictability is not good and the detection efficiency is low. The optical electric field sensor based on the Pockels effect of optical crystals can realize charged detection, improve detection accuracy, reduce environmental impact, and make the detection more stable, lower cost, better economy compared with methods widely used in the market, such as infrared detection method, ultraviolet detection method, sonic detection method, manual methods. Further consideration can be given to combining with drones to expand usage scenarios and improve detection performance for widespread use.

Key words: insulators deterioration, optical electric field sensors, charged detection.

1. Introduction
The outbreak of the COVID-19 has brought great challenges to China's economy and related industries, and its impact on energy consumption and power industry cannot be ignored. But the opportunity is born in the challenge, the epidemic will bring about a reconstruction and upgrading of my country's economy and business.

"Smart grid" will become a new direction [1], the guarantee of power supply reliability reflects the country's emergency management capabilities in response to major incidents. Comprehensive use Internet technology, big data systems, cloud computing technology to transform and upgrade. In the future, green power, energy saving and efficiency, smart grid will be the main theme of the development of the national power industry.

With the acceleration of uh-voltage transmission engineering construction, transmission lines are becoming more and more important to maintain the safe and stable operation of the power grid. Since 2010, the size of the power grid has nearly doubled, ensuring the demand for energy and electricity for economic and social development. The length of transmission lines of the State Grid has been increasing.
As of the end of 2019, the length of transmission lines of 110 (66) kV and above was 1.0934 million kilometers.

![The length of transmission lines of the State Grid](image)

**Figure 1.** The length of transmission lines of the State Grid

2. **Analysis of the insulator**

Insulators are important components of mechanical support and electrical connection in transmission lines. Although the structure is relatively simple and the cost is low, its importance is no less than other equipment and components of the power system. [2, 3]

2.1. **Insulators are in high demand.**

Insulators are the most used devices in power systems. As of December 2017, in the area under the jurisdiction of Hebei Electric Power Company, there are 192,730 series of 110 kV line insulators, 95,817 series of 220 kV lines, and 47,591 series of 500 kV lines. Among them, composite insulators account for 80% of all insulator strings, porcelain insulator string and glass insulator account for about 20%.

With the introduction of the UHV policy in the new infrastructure, the insulator industry is also developing rapidly. According to the "2018-2022 China insulator industry market monitoring and future development prospects research report" released by the New Think Industry Research Center, in 2013-2017, China's insulator product output overall showed an increasing trend, sub-products in the porcelain insulator products showed a rising trend of fluctuations, glass insulators and composite insulator products production is increasing.

**Table 1.** Insulator production in China for 2013 and 2017.

| Year | Composite insulator production / million units. | Porcelain insulator production / thousand tons. | Glass insulator production / million pieces. |
|------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------|
| 2013 | 456                                            | 456                                             | 123                                        |
| 2017 | 789                                            | 213                                             | 644                                        |

From a longer period of time, with the adjustment of domestic and foreign energy layout and the construction of transmission lines, the insulator industry will face a broader market prospects, the concentrated and rapid development of UHV has brought more rare opportunities for development.

2.2. **Insulators are deteriorated year by year.**

Line flashover and blackouts caused by the faulty insulators occur from time to time, posing a serious threat to the safe and stable operation of the power grid.

Insulators may have physical deformations during production, transportation and installation, resulting in local cracks. At the same time, as the operating life increases, insulators that have been working outdoors for a long time are subjected to mechanical and electrical loads, sun and rain, cold and heat changes, etc., and may experience reduced insulation resistance, zero value, breakdown, and other failures, reducing electrical and mechanical performance.
For example, from 2010 to 2016, the Mianyang Power Supply Company of the State Grid Sichuan Electric Power Company had insulator explosion failures on transmission lines of 110kV and above in the jurisdiction 8 times, including 4 times for 110kV lines and 4 times for 220kV lines. [4]

The insulator will lose its function after deterioration, which will damage the operating life of the entire line and affect various social life and industrial production. Electricity department data indicate that the loss caused by the flash accident due to the deterioration of insulators has ranked second in the national economy loss caused by electricity consumption, only behind lightning.

Therefore, it is necessary to detect the faulty insulator in advance, and to carry out the test in the operating state of the insulator string to identify and replace the faulty insulator string in time.

3. Insulator detection
There are many methods widely used in practical engineering, such as infrared detection method, ultraviolet detection method, sonic detection method, manual methods.

3.1. Existing insulator detection methods compared.

| Table 2. Four methods comparing. |
|---------------------------------|
| **Observation method** | **Ultraviolet method** | **Infrared temperature method** | **Sonic method** |
| **Media** | **Appearance** | **Ultraviolet light** | **Surface temperature** | **Acoustic wave** |
| **principle** | When the umbrella skirt is corroded, cracked, broken, etc, it can be found by direct observation. | | When the insulator is seriously contaminated or deteriorated, the leakage current of the insulator is abnormal, and local heating or cooling will occur. | When the insulator deteriorates, the voltage distribution will change, and the electric energy will be released accordingly, which will produce regular pressure on the surrounding air and cause the phenomenon of sound wave emission. |
| **Operation** | Electric inspectors use telescopes to patrol, inspect, or climb the tower to detect from close. | Ultraviolet imager is used to observe changes in ultraviolet light around the insulator. | The far-infrared thermometer is used to measure the thermal field distribution around the insulator string and analyze the deterioration of the insulator. | The sound wave detector is used to measure the sound amplitude value to determine the strength of the discharge of the insulator. |
| **Instrument** | Telescope. | Ultraviolet imager | Far-infrared thermostat | Sonic detector |

3.2. The disadvantages of existing detection methods.
The existing methods of detecting insulators in actual projects have many drawbacks. The detection is greatly affected by the environment, not accurate enough, the predictability is not good, and the detection efficiency is low

Observation method: Manual climbing detection is dangerous, and it is impossible to find the internal deterioration of insulators by direct observation.

Ultraviolet method: Ultraviolet imagers are too expensive and require too much investment in testing. And only strong discharge signals can be observed. In general, it only detect corona and partial discharge

Infrared temperature method: The temperature change of the insulator is not obvious when its insulation resistance is between 5-10Ω. For porcelain insulators with ordinary glaze, the normal surface temperature and the surface temperature of faulty insulators differ only by about 1 degree C, and it is difficult to detect zero-value, low-value insulators [5]. At the same time, infrared detection is susceptible
to environmental influences and is sensitive to environmental factors such as interference from solar and background radiation and meteorological conditions.

Sonic method: Since the sound wave is an accessory phenomenon caused by the deterioration of the insulator, in the actual measurement, the sound wave phenomenon is relatively common in the environment of high voltage electromagnetic field, and it is difficult to distinguish the accurate discharge situation. Therefore, it is difficult to predict the defects of the deterioration of early insulators and the decrease of insulation resistance.

3.3. Optical electric field method detects the principle of insulator deterioration.
The sensor uses the Pockels effect of the photoelectric crystal lithium niobate, that is, under the action of an external electric field in a certain direction, the light refractive index of the crystal is different. [6] It converts the spatial field strength signal into an optical power signal for transmission, and then converts the optical power signal into a voltage signal through a photoelectric converter to realize transient measurement of the external electric field. The electric field distribution data and images around the degraded insulator are collected, and compared with the electric field distribution under normal operation and the typical defect situation obtained, the defect type and degree are obtained. Using shielded sensors, the measurement circuit is completely isolated from the high-voltage circuit, which can have better anti-interference.

3.3.1. Compare with capacitive electric field methods. In the early years, the research direction of the electric field method of insulators was capacitive electric field sensors. [7~10]. It uses the sensor to generate induced charges in the alternating electric field, thereby generating a voltage on the capacitor, and the size of the electric field can be deduced by the voltage situation. [11] Finally establish the connection between the degraded insulator and the electric field.

Because this type of sensor contains metal electrodes and a metal shell, the electric field to be measured is distorted and the fault detection sensitivity is low. Some detection methods can only be implemented in the laboratory, and cannot be tested with electricity.

3.3.2. Compare with observation, ultraviolet, sonic, infrared temperature method. The advantages of electric field detection.

①Charged detection: The new detection principle realizes the charged detection of insulator deterioration. [12]

②Detection accuracy: the domestic mainstream insulator type is porcelain insulators and composite insulators. For these two types of insulators, the electric field method detects the positioning accuracy. The ceramic insulator can be accurate to the sheet and the composite insulator can be accurate to the centimeter.

③Low environmental requirements: Compared with infrared and ultraviolet detection, electric field method is less affected by changes in the external environment, and the results are more stable.

④ Lower product cost: Compared with UV imager, the cost is lower.

4. Combine drones to further improve

The electric field sensor can be highly integrated and mounted on the drone to achieve application innovation. The detection range will be increased, the application scenarios will increase, and the potential danger caused by manual climbing will reduce.

But it must be noted that when using drones, it is necessary to consider that the distance between the drone and the point to be measured remains constant to ensure the stability and rationality of the collected data. It is possible to install a laser positioning probe on the UAV for distance measurement, so that the UAV can hover at a specified distance.

At the same time, because the electric field around the insulator is used as the detection principle, the influence of the electric field of the UAV's own electrical equipment on the electric field sensor must be considered. It is recommended to measure and compare UAV related parameters, and then modify
the original degraded insulator electric field model to make it suitable for use on the basis of UAV loading.

5. Conclusion

Insulators are in huge demand in power systems, and their operation is related to line stability and national electricity safety. It is very necessary to detect the degraded insulators in advance, however, the current methods of detecting insulators (infrared method, ultraviolet method, ultrasonic method, manual observation method) have many drawbacks.

Therefore, the optical electric field method is generated on this basis and solves the above drawbacks and deficiencies. The electric field method realizes charged detection, improves detection accuracy, reduces environmental impact, and has lower cost.

It can further expand its advantages and promote its application when combined with drones.

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