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Study of Non-contact Voltage Detector of 1000kV UHV AC Based on MEMS Electric Field Sensor

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Abstract. This paper expounds the working principle of non-contact voltage detector and the electric field sensor which made by the technology of microelectromechanical systems (MEMS), determined the requirements of the detecting area and the threshold of the detector through simulation, and correct the threshold by carrying out experiments, which shows that by setting the threshold of the detector at 25kV/m, when the detector is 10-15m away from the conductors, or 2m away from the tower toward the conductor at the tower body whereas the same high as the conductor or on the crossarm, the detector can effectively identify whether the conductor is power on or off. The MEMS no-contact voltage detector and the method put forward by this paper can solve the problem of voltage detecting on UHV transmission lines, which has wide popularization and application value.

1 Introduction

Voltage detecting is an important content of operation on transmission line, at present the main method of voltage detecting used on HV transmission lines is by capacitive type voltage detector. Study of voltage detecting on 500kV and the following voltage transmission project are quite a lot, and related products and technologies are mature and reliable and has been popularized and applied [1-5]. But for the UHV transmission line, contact voltage detector needs very long insulation rod, so it is difficult to use [6-7].

For the UHV transmission lines, non-contact voltage detecting is a fast and convenient method. At present, research on non-contact voltage detecting method includes ultraviolet pulse [8-10], ultra high frequency partial discharge detection [11-13] and electric field detection near the ground [14-15]. Ultraviolet pulse and ultra-high frequency partial discharge detection can easily be affected by weather conditions and equipment status, and have poor accuracy and high cost; electric field detection near the ground can be influenced by the environment of the ground, the tower structure, the wire layout and other factors, it has poor anti-interference, complex operation, and there are false detecting and misinformation.

In this article, according to the operation characteristics of UHV transmission lines and non-contact voltage detecting problems, based on the MEMS electric field sensor, we determined the method and threshold of non-contact voltage detecting through simulation and corrected it by testing, developed two types of non-contact voltage detectors.

2 Principle of MEMS electric field sensor and voltage detecting method

The MEMS electric field sensor is based on the principle that the conductor induces charge in the electric field, as shown in figure 1. The shielding electrode and induction electrode of the sensor are conductive polysilicon material, when the shielding electrode vibrates, the induced charge on the induction electrode will change, therefore produces induced current. By using the differential detection circuit, the induced current can be detected, so as to realize the detection of electric field.

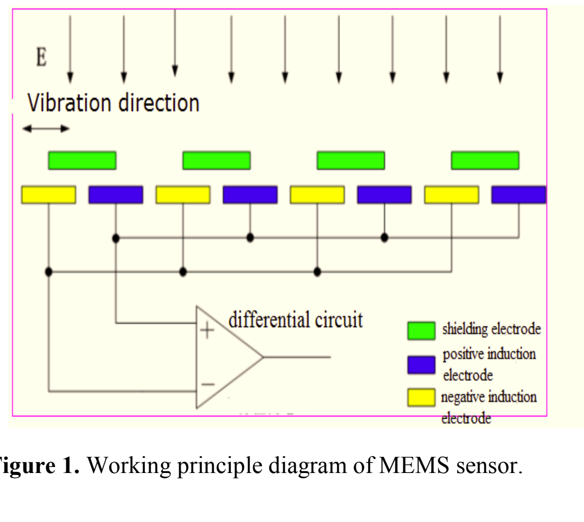


Figure 1. Working principle diagram of MEMS sensor.

Assume that the frequency of the sensor is ω_1 (2kHz~4kHz), and the initial phase is φ_1. If the electric field E is the power frequency electric field, the input electric field is:

$$E=E_0\sin(\omega_e t+\varphi_e) \quad (1)$$

E_0 is the electric field amplitude, ω_e is the signal frequency (50Hz), and φ_e is the initial phase.

As the shielding electrode vibrates periodically, the sensor formats induced current periodic, and the voltage output converted by the I/V will be:

$$V_s=\frac{dQ}{dt}\cdot R_s=K_1\cdot E_0\cdot\sin(\omega_1 t+\varphi_1)\cos(\omega_e t+\varphi_e)$$
$$+K_2\cdot E_0\cdot\cos(\omega_1 t+\varphi_1)\sin(\omega_e t+\varphi_e) \quad (2)$$

K_1 and K_2 are constants.

After the output signal is demodulated, the amplitude or the effective value is extracted, and then the signal is amplified and processed, and transmitted to the alarm circuit so to realize the function of voltage detecting. Functional diagram block of the non-contact voltage detector based on MEMS sensor is as shown in Figure 2.

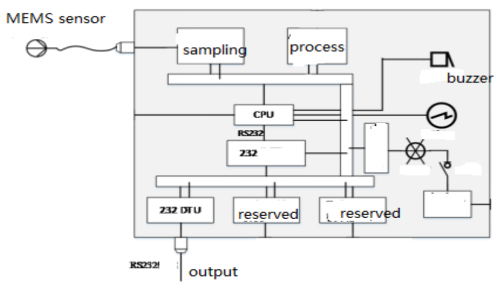


Figure 2. Functional diagram block of non-contact voltage detector.

By using the MEMS electric field sensor, the electrified condition can be determined by detecting the electric field around the UHV line. The existing research shows that the distribution of electric field around the UHV transmission line is greatly affected by the environment, and the distortion of electric field can be caused by different terrain structures, surface buildings and vegetation, etc.[16-19]. UHV double circuit lines can induce charge when one circuit is out, and there will be electric field around it; and other UHV voltage lines on the same tower will also affect the distribution of the electric field around the UHV transmission line [20-22].

In order to avoid the influence of environmental factors and induction, we can detect the electric field near the circuit. In the premise of ensuring safety, we can put the voltage detector as near as possible to the circuit. The closer to the wire, the greater the electric field intensity, the detection will be more reliable; at the same time, the closer to the wire, the more open of the surrounding, the smaller the impact of the environment.

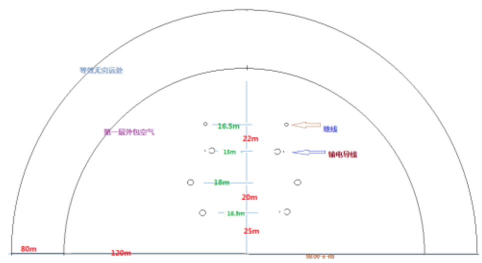
So the following two ways can be taken into consideration: 1) Using UAV carrying the voltage detector to the certain area near the circuit; 2) the workers climb up the tower, send the voltage detector to the certain area by using insulating rod. The UAV can achieve precise positioning, ranging and automatic flight and other functions, which can fully meet the detecting requirements; the workers can carry a portable insulating rod and the voltage detector to climb the tower, which is simple and safe. The two methods not only can avoid the influence of the ground environment factor, but also can avoid the inductive voltage of other lines by setting the threshold of the detector.

3 Simulation and analysis of threshold of the non-contact voltage detector

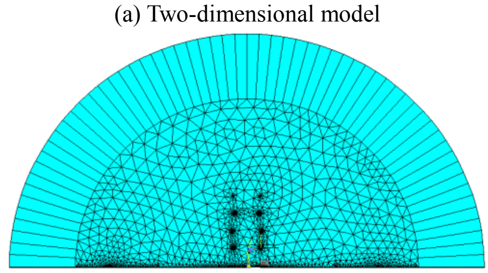
According to the principle of MEMS electric field sensor, this article built the UHV transmission line simulation models through ANSYS, and calculated the electric field distribution, so as to determine the threshold of non-contact voltage detector. According to the structural characteristics of UHV transmission line and the detecting methods, electric field distributions around the mid-span conductors and around the tower body were calculated.

3.1 Threshold of detecting near mid-span conductors

Mid-span refers to that the detecting position is more than twice the height of the tower away from the tower, under this condition the influence of tower can be ignored. Distribution of electric field around the conductor can be calculated using two-dimensional calculation method, according to the typical design of UHV transmission lines, the calculation models are as shown in Figure 3.



(a) Two-dimensional model



(b) Calculation models

Figure 3. Models of the conductors.

(1) Operation with both circuits

Assume that the double circuit of UHV transmission line is running at rated voltage, and the electric field distribution of the vertical plane is calculated, as shown in Figure 4.

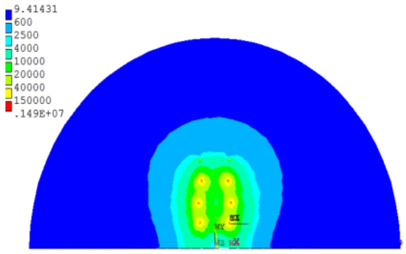


Figure 4. Electric field around the conductors when both circuits are charged.

Taking the wire as the center, the electric field lines are as shown in Figure 5.

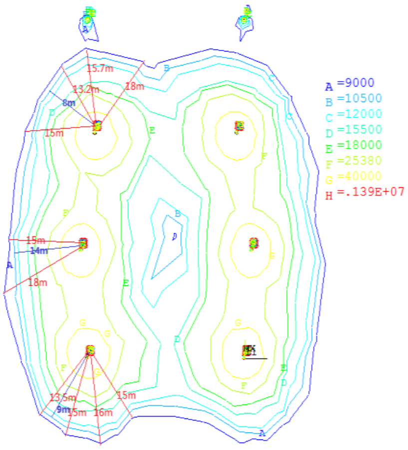


Figure 5. Electric field lines around the conductors when both circuits are charged.

(2) Operation with only one circuit

UHV double circuit lines can operate with only one circuit, according to the actual operating parameters, the electric field is calculated and is as shown in Figure 6 and Figure 7.

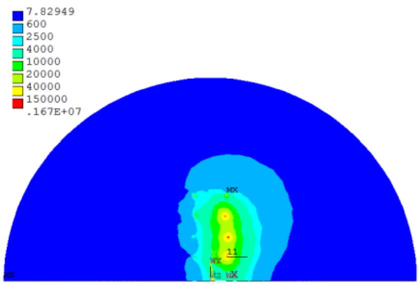


Figure 6. Electric field around the conductors when only one circuit is charged.

The results show that when the double circuit are both charged, the electric field generated around the two circuit transmission lines on both sides are the same, the closer to the conductor, the stronger the electric field intensity.

When only one circuit is running, the distribution of the electric field around the running line is nearly the same as that of the double circuits. The electric field over 2m away from the un-changed circuit is less than 7kV/m. The maximum and minimum electric field 15m away from the left and right wire on the vertical path are as shown in table 1.

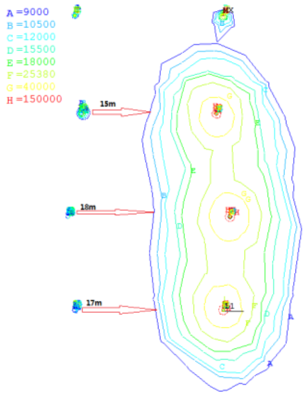


Figure 7. Electric field lines around the conductors when only one circuit is charged.

Table 1. Eigenvalue of the electric field (kV/m).

	Un-charged side	Charged side
Maximum value	0.88	20.04
Minimum value	0.46	7.82

Considering the safety of voltage detecting, chose the outside aera that 2m-15m away from the conductor as the detection aera of the non-contact voltage detector, and set the threshold as 7kV/m, then it can accurately tell the voltage condition.

3.2 Threshold of detecting on the tower

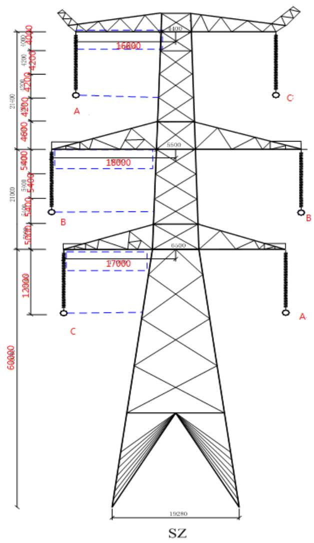


Figure 8. Structure of straight tower of the UHV transmission lines.

Ttypical tower structure of UHV double circuit lines is as shown in Figure 8, in this situation the electric field around the tower body is calculated including the situation of both circuits are charged and with only one circuit is charged.

(1) Operation with both circuits

Assume that the double circuit of UHV transmission line is running at rated voltage, and the electric field distribution of the vertical plane around the tower body is calculated, as shown in figure 9.

In the same way, the electric field distribution lines is as shown in figure 10.

The simulation results show that the electric field are larger at the tower body where is as high as the conductor and at the cross arm than the other positions.

(2) Operation with only one circuit

When one circuit is charged and the other circuit is off, the electric field distribution and contour around the tower are calculated. The results are as shown in Figure 11 and Figure 12.

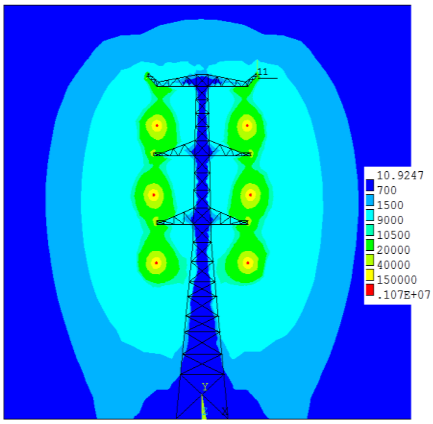


Figure 9. Electric field around the tower body when both circuits are charged.

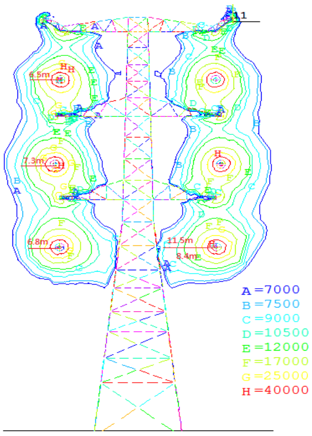


Figure 10. Electric field lines around the tower body when both circuits are charged.

It can be concluded from the calculation results that, when both circuits are charged, the electric field distribution on both side of the tower are the same, when only one circuit is charged, the electric field distribution on the live side is almost the same as that of both circus are charged, and the electric field distribution electric field distribution electric field distribution on the other side is almost shielded by the tower.

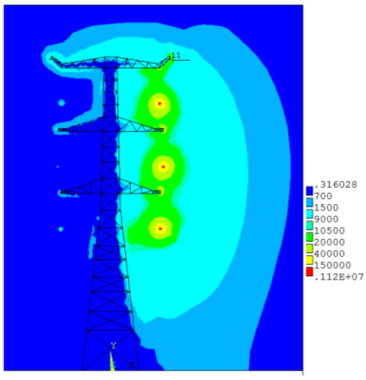


Figure 11. Electric field around the tower body when only one circuit is charged.

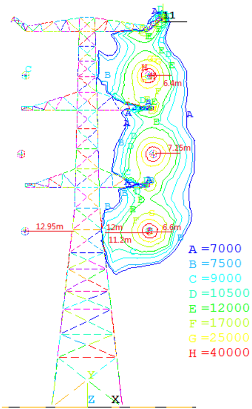


Figure 12. Electric field lines around the tower body when only one circuit is charged.

When the is circuit is charged, at the hight as the conductor on the tower body, the electric field intensity is no less than 9.8kV/m where 2m away from the tower body toward the conductor , and electric field intensity is no less than 12kV/m on the cross arms. When the circuit is off (with the other one charged), the electric field intensity less than 1kV/m from the tower and 10m away toward the conductor, and it is is less than 1kV/m where is 5m away from the conductor on the cross arms.

For the safety of voltage detecting, the threshold of the detector can be is set as 9kV/m, and fix the non-contact voltage detector to a 2m-long insulating rod, the operator can hold the insulating rod, and detect the conductor on the tower body or on the cross arms, which can accurately tell the voltage condition.

4 Calibration test of the threshold

In the actual detecting process, due to the introduction of the detector and auxiliary equipment, electric field will be distort. To determine the final threshold of non-contact voltage detector, prototype of non-contact voltage detector based on MEMS sensor is made(Figure 13). The prototype combines the sensor, signal processing circuit, alarming circuit and a display module, the sensor probe is at top of the detector, and there are start switch, liquid crystal display, parameter setting buttons and charging port on the outside of it.

In order to study the quantitative effect of the detector to the electric field distortion, this paper carried out calibration tes in the laboratory. The test uses a standard electric field electrode with an electrode spacing of 1m, and the power supply is adjustable from 0-50kV, which is shown in Figure 14. By changing the arrangement of the detector, including vertical, lateral and 60 degree angle with vertical direction, adjusting the voltage and recording electric field intensity, the result is as shown in Figure 15.

Figure 13. MEMS non-contact voltage detector.

From the results, the measurement of electric field have a good linear relationship with the power supply voltage (standard electric field). In the vertical situation, the measurement result is about 12 times of the standard electric field strength, in the lateral situation the result is smaller than inthe vertical situation, which is about 4 times of the standard electric field strength, and in the 60 degrees angle situation, the result is about 7 times. According to the test results, when the senor is right toward the the high voltage electrode, the measured value of electric field distortion is the largest.

Figure 14. Arrangement of electric field measurement correction test.

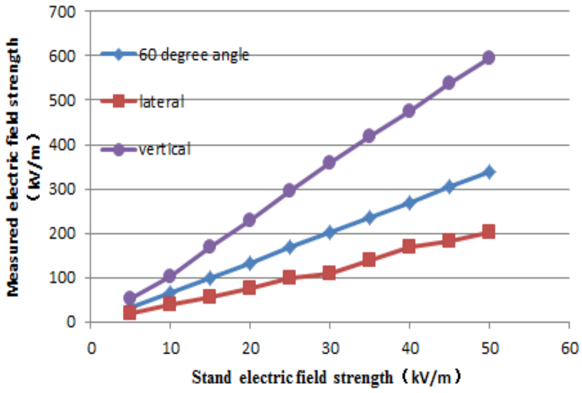


Figure 15. Results of electric field measurement correction test.

According to the simulation results of Chapter 2, when detecting at mid-span conductors, the maximum value of the electric field in the test area of the outage circuit is about 0.88kV/m, and the minimum value of the electric field is about 7.82 kV/m in the test area of the charged circuit. According to the influence of non-contact voltage detector, the alarming threshold should be set in the range of [0.88 * 12,7.82 * 4], namely [10.56,31.28]. Similarly, when detecting on the tower, the alarming threshold should be set in the range of [12,39.2].

Considering the other lines on the same tower or in the same corridor, mutiply the threshold by 2(for that the induced voltage is no more than the operation voltage), then the alarming threshold can be set to 25kV/m, which can judge the charging condition of UHV transmission lines by the methods put foward in chapter 2.

5 Applications

According to the calculation and test results, the applications are carried on actual UHV lines by using the non-contact voltage detector and methos proposed by this article, the applications are as shown in Figure 16.

Figure16. Application of the MEMS non-contact voltage detector.

The application results show that according to the detecting methods and the threshold and the the test area , interference of environmental factors and effective other transmission lines can be avoid, and can judge the charging condition of the UHV transmission lines correctly, which can solve the voltage detecting problem of UHV lines.

6 Conclusion

In this paper, based on the principle of MEMS electric field sensor, study and application of alarming threshold of the non-contact voltage detector and detecting methods are carried out, and the following conclusions can be acquired:

1)the alarming threshold of MEMS non-contact voltage detector can be set to 25kV/m.

2) when detecting at mid-span conductors, it can effectively judge the charging condition inthe aera of 2-15m away from the conductor.

3) when detecting on the tower, it can effectively judge the charging condition by extending the MEMS non-contact voltage detector toward the conductor about 2m,whether at the tower body or on the cross arm.

4) the non-contact voltage detector and the method is simple and feasible, which can meet the requirements of voltage detecting on UHV transmission lines.

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