Intelligent detection method of abnormal state of power equipment based on infrared and visible image information

Tao Liu¹, Bo Qu¹, Guolong Li*¹

¹State Grid Tieling Electric Power Supply Company, Tieling, Liaoning 112000, China
*1142101056@ncepu.edu.cn

Abstract—Infrared thermal imaging cameras are usually used to detect the thermal state of the equipment. According to the heat radiation situation and temperature value emitted by the equipment, the thermal failure of the equipment is inferred, and whether the equipment is working is verified properly. This paper analyzes the thermal imaging principle of infrared technology and the characteristics of infrared images, and quantifies the surface temperature indicators of insulators. Through infrared and visible light image information, the pollution degree of insulators can be detected, and the abnormal condition of the equipment can be checked. The evaporation of moisture on the surface of the insulator mainly depends on the assumption that the surface heats up. A method for analyzing heat on the surface of wet-contaminated insulators is proposed, and the judgment conditions for arc generation in the drying zone and the drying zone and the heating models of the insulators in different operating conditions are established. The computer simulation results reveal the distribution of heat on the surface of insulators under different operating conditions, and the influence of the occurrence of drying zone and drying zone arc on leakage current and heating. The infrared thermal imaging test results of wet-contaminated insulators show that the model is reasonable and provides theoretical support for infrared thermal imaging detection of insulator contamination levels.

1. Introduction
The root cause of the transmission line pollution flashover accident is due to the deposit of pollutants on the surface of the insulator. After it absorbs the moisture in the humid air, the insulation strength drops sharply, and it cannot withstand the working voltage and flashover occurs. Pollution flashover is a regional problem. The probability of multi-point tripping is high, and it is easy to cause large-scale and long-term malignant power outages. If the power failure cannot be resolved in time after the power failure occurs, the scope of the failure will expand, and even cause a large-scale blackout, which will have a serious impact on people's lives and the national economy. Taking effective measures to prevent and reduce pollution flashover accidents is an important guarantee for the safe operation of the power grid.

In addition to strengthening the research on pollution flashover characteristics [1], optimizing the insulator structure and the design of the equalizing ring [2]. The main methods that currently exist to prevent pollution flashover are: Literature [3] proposes a simplified equivalent circuit of a porcelain insulator string, and obtains the heating power distribution of the insulator string and the insulation resistance value during maximum heating. Literature [4] established the equivalent circuit of semiconductor glaze insulator string. Solve the temperature distribution of the insulator string through the heat balance equation. Conduct heat generation research on the insulator as a whole. The detection
of zero-value insulators has certain guiding significance. But it cannot provide information on the heat distribution along the surface of the insulator. It is also impossible to judge the formation and positioning of the drying belt. The numerical calculation results in literature [5] are all related to multiple physical parameters that need to be determined manually. The actual value is difficult to determine. And the model does not consider the drying zone and drying zone arc that may occur in the actual situation.

Leakage current method is a hot spot of current research, and a large number of researchers and scholars have done a lot of research. At present, there are many practical leakage current sensors, and the measurement accuracy is relatively high. There is a lot of interference in the measurement of leakage current. The adaptive noise cancellation technology and wavelet denoising method have also achieved good results. Therefore, there is no major problem in the measurement of leakage current, and it has been verified in practical applications. This paper proposes a method for analyzing the heat generation of wet-contaminated insulators. Experiment to obtain infrared and visible images of insulators with different pollution levels. Extract the surface of the insulator through image processing, and calculate the temperature and color characteristics of the surface respectively. It avoids manual setting of parameters, and the feature vector is concise. The results show that the information fusion method in this paper can improve the accuracy of the insulator contamination level identification. The field test results verify its practicability and effectiveness, and it is of positive significance to the field insulator contamination status detection.

2. Heating Model of Wet Contaminated Insulator

2.1. Modeling of insulator surface heating model

The pillar ceramic insulator is composed of iron caps, tempered glass parts and steel feet, and is glued together with cement glue. This article takes ZSW-12/4 type post ceramic insulator as an example. The basic parameters are listed in Tab.1.

| Parameter name | Total height/mm | Diameter /mm | Creepage distance/mm | Mounting size of upper accessory/mm | Attachment installation size/mm |
|----------------|-----------------|--------------|----------------------|-------------------------------------|-------------------------------|
| Parameter value | 210             | 155          | 240                  | Center distance 36                  | Center distance 130           |

The insulator is contaminated and damp, but \( R_j \) and \( R_s \) are basically unaffected. Evenly wet and dirty surface resistance.

\[
R = \int_{r_0}^{r_1} \frac{\rho_{ws}}{2\pi l} dl = f\rho_{ws}
\]  

In the formula, \( L \) is the total creepage distance of the insulator, \( m; \) \( dl \) is the creepage distance of the outer insulating surface, \( m; \) \( r(l) \) is the distance from the creepage distance to the insulator's rotation axis, \( m; \) \( f \) is the form factor, which is defined as

\[
f = \int_{r_0}^{r_1} \frac{dl}{2\pi l}
\]

where \( R_s \) is proportional to \( \rho_{ws} \). As the degree of contamination increases, \( \rho_{ws} \) drops sharply, so the contamination and dampness of the insulator can be simplified as a parallel circuit of \( C_o \) and \( R_s \). The heating power of the insulator is mainly changed from dielectric loss heating to surface leakage current heating.

It can be seen from the equivalent circuit of the damp and dirty insulator that the leakage current amplitude is large at this time, and the heat generated is consumed by convection, conduction,
radiation and water evaporation. The author’s experimental observations and the results of the literature all show that evaporation heat dissipation is the main heat dissipation method of wet-contaminated insulators. When the amount of water falling is less than the amount of water evaporation, the surface of the insulator is dried to form a dry zone; when the amount of water falling is greater than the amount of water evaporation, there will be no drying zone. If the electric field intensity on the drying belt exceeds a certain value, an arc will be generated in the drying belt. Therefore, the operating states of wet pollution insulators can be divided into three types, namely uniform wet pollution as a whole, wet pollution + dry zone and wet pollution + dry zone arc.

A uniform wet pollution insulator can be equivalent to a wet pollution layer resistance $R_{sw}$, as shown in Fig.1(a); after the dry belt is formed, the insulator is equivalent to the series connection of dry pollution layer resistance $R_{sd}$ and wet pollution layer resistance $R_{sw}$ (assuming the dry belt It appears on the first umbrella skirt), as shown in Fig.1(b); if a dry arc occurs, the insulator is equivalent to the series connection of the arc resistance $R_{sa}$ and the wet dirt layer resistance $R_{sw}$ as shown in Fig.1(c). Since the contamination state of insulators in actual operation is very complicated, it is assumed that:

1) The surface of the insulator is evenly polluted and damp, and the surface resistivity $\rho_{sw}$ is constant;
2) The insulator is smooth and axisymmetric, and the drying belt is in a circular ring shape;
3) At most one drying zone and one arc can be formed at the same time;
4) The arc current waveform is a sine wave when the arc is generated in the drying zone;
5) When heat generation and heat dissipation reach a thermal balance, the surface temperature of the insulator does not change with time.

\begin{align*}
U &= I\rho_{sw} \\
U &= I \left[ l_{d} \int_{0}^{l_{d}} \frac{\rho_{sd}}{2\pi(l)} \, dl + \int_{l_{d}}^{l-l_{d}} \frac{\rho_{sw}}{2\pi(l)} \, dl \right] \\
U &= I \left[ \pi a \left( \sqrt{2I} \right)^{m-1} + \int_{l_{d}}^{l-l_{d}} \frac{\rho_{sw}}{2\pi(l)} \, dl \right]
\end{align*}

In the formula: $U$ is the working voltage of the insulator, V; $I$ is the effective value of the surface leakage current, A; $l_{d}$ is the width of the drying zone, m; $l_{a}$ is the arc length, m; $\rho_{sd}$ and $\rho_{sw}$ are the
surface resistivity of the drying zone and the wet contaminated layer, respectively. \( \Omega; A \) and \( n \) are constants.

2.2. Model solution results and analysis

(1) Uniform wet soil model
The surface resistivity of the wet-contaminated insulator is about \( 10^6-10^8 \Omega \). In this paper, the resistivity \( \rho_{sw} \) of the wet-soil layer on the surface of the insulator is taken as \( 5\times10^6, 8\times10^6, 2\times10^7, 5\times10^7 \). Solve the heating power \( \rho_s \) and temperature \( T \) along the disc diameter of the three heating models respectively.

The solution results of the uniform wet pollution model of insulators with different surface resistivities are shown in Fig.2(a) and Fig.2(b). The more serious the degree of wet contamination of the insulator, the lower the surface resistance, the greater the leakage current, and the higher the temperature rise at the same disk diameter. The change trend of \( T \) is slightly slower than that of \( \rho_s \), which is due to the non-linear heat dissipation of thermal radiation, which causes faster heat dissipation in areas with increased temperature.

Fig.2. Heating power and temperature distribution on disk surface of the three models
(2) Dry zone + wet pollution model

Suppose the resistivity of the drying zone is 10 times that in the wet and dirty state, that is, $\rho_{sd} = 10\rho_{sw}$. The model solution results show that only when $\rho_{sw} = 5 \times 10^6 \Omega$, the leakage current is large enough to completely evaporate the moisture on the drying zone and maintain the stability of the drying zone exist. Due to the large surface resistance of the drying belt, the heating power caused by its leakage current exceeds $2 \times 10^3 \text{ W/m}^2$, which is much higher than that of the wet dirt layer; so the temperature rise of the dry zone and the temperature rise of the wet soil layer are maintained at the same order of magnitude.

(3) Arc + wet pollution model

The heating power and temperature distribution of the arc + wet pollution model when $\rho_{sw} = 5 \times 10^6 \Omega$ are analysed. The comparison shows that the arc heating power is higher than the leakage current heating power, which causes a higher temperature rise in the drying zone, and the maximum temperature rise of the disk surface reaches nearly 20°C. It should be noted that the solution of this model is based on the assumption that the insulator can stably generate a dry zone arc and reach a thermal equilibrium state, which is difficult to appear in this operating state in practice. Combining the above three models, it can be seen that the higher the pollution degree of the insulator, the greater the gradient of the surface temperature along the radius, and it is more likely to produce drying zone and drying zone arc, thereby generating a greater temperature gradient. Therefore, theoretically, the temperature characteristics of the insulator disk surface, such as the maximum temperature variance, etc., can be used to identify its pollution level.

3. Experimental Results and Analysis

The post-ceramic insulator ZSW-12/4 is used for contamination test. Simulate the pollution status of insulators operating on-site in our country. Sample preparation, sample contamination and test methods are carried out in accordance with the provisions of GB/T 4585-2004. The salt density is respectively taken as 0.04, 0.8, 0.15 mg/cm²; the pressurization experiment is carried out in a 3m×3m×3m artificial airtight fog chamber, and the laboratory environment temperature is 20°C. The electrical connection is shown in Fig.3.

![Fig.3. Experimental electrical wiring diagram](image)

Infrared instrument Daipu X3 was used for shooting to shoot the insulators. Each insulator is subjected to a pressure test with a relative humidity $H$ of 0%, 80%, and 90%; After humidifying the artificial airtight fog chamber to the required humidity and stabilizing it with a humidifier, add 10 kV voltage for 2 h to make the insulator reach a thermally stable state. After that, it will be taken every 10 minutes, the shooting distance is 2 m, and the shooting depression angle is 15°~30°. Fig.4 is an example of infrared samples under different pollution levels and relative humidity.

The gray value of the infrared thermal image is proportional to the temperature of the surface of the object. The larger the gray value, the higher the temperature value. The analysis shows that the temperature rise decreases with the increase of r, the upper surface of the insulator is smooth along the radial temperature distribution curve, and the lower surface has a jump change, which is basically
consistent with the heat distribution. The test results are basically consistent with the simulation results. The infrared thermal image analysis of the artificial pollution test of insulators preliminarily verifies the validity of the model.

![Infrared image](image)

**Fig.4. Infrared image**

4. **Conclusion**

By using the two parameters $J$ and $\rho_{sw}$ to measure the moisture and contamination status of the insulator surface, a new method of heat analysis of wet and dirty insulators is proposed. The heat generation models are established for different operating conditions, and the numerical analysis method is applied to solve them, revealing the insulators The heat distribution law on the surface. This method realizes the discrimination of the pros and cons of filtration characteristics, the method is simple, easy to implement, easy to understand, and strong in practicability. Using this method to select features prevents bad features from entering the classification feature set, ensures the optimal design and performance of the classifier, and improves the accuracy of classification. The drying zone and the arc generation conditions of the drying zone are deduced.

**Acknowledgements**

This work was supported by the Science and Technology Project of State Grid Corporation of China (Project No. 2021YF-33).

**References**

[1] Jin, L.J, Zhang, D. (2014) Research of Insulator Contamination Grades Recognition Methodology Based on Visual Image. Journal of System Simulation, 26(9): 2073-2078.

[2] Shi, J.J. (2017) Substation equipment identification and thermal fault diagnosis based on infrared image processing . Shanghai Dianji University.

[3] Huang, Q.D, Yang, Z.Y, Song, H.Y. (2016) Measurement and ion-pairing analysis of natural contamination constituents on insulators with different material. High Voltage Engineering, 42(12): 3917-3923.

[4] He, Z.H, Wang, Y.Q. (2016) Influence of salt deposit density and salinity on AC artificial pollution flashover performances of various types insulators . High Voltage Engineering, 42(12): 3810-3815.

[5] Zhang, Y, Tang X.Y, Zhang, Y. (2017) Determination and analysis of soluble anions in insulator contamination by capillary ion chromatography . High Voltage Engineering, 43(4): 1296-1301.