Monitoring method for leakage current of transmission line insulators under typical environmental conditions

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Abstract. There are many factors affecting insulator leakage current of transmission line, resulting in low accuracy of leakage current monitoring. This paper designs a monitoring method for insulator leakage current of transmission line under typical environmental conditions. The influence of different factors on the accuracy of leakage current monitoring is analyzed. Based on the fuzzy mathematics theory, the insulator operating characteristic quantity is analyzed, and the uncertain factors in the insulator operating characteristic quantity are calculated, so as to realize the insulator leakage current monitoring of transmission line under typical environmental conditions. The example analysis shows that the leakage current monitoring accuracy of the method studied in this paper is high in the case of no arc, local arc, adjacent flashover, pollution and saturated environment, which proves the effectiveness of the method studied.

1. Introduction

The safe and reliable operation of power system is closely related to the working state of insulators. Insulators have the dual functions of mechanical support and electrical insulation. In the process of application, the insulator is affected by many self and external factors. After long-term use, it is easy to produce pollution flashover accidents. For example, in the environment of fog and condensation, the pollution layer is fully wetted, resulting in flashover of the insulator along the surface. After the pollution flashover accident, there will be a long power outage, which will seriously affect the stable operation of the power system. Therefore, the research on insulator fault monitoring and diagnosis is of great significance for the safe operation of insulators.

Leakage current is the key characteristic of insulator operation state. Literature [1] studied the prediction method of line insulator surface leakage current based on BP neural network, preprocessed all the data, trained the measured data, obtained the neural network model, and applied this model to predict the leakage current. Reference [2] studies the real-time measurement method of active leakage current in distribution network. The resonant grounding method is used to measure the leakage current in real time. The returned voltage signal is measured in the arc suppression coil, and the active leakage current is calculated. Reference [3] studies the influence of local arc on the relationship between insulator leakage current and surface conductivity. The test results show that the emergence of local arc changes the development path of current on the residual pollution layer, resulting in the change of shape coefficient, resulting in the reduced value of insulator surface conductivity less than the actual value. Reference [4] studies the influence of moisture absorption of insoluble matter on insulator leakage...
current. The research results show that moisture absorption of insoluble matter will affect insulator leakage current, and the degree of influence is determined by atmospheric humidity and strong moisture absorption pollution content.

Although the above method can realize transmission line insulator leakage current monitoring, it has the problem of low monitoring accuracy and is difficult to deal with the changeable external environment. Therefore, a transmission line insulator leakage current monitoring method under typical environmental conditions is designed to solve the current problems.

2. Analysis on Influencing Factors of insulator leakage current
There are many factors affecting the insulator leakage current. The most direct reason is that the insulator is often exposed to the atmosphere and has been in a harsh environment, resulting in internal cracks and surface damage of the insulator, resulting in impedance reduction, pollution flashover and other faults. The flashover phenomenon of wetting along the insulator surface is a heat balance process, involving electrical, thermochemical and other factors, which is expressed as:

\[ U I_0 = W_0 + M \Delta W_q \]  

Where, \( U \) represents the working voltage of insulator, \( I_0 \) represents the surface leakage current, \( W_0 \) represents the heat value generated in insulator radiation, and \( M \) represents the quality of evaporated water in calculation, \( \Delta W_q \) represents the heat of gasification of water.

Considering the influence of temperature on leakage current, humidity mainly refers to the physical quantity of water vapor content, which is a dynamic concept. The water content curve of saturated air is shown in Figure 1.

![Figure 1. Saturated air water content curve](image)

The leakage current on the insulator surface is closely related to humidity. The greater the humidity, the greater the surface leakage current. In order to further study the influence of humidity on current, the collected data are normalized and expressed as:

\[ I' = I_{100} / I_{H} \]

Where, \( I_{100} \) represents the leakage current parameter under saturated moisture condition, and \( I_{H} \) represents the leakage current value when the humidity is \( H \).

3. Analysis on Influencing Factors of insulator leakage current
Pollution and damp are the important reasons for the increase of insulator leakage current[5]. Therefore, these two typical environmental conditions are set to monitor the insulator leakage current.

3.1. Quantitative division of pollution level
First: equivalent attached salt density, which is the content of electrolyte in insulator pollution, which is related to the composition and properties of insulator[6]. Therefore, it is necessary to measure and calculate it.
During the measurement, the dirt on the insulator surface shall be removed with distilled water in advance, the dirt shall be divided into containers, the conductivity shall be measured after mixing evenly, and then the salt content on the insulator surface shall be calculated in combination with the following formula:

\[ y = \frac{NM}{100S} \]  

(3)

Where, \( M \) represents the content of distilled water used, \( N \) represents the salt content, and \( S \) represents the surface area of insulator.

Second: the conductivity of surface fouling layer is expressed as:

\[ G = \frac{I}{U} \]  

(4)

Third, leakage current. Leakage current is the comprehensive expression of pollution, voltage and climate factors. The calculation formula is as follows:

\[ I_l = \frac{U}{R_m} = \frac{U\gamma_m D}{l} = E\gamma_m D \]  

(5)

Where, \( R_m \) represents the resistance parameter of the insulator, \( l \) represents the creepage distance of the electrical surface of the insulator, \( \gamma_m \) is the pollution conductivity, \( D \) is the insulator diameter, and \( E \) is the leakage current reduction parameter.

Fourth, air quality index, through the measurement of air quality index, the maximum pollution accumulation of insulator is estimated and the pollution characteristics are described quantitatively.

In the calculation, the sample is immersed in 100ml rectified water in advance, and the conductivity and water temperature of the aqueous solution are measured after 1 hour.

\[ E = 10 \times \frac{VD}{W} \]  

(6)

Where, \( V \) represents the distilled water volume, \( D \) represents the percentage salt concentration of the total suspended particulate matter, and \( W \) represents the weight of the particulate matter on the insulator surface.

The calculation formula of particle concentration is:

\[ T = k \frac{W}{Q_n t} \]  

(7)

Where, \( k \) represents the constant, \( Q_n \) represents the average extraction volume of the sampler, and \( t \) represents the sampling time.

The quality index of the atmosphere is:

\[ A = T \times E = K \frac{VD}{Q_n t} \]  

(8)

Where, \( K \) represents the calculated air quality index.

Based on the above process, the pollution level is quantitatively divided to achieve the purpose of characterizing the state of insulators in operation.

3.2. Conductivity calculation under damp condition

After the humidity increases, the insulator will be more and more seriously affected by moisture. Under the action of a certain pressure, the leakage current will increase\(^7\). At this time, the conductivity of the pollution layer is expressed as:

\[ \sigma_{H} = \frac{1}{\alpha_{H}}(\sigma_{100} - \beta) \]  

(9)

Where, \( \sigma_{100} \) represents the conductivity of the contaminated surface when the moisture condition is 100\%, \( \alpha_{H} \) is the conductivity when the relative humidity is \( RH \)%\(^8\), \( \beta \) indicates the conductivity value caused by the increase of humidity caused by water droplet collision.
On this basis, the transformation relationship of leakage current under tide and low humidity is established, and more accurate calculation results are obtained. The calculation formula is:

\[ I_{100} = k_H I_H + \Delta H \]  

(10)

Where \( k_H \) represents the scale coefficient and \( H \) represents the corresponding intercept.

4. Construction of leakage current on-line monitoring model

After analyzing the factors affecting insulator leakage current, the leakage current in two typical cases is analyzed. However, there are other influencing factors and many uncertain factors. Therefore, the on-line monitoring model of insulator leakage current is established by using fuzzy mathematics theory, and the accurate prediction of insulator leakage current is realized. Fuzzy mathematics refers to the uncertainty of the concept definition and meaning of language, which is expressed as:

\[ \mu_A : X \rightarrow [0, 1] \]

(11)

Where, \( \mu_A \) represents the membership of A, \( \mu_A(x) \) represents the membership of X to a.

Taking X and Y as a general set, the binary fuzzy relationship from X to Y is recorded as:

\[ X \rightarrow Y \]

(12)

\[ \mu_R : X \times Y \rightarrow [0,1] (x, y) \rightarrow \mu_R(x, y) \]

When \( X=\{x_1, x_2, \ldots, x_n\} \), \( Y=\{y_1, y_2, \ldots, y_n\} \) is a finite set, the fuzzy relationship of \( X \times Y \) is expressed as:

\[ R = \begin{bmatrix}
\mu_R(x_1, y_1) & \mu_R(x_1, y_2) & L & \mu_R(x_1, y_m) \\
\mu_R(x_2, y_1) & \mu_R(x_2, y_2) & L & \mu_R(x_2, y_m) \\
M & M & O & M \\
\mu_R(x_n, y_1) & \mu_R(x_n, y_2) & L & \mu_R(x_n, y_m)
\end{bmatrix} \]

(13)

In the above matrix, the value is between (0~1), \( \mu_R \) represents the fuzzy parameter of the r-th index. Through the above process, the leakage current of transmission line insulator is fuzzy inferred, and the leakage current is predicted after reasoning. The process is shown in Figure 2.

![Figure 2. Forecast flow chart](image)

Based on the flow in Figure 2, after an abnormality occurs, the accurate transformation relationship is obtained by matching the historical data, so as to further upload the leakage current and alarm the leakage current, so as to realize the monitoring of leakage current.

5. Example analysis

In order to verify the effectiveness of the proposed transmission line insulator leakage current monitoring method, experimental comparison is carried out. The prediction method based on BP neural network is compared with the real-time measurement method of active leakage current in distribution network, and the monitoring effects of the three methods are compared.
5.1. Monitoring results of transmission line insulator leakage current under self fault environment

5.1.1. Leakage current monitoring results without arc
In this part of the experiment, the leakage current is mainly monitored when there is no arc. The comparison results between the studied method and the other two methods are shown in Figure 3.

![Figure 3: Leakage current monitoring results without arc](image)

Through the analysis of Figure 3, it can be seen that when there is no arc, the leakage current monitoring results of the three methods have little difference from the actual value. When there is no arc, the three methods ensure high monitoring accuracy, but the monitoring accuracy of the studied method is the highest.

5.1.2. Current monitoring results in case of local arc
The leakage current monitoring results of the three methods in case of local arc are shown in Figure 4.

![Figure 4: Monitoring results of leakage current in case of local arc](image)

It can be seen from Figure 4 that the current monitoring results of the monitoring method studied are more accurate than those of the other two methods when local arc occurs.

5.1.3. Monitoring results of leakage current during adjacent flashover
The monitoring results of leakage current during adjacent flashover of the prediction method studied and the other two methods are shown in Figure 5.

![Figure 5: Monitoring results of leakage current during adjacent flashover](image)

It can be seen from Figure 5 that the leakage current value of the studied monitoring method is less different from that of the actual adjacent flashover, while the leakage current of the other two methods...
is greatly different from that of the actual adjacent flashover, and the monitoring accuracy is not as good as that of the studied method.

5.2. Monitoring results of transmission line insulator leakage current under typical environmental conditions

5.2.1. Monitoring results of leakage current under pollution

The leakage current monitoring results of the three methods under pollution are shown in Figure 6.

![Figure 6. Monitoring results of leakage current under pollution](image1)

It can be seen from Figure 6 that the difference between the studied method and the actual value is small, while the other two methods fluctuate greatly and the monitoring accuracy is low.

5.2.2. Monitoring results of leakage current under damp conditions

The comparison results of leakage current monitoring results under damp conditions are shown in Figure 7.

![Figure 7. Monitoring results of leakage current under damp conditions](image2)

It can be seen from Figure 7 that the difference between the other two methods and the actual value is large, and the difference between the studied method and the actual value is small, which proves that the studied method also has high accuracy under saturated and humid conditions.

In conclusion, the transmission line insulator leakage current monitoring method studied has high monitoring accuracy because the monitoring method studied analyzes the influencing factors of transmission line insulator leakage current in advance and predicts the special conditions. At the same time, the fuzzy mathematical theory is used to simulate the leakage current, so as to improve the accuracy of monitoring.

6. Conclusions

In this paper, a monitoring method of insulator leakage current of transmission line in typical environment is designed.

Firstly, the factors affecting the insulator leakage current of transmission line are summarized, and the current leakage under different conditions is analyzed.
Secondly, the basic principle of mathematical morphology is described, and the signal is further analyzed by using fuzzy mathematics theory, which can further improve the detection accuracy of leakage current.

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