Insulator filth monitoring and situation awareness based on ultraviolet pulse and least square method

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Abstract—To monitor the filth state of insulators in time, a method based on ultraviolet pulse method is proposed to monitor the filth status of insulators, which can detect the early corona discharge of insulators by detecting UV signals and determine the degree of insulator filth. On this basis, the response characteristics of spot area to electrical pulse signal are studied and theoretical analysis is carried out, the relationship between spot area and electrical pulse signal amplitude is studied, and the correlation curve is obtained. By observing the change law of image size with the observation distance in ultraviolet image, the experiment found that the image size of UV channel and the image size of visible light channel increased or decreased in approximate proportion with the observation distance and proposed a new method to estimate the "discharge imaging area " of discharge on the surface of the insulator by using the image information of the visible light channel. According to the discharge "relative spot area mean", one minute time "number of large spot area image frames" two ultraviolet imaging parameters used to characterize the filth discharge characteristics, combined with the ambient humidity to establish a fuzzy logic reasoning model of the filth state, to achieve the assessment of the filth state of the insulator. By using the proposed UV image processing method, the accuracy of insulator filth detection is improved.

1. Introduction
Surface discharge of insulators is a common discharge phenomenon, and the analysis of their discharge strength can be used to assess the hazards of discharge, the stage of discharge development and the realization of flash warning. At present, the most common method for detecting and quantifying discharge strength is pulse current method, pulse current signal is also the most direct physical signal to characterize discharge, and the relevant parameters have become the parameters of quantitative discharge strength in fact [1-4].

Day-blind UV imaging method is a hot research topic of non-contact discharge detection in recent years, the imager uses dual-optical imaging technology, in which the detection of visible light signal to the device body imaging, and the other way to detect 240 to 280nm band of ultraviolet light signal, the discharge of the luminescent area imaging, the discharge of the luminescent area image superimposed on the visible light channel image is obtained ultraviolet image [5]. Compared with the pulse current method, UV imaging has a good discharge positioning ability, and can directly observe the discharge image invisible to the naked eye, very intuitive, but the optical signal detected by this method is an indirect physical parameter that reflects discharge, what kind of relationship exists between UV imaging signal and electrical signal, whether ultraviolet imaging can be used to quantify discharge is a matter of great concern in scientific research and engineering [6]. At present, there are the following difficulties in quantifying discharge by ultraviolet imaging: first, what parameters should be selected to quantify UV
imaging, second, the establishment of the relationship curve between UV imaging quantitative parameters and electrical signals, and the observation distance and gain have obvious effects on UV imaging, so that the results of detection are not comparable, which brings some difficulties to quantitative discharge [7-8].

At present, the characterization and quantitative discharge intensity of ultraviolet imaging method is generally using the parameters of "photons", according to the characteristics of UV images with the intensity of discharge and change, the digital image processing algorithm is used to divide out the spot area, calculate the area of light spot and use it for the characterization of discharge strength and then test and study the change characteristics of electrical pulse signals and ultraviolet images under different discharge intensity and establish the relationship between the peak of the typical instrument gain and the light area at fixed observation distance. On this basis, the relationship between spot area and observation distance is studied, the method of estimating the area of discharge imaging area by using visible light channel information is proposed, the corresponding calculation formula is obtained, and the minimum second-square support vector regression model is established based on the data obtained from the experimental results, and the intensity of discharge signal based on ultraviolet image spot area is realized.

2. Insulator Discharge Detection Method Based on Ultraviolet Imaging
This paper analyzes the mechanism of dirty insulator discharge photoramasing, the attenuation of ultraviolet light signal in the air from the perspective of plasma, establishes the relationship between radiation power of ultraviolet light signal and discharge power, and puts forward the method of video analysis and digital image to extract the characteristics of relevant parameter quantitative discharge and characterization discharge, and studies the influence of gain on spot area. Through a quasi-synchronous acquisition and analysis of electrical pulse signal and UV image parameters, the response characteristics of ultraviolet image to electrical signal are analyzed, the relationship between the area frame of large spot and the number of discharge pulses is analyzed, and the relationship between the area of light spot and the amplitude of electrical pulse signal is studied. The relationship between spot area and visible light image and observation distance in ultraviolet image is studied, the method of "discharge imaging area area area area" is proposed by using the image information of visible light channel, the method of area calculation is derived, the relationship between the area of discharge imaging area and the magnitude of electrical pulse is established, and the estimation of the magnitude of discharge pulse of composite insulator is realized by the least-square support vector regression method. Based on the artificial climate chamber, the ultraviolet image characteristics of the discharge of porcelain insulators at different filth and humidity levels are studied, and the "relative spot area mean" and "number of image frames of large spot area" are proposed, and two UV imaging parameters are used to characterize the filth discharge characteristics.

3. The Relationship Curve Between UV Pulse Parameters, Filth and Humidity
Using ultraviolet pulse method to evaluate the soiling state of insulators, the relevant characteristic parameters need to be extracted, in the current prediction study on the degree of insulator filth, the method of measuring leakage current has been widely used, and the most commonly used leakage current characteristics at home and abroad are: the maximum pulse amplitude of leakage current; Each discharge of the insulator corresponds to a set of ultraviolet pulse signals, but unlike the leakage current method, it dose not reflect the current frequency component, can only get the discharge of the pulse high frequency component, that is, can only reflect its discharge characteristics, so the extracted parameters and leakage current method there is a certain difference. It can be seen from the relevant experimental research that, in the case of pollution shift, with the increase of humidity, the amplitude of its optical pulse signal increases significantly, the number of pulses is more in the corona discharge stage, but the duration of a single pulse is very short, and in the stage of spark and arc discharge, not only the magnitude of the pulse increases, the duration of its individual pulse increases significantly, the pulse width is wider, and the number of pulses may be reduced. According to the above characteristics, two
parameters are extracted here to characterize the discharge optical signal characteristics: the maximum discharge pulse in one minute, \( L_m \), the average of discharge pulses in one minute, \( L_{av} \). The two parameters are defined as follows:

\[
L_m = \frac{\sum_{j=1}^{M} \max(l(i))}{M}
\]

\[
L_{av} = \frac{\sum_{j=1}^{N} l(i)}{N}
\]

where \( l(i) \) is the optical signal series collected by the data set card, \( M \) is the number of half the frequency cycles in one minute, \( N \) is the maximum number of points of data collected in one minute for the pulses in that half of the frequency period. In fact, \( L_m \) averages the maximum pulse value over a half-hour period, while \( L_{av} \) refers to the average of the light pulse signal over a one-minute period. According to the above parameters, the ultraviolet pulse parameters under different filth and humidity are calculated, and the corresponding parameters and humidity and soiling degree of the relationship curve, Fig.1 and Fig.2 are the insulator with the increase of humidity, different soiling conditions of the maximum light pulse, \( L_m \) and pulse mean, \( L_{av} \) change curve.

![Graph](image)

Fig.1 The change curve of the maximum pulse of the optical signal
4. Estimation of the Discharge Strength of Insulators Based on Ultraviolet Imaging

From the above theoretical analysis and practical tests, it can be seen that, with the increase of the observation distance, the ratio of the diameter (or radius) of the spot area in the ultraviolet image to the height of the insulator is approximately a constant, while the type and type of insulator commonly used in power systems are relatively fixed, and the relevant geometric parameters are known, in this paper, the method of estimating the discharge "imaging area" of the insulator surface is proposed. At the same time, the area of the discharge luminescent area is determined by the ionization area, but the ionization area is unknown, the discharge "imaging area" described herein refers to the area of the light-emitting area detectable by the ultraviolet imager under a certain gain of the UV imager, obviously when the discharge intensity remains constant, the larger the area of the light-emitting area that can be detected, that is, the larger the area of the imaging area.

Suppose that the spot area in the ultraviolet image is circular, with a radius of $R$ and a structural height of $L$ for the insulator. It is assumed that at a gain of the UV imager, the radius of the discharge imaging area that can be detected by the UV imager is $r$, and the true height of the insulator corresponding to $L$ in the UV image is $l$, which is approximately satisfied at different observation distances:

$$\frac{r}{l} = \frac{R}{L}$$  \hspace{1cm} (3)

Therefore, at this gain, the radius of the discharge imaging luminous area is:

$$r = \frac{R}{L} \times l$$  \hspace{1cm} (4)

The size of the area of the corresponding imaging area is:

$$S = \pi r^2 = \frac{\pi R^2}{L} \cdot l^2$$  \hspace{1cm} (5)
where \( S \) is the area of light spots in ultraviolet images, \( L \) is the height of the insulator in the image, \( l \) is the actual height (cm) of the insulator corresponding to \( L \).

Therefore, as long as the light spot area value \( s \) in the UV image, a height \( L \) of the insulator and the corresponding actual height \( l \), the size of the imaging luminous area that can be detected under a certain gain can be estimated by (5). In order to reflect the validity of the above formula, this paper makes the actual calculation of the area of the luminous area when the insulator corona discharges, and selects \( L \) as the height of the composite insulator, whose actual structure length is \( 1-38 \) cm, and the area of the luminous imaging area obtained by (5) is shown in Fig.3.

As can be seen from Fig.3, under the same gain, the area of discharge imaging estimated by the UV image at different distances is basically the same, with small fluctuations; This shows that in ultraviolet imaging detection, it is feasible to estimate the size of the imaging area by combining the image information of the visible light channel within a certain detection distance, and the estimated area value of the imaging area is basically the same, with little to do with the detection distance. The above method avoids the problem that the detection results are incomparable when detecting discharge in engineering because it is not easy to determine the observation distance.

5. An Estimate of Discharge Strength Based on the Least Square Method

The estimation of pulse peak is used as an example to illustrate the estimation process of discharge intensity. The electrical signal peak of the surface of the insulator, \( i_{\text{max}} \), is related to the area of the discharge imaging area, \( s_r \), and the gain \( g \) of the instrument, expressed as a function

\[
i_{\text{max}} = f(s_r, g)
\]

This problem belongs to the regression problem, this paper uses the least square regression to establish the corresponding regression model, the input of the model is \( g \) and the area of the imaging area, \( s_r \), is the nuclear function selects Gauss radial base function. The input and output sample data are entered into the above model for training, and after the training is completed, the average error value of the training sample is 1.2% and the average error of the check sample is 1.8%, which shows that the model has good prediction accuracy and generalization ability. Using the trained support vector machine to predict the electrical signal of the surface of other actual insulators in the experiment, the results show that the error of discharge of the surface of the insulator estimated by the method proposed in this paper
is generally within 15%, the cause of the error may come from two aspects, on the one hand, because the discharge itself has a certain randomness; That is, the corresponding current signal under the same area in practice is actually fluctuating up and down around the curve, with some randomness.

Although the use of ultraviolet imaging to quantify the analysis of discharge, the error is still somewhat large, but the actual engineering often does not require a very accurate current value, so the use of ultraviolet imaging to estimate the discharge of the surface of the insulator is feasible, with engineering application value.

6. Conclusion
This paper analyses the characteristics of ultraviolet pulses discharged by insulators at different filth and humidity levels, and on this basis extracts the parameters of "maximum light pulse" and "average light pulse" over a period of time and obtains the curve between the above parameters and the filth and humidity of insulators. According to the law of the reduction of the image size of the insulator onto body of the ultraviolet channel and the insulator body size of the visible light channel with the increase of the observation distance, the problem of ultraviolet imaging method detecting the effect of the discharge time spot area on the observation distance in practice is solved. At the same time, the regression relationship between the area of the imaging area, the gain of the instrument and the amplitude of the electrical pulse signal is established by using the least-square support vector regression algorithm, and the estimation of the amplitude of the electrical pulse signal is realized. The results of this paper are helpful to improve the intelligent monitoring level of power system.

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

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