Relationship between UHF Signals and Apparent Charge of Partial Discharge Defects in GIS Model

Xiaoxing Zhang, Junzhong Tang, Ju Tang, Yang Chen, Yanbin Xie

the State Key Laboratory of Transmission & Distribution Equipments and Power System Safety and New Technology, Chongqing University, Shapingba District, Chongqing 400044, China

Abstract: The relationship between the signal of UHF and the apparent charge is always a hard problem in the research and application of UHF method. In this paper, four typical defects of partial discharge in GIS model are used to study the relationship between the UHF signals and the parameter by pulse current method, from which conclusions can be drawn that the highest coefficient of determination and the best regression curve exist between the signal energy of UHF and the square of apparent charge by comparing the relationship between the UHF signal energy, quadratic integral, peak voltage, peak-to-peak value, wave area quantities and apparent charge. In other words, there is a linear relationship between the energy of UHF signal and the square of the apparent charge. The results of this study provide very important reference value and directive function for the partial discharge of electrical equipment detected by the UHF method.

1. INTRODUCTION

Gas Insulated Switchgear (GIS) with SF_6 gas for insulating medium has been widely used in the current construction and reconstruction of power grids. Compared with opening substation, there are many advantages of GIS, such as smaller coverage area , more stability and reliability, less environmental effect, less constant-maintenance. Most operation experience shows that the intrinsic inevitable defects of GIS with high reliability can still bring about inconvenience, even expand gradually, and lead to the occurrence of fatal failure eventually. As one of the important factors for failures, Partial Discharge (PD) is researched extensively[1-4]. Currently, pulse current method and Ultra-High Frequency (UHF) method are two mature detection methods in GIS.

The relationship between UHF signal and apparent charge is always a difficulty in the research of UHF method. In recent years, a small number of scholars make intensive analysis and experimental studies to the problem. Nevertheless, most theoretical analysis is qualitative research and experimental studies are usually based on the needle plate electrode (metal protrusions) defects. For instance, paper [5] qualitatively describes the linear relationship between UHF energy and the square of apparent charge; paper [6] proposes the basic linear relationship between quadratic integral of UHF signal and apparent charge, but it doesn't present a strict proof; paper [7] proves that the peak to peak voltage, accumulated energy and apparent charge as PD UHF signal measured from the needle plate air-gap respectively have linear function and quadratic function relation, which are verified by experimental data.

Based on the existing theoretical research, we do a large number of experimental researches to the following four typical defects, metal protrusions, free metal particles, metal contaminants on insulator surface as well as air-gap between insulators and the high-voltage conductor. Meanwhile, the relationship between UHF signal of partial discharge and apparent charge is analyzed deeply in this paper.

2 EXPERIMENTS

2.1 Experimental device

According to IEC60270 standard, pulse current method is conducted in this experiment. The measured signal is UHF electromagnetic signal and the detectable quantity is the amplitude of electromagnetic signal in the UHF method, with the unity of mV. The experiment circuit is showed in Figure 1. The power supply is acquired by no-halo test transformer (YDTW-25/100) ,the sensor is the external microstrip antenna and the oscilloscope is Tektronix 7104(the bandwidth is 1GHz and the maximum sampling rate is 20G/s).

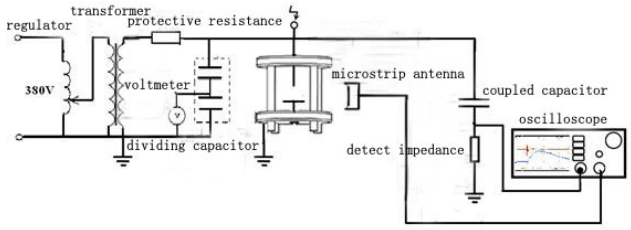


Figure.1 Experiment circuit

2.2 System calibration

The value of PD pulse voltage detected by IEC60270 is in proportion to apparent charge of the test product, but proportional coefficient has to be calibrated to determine the scale factor K_c of the experiment circuit and instruments because it is related with them. The circuit must be connected before calibrating in terms of real situation of experiment, and the calibration circuit is showed in

Figure 2. A PD calibrator which has adjustable output is in parallel with the test product. Meanwhile, a pulse signal whose apparent charge is known is generated in the test product. The voltage amplitude across the detection impedance could be measured by the oscilloscope.

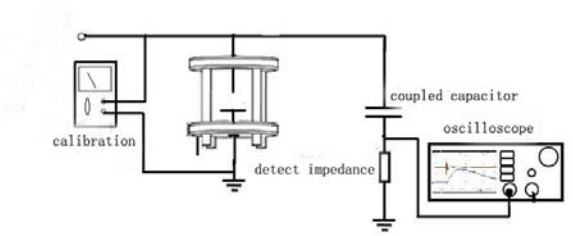


Figure.2 Calibration circuit

The outputs of different discharge are obtained by adjusting the PD calibrator. The relationship between the voltage across the detection impedance U(mV)and the apparent charge q(pC) is drawn in Figure 3. The equation of the fitting curve is within the allowable error range.

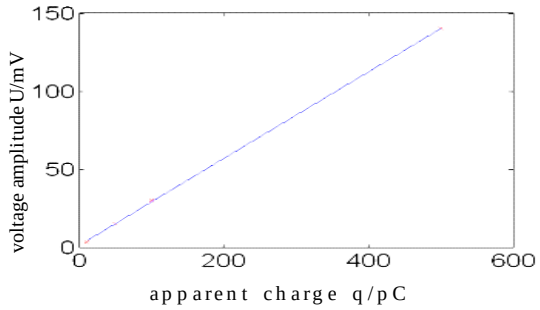


Figure.3 Calibration curve of pulse current method

2.3 Analysis of experimental data

To study the connection between UHF signal and the apparent charge, various mathematical treatment of UHF signal is done, such as peak voltage (max), peak-to-peak value (pp), wave area (area), energy (energy) and quadratic integral (int2). Besides, the apparent charge (q) and the square (q^2) of pulse current signal are calculated. The energy of UHF signal is calculated as follows:

$$E = \frac{\Delta t}{R}\sum_i V_i^2 \qquad (1.1)$$

Where V_i is the voltage value of the *i*th sampling point of UHF signal. Because the 50Ω DC matching mode is adopted in this paper, the value of R as the load impedance is 50Ω. Δt is the time-lag between two sampling sits and $\Delta t = 0.1$ns as the sampling rate is 10GS/s.

The concept of the coefficient of determination R^2 is introduced by the degree of regression after regression analysis worked for all experimental data. The so-called coefficient of determination R^2 is a parameter which is used to judging how closely the sample observation aggregates around the sample regression line, whose range is from 0 to1. The higher value shows, the higher degree of correlation between variables is. The formula is as follows:

$$R^2 = \frac{SSR}{SST} = \frac{\sum_{i=1}^{n} W_i(\hat{y}_i - \bar{Y})^2}{\sum_{i=1}^{n} W_i(Y_i - \bar{Y})^2} \qquad (1.2)$$

Where Y_i is the observed value, $\bar{Y}$ is the average of observations and $\hat{y}_i$ is the fitted value. As regression quadratic sum, SSR reflects the effect on the value of dependent variables caused by the value of independent variables affects. SST is the total quadratic sum what is the quadratic sum of the difference between observed value and the fitted value. It reflects the total dispersion between the observed value of the independence variables and their averages.

3. EXPERIMENTAL RESULTS

3.1 Mental protrusions detects

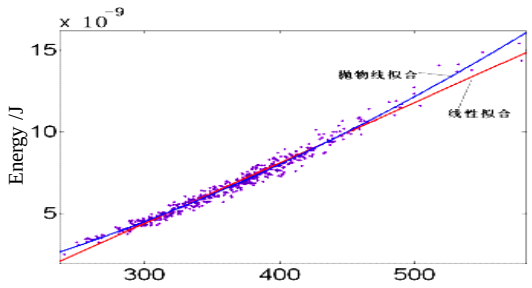
The partial discharge caused by mental protrusions detects is typical corona discharge. In this paper, needle plate electrode is used to simulate the mental protrusions detects. The needle electrode is connected with the high-voltage terminal. The discharge will occur by regulating the gap length between needle and plate.

By applying different voltages on the same detect in the metal protrusions, PD signals of different apparent charge are obtained. The R^2 values of UHF signal parameters are showed in Table 1. A high linearity has always been found between the energy of UHF signal and the square of apparent charge by comparing the values in the table. Moreover, when the voltage increases, the dispersion of the discharge does not change for defects in metal protrusions and the stability of the discharge remains unchanged.

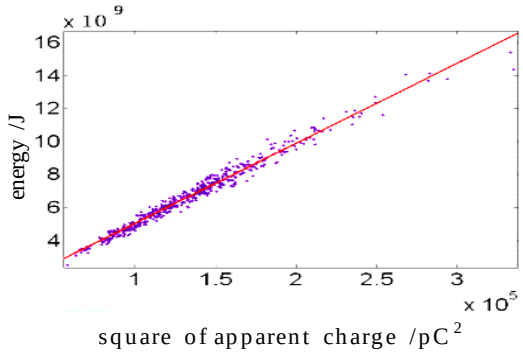
Table.1 The value of R^2 of UHF signals

voltage	max	pp	area	Energy		q^2	int2
				liner	square		
7kV	0.947	0.922	0.976	0.976	0.977	0.978	0.974
9kV	0.955	0.928	0.979	0.973	0.979	0.977	0.979
10kV	0.949	0.921	0.975	0.958	0.976	0.976	0.975

Taking the discharge at 9kV voltage for example, the relationship between the energy of UHF signal and the apparent charge is showed in Figure 4. From the figure, it can be clearly seen that a parabola used to fit the relationship has a better effect than a line. The energy of UHF signal and the square of apparent charge have a line relationship.



(a) Relationship between UHF signal and charge quantity



(b) Relationship between UHF signal and the square of charge quantity

Figure.4 Relationship between UHF signal and charge quantity at 9kV voltage

With different voltages at 7.0kV, 9.0kV and10.0kV, the relationship between the signal energy of the same PD source and the square of apparent charge is showed in Figure 5. As the voltage increases, UHF signal energy has a tendency to increase. However, the experimental data of different voltages return to the same line. Therefore, the relationship can be used to quantify apparent charge of UHF signal of detects in the mental protrusion.

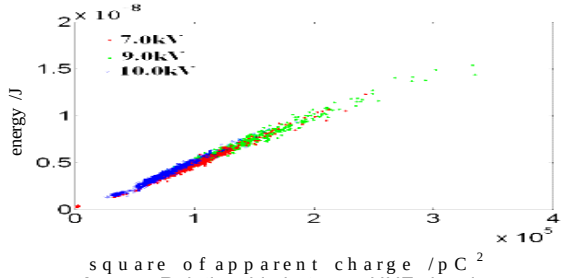


Figure.5 Relationship between UHF signal and charge quantity at different voltage

3.2 Free metal particles detects

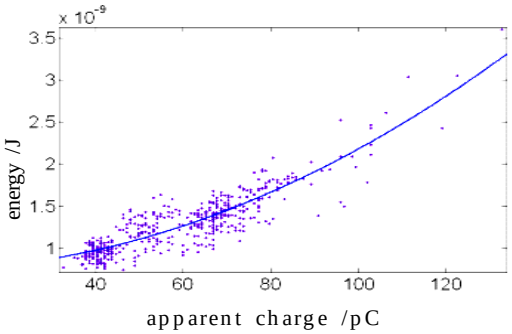
In external electric field, the charges induced from free metal particles obtain energy. Free metal particles will beat or displace under the electric field force, thus, the gas-insulated breakdown voltage will greatly reduce. There are some rectangular aluminum sheets with the dimensions of 2×2mm^2 between high and low voltage electrodes of the experimental device to simulate the discharge type.

By applying different voltages on the same free metal particles detect, PD signals of different apparent charge are obtained. The R^2 values of UHF signal parameters are showed in Table 2. As the voltage increases, the coefficient of determination of the data is higher. It's showed that the discharge tends to stabilize in high voltage, but the dispersion of the data is large generally. Meanwhile, the linear relationship between the energy of UHF signal and the square of apparent charge is the best for free metal particles detect no matter high or low voltage.

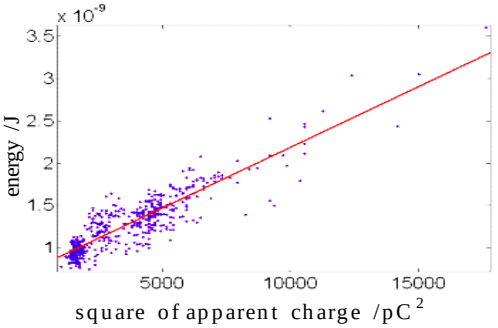
Table.2 The value of of R^2 of UHF signals

voltage	max	pp	area	Energy		q^2	int2
				liner	square		
3.6kV	0.773	0.747	0.439	0.767	0.794	0.794	0.520
4.0kV	0.824	0.672	0.609	0.842	0.849	0.848	0.674
6.0kV	0.761	0.652	0.950	0.916	0.920	0.919	0.914

Taking the discharge at 4kV voltage for example, the relationship between the energy of UHF signal and the apparent charge is showed in Figure 6. From the figure, it can be clearly seen that a linear relationship exits between the energy of UHF signal and the square of apparent charge.



(a) Relationship between UHF signal and charge quantity



(b) Relationship between UHF signal and the square of charge quantity

Figure.6 Relationship between UHF signal and charge quantity at 4kV voltage

With different voltages at 3.6kV, 4.0kV and 6.0kV, the relationship between the signal energy of the same PD source and the square of apparent charge is showed in Figure 7. As the voltage increases, UHF signal energy has a tendency to increase. However, the experimental data of different voltages return to the same line. Therefore, the relationship can be used to quantify apparent charge of UHF signal of free metal particles detects.

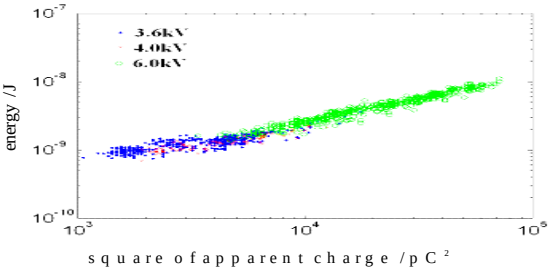


Figure.7 Relationship between UHF signal and charge quantity at different voltage

3.3 Insulator surface contamination defects

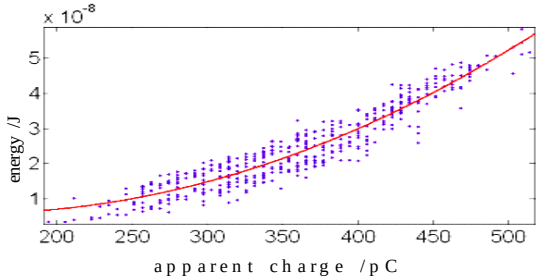
The discharge of insulator surface contamination defects occurs between metal particles and insulator surface. Therefore, the charge accumulation characteristics of the insulator surface have important influence on the discharge process. The insulator with metal particles detects stocked is placed between high and low voltage electrodes to simulate such type in this paper. The particle, an aluminum sheet with the length of 10mm, is 5mm away from the high voltage side.

By applying different voltages on the same insulator surface contaminants detect, PD signals of different apparent charge are obtained. The R^2 values of UHF signal parameters are showed in Table 3. As the voltage increases, the linearity of the data is getting worse, which means the increasing of dispersion of discharge makes the discharge become more and more unstable under appropriately high voltage. However, the linear relationship between the energy of UHF signal and the square of apparent charge keeps the best for free metal particles detect no matter how high or low voltage.

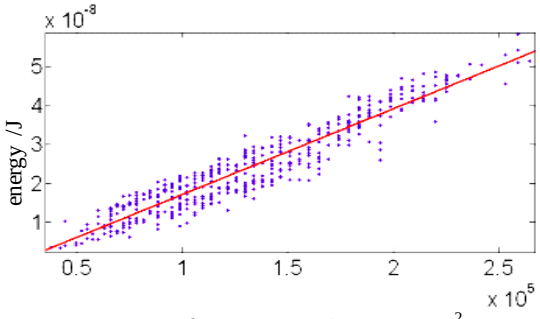
Table.3 The value of of R^2 of UHF signals

voltage	max	pp	area	Energy		q^2	int2
				liner	square		
5.2kV	0.817	0.866	0.971	0.936	0.971	0.970	0.961
7.0kV	0.690	0.690	0.882	0.875	0.901	0.897	0.852
9.0kV	0.651	0.689	0.842	0.854	0.868	0.868	0.799

Taking the discharge at 7kV voltage for example, the relationship between the energy of UHF signal and the apparent charge is showed in Figure 8. From the figure, it can be clearly seen that there is also a linear relationship between the energy of UHF signal and the square of apparent charge.



(a) Relationship between UHF signal and charge quantity



(b) Relationship between UHF signal and the square of charge quantity

Figure.8 Relationship between UHF signal and charge quantity at 7kV voltage

With different voltages at 5.2kV, 7.0kV and 9.0kV, the relationship between the signal energy of the same PD source and the square of apparent charge is showed in Figure 9. As the voltage increases, UHF signal energy has a tendency to increase. However, the experimental data of different voltages return to the same line. Therefore, the relationship can be used to quantify apparent charge of UHF signal of insulator surface contamination defects.

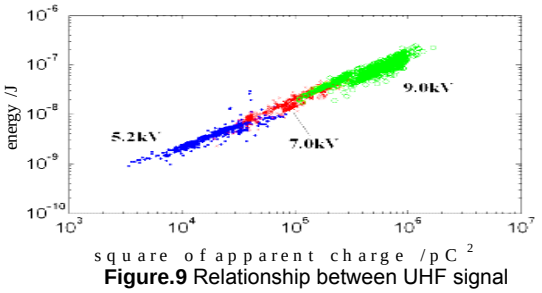


Figure.9 Relationship between UHF signal and charge quantity at different voltage

3.4 Air-gap defects between insulators and the high-voltage conductor

The gap possibly existing between the medium and the electrode may cause internal partial discharge, which is connected with the characteristic of medium and nature of the gap in shape, size and location. Left 3mm up to high voltage side, the insulator is placed between high and low voltage electrodes to simulate such defects in this paper.

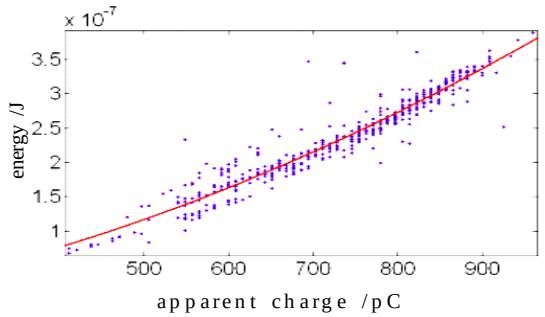
By applying different voltages on the same air-gap defect between insulators and the high-voltage conductor, PD signals of different apparent charge are obtained. The R^2 values of UHF signal parameters are showed in Table 4. A high linearity has always been found between the energy of UHF signal and the square of apparent charge by comparing the values in the table. The higher voltage turns, the less dispersion of discharge is, and the discharge becomes more and more stable.

Table.4 The value of of R^2 of UHF signals

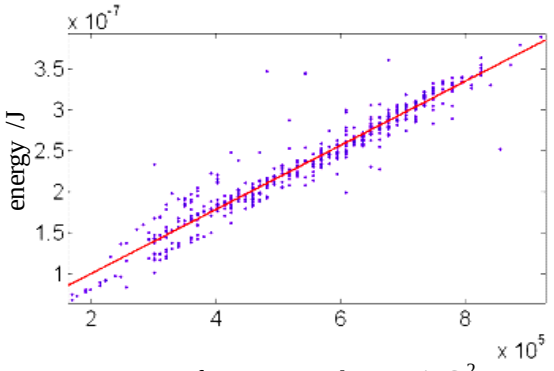
voltage	max	pp	area	Energy		q^2	int2
				liner	square		

2.6kV	0.868	0.901	0.891	0.856	0.918	0.912	0.877
6.0kV	0.911	0.931	0.825	0.915	0.945	0.947	0.818
9.0kV	0.901	0.904	0.924	0.967	0.977	0.977	0.931

Taking the discharge at 9.0kV voltage for example, the relationship between the energy of UHF signal and the apparent charge is showed in Figure 10. From the figure, it can be clearly seen that there is a linear relationship between the energy of UHF signal and the square of apparent charge.



(a) Relationship between UHF signal and charge quantity



(b) Relationship between UHF signal and the square of charge quantity

Figure.10 Relationship between UHF signal and charge quantity at 9kV voltage

With different voltages at 2.6kV, 6.0kV and 9.0kV, the relationship between the signal energy of the same PD source and the square of apparent charge is showed in Figure 11. As the voltage increases, UHF signal energy has a tendency to increase. However, the experimental data of different voltages return to the same line. Therefore, the relationship can be used to quantify apparent charge of UHF signal of air-gap defects.

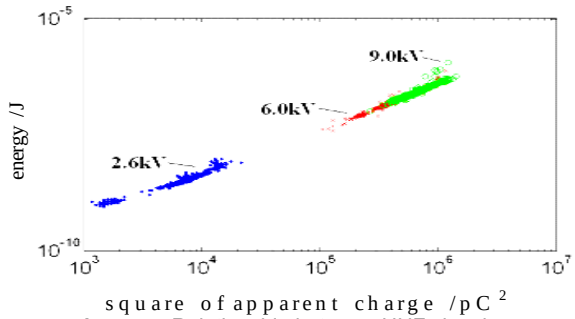


Figure.11 Relationship between UHF signal and charge quantity at different voltage

4. CONCLUSION

After comparing the relationship between the results of UHF method attained from four typical defects models of GIS PD, and the parameter of pulse current method, together with a large number of experimental data, the following conclusions are drawn:

(1) the linear relationship between energy of UHF signal and the square of the apparent charge has the highest coefficient of determination from the four types of GIS defects. Namely, they are linearly related to each other.,

(2) The experimental data of the same PD source under different voltages returns to the same line. This relationship can be used to quantify apparent charge of UHF signal of the four typical defects.

5. ACKNOWLEDGMENTS

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