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Measurement and Analysis of the Leakage Current on the Surface of Polluted Suspension Ceramic Insulator

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ABSTRACT: The artificial pollution tests are implemented on an IEC standard suspension insulator, and the leakage current waveforms and frequency characteristics were investigated under different equivalent salt deposit density *ESDD* and relative humidity. It was found that the peak values of the leakage current, the total harmonic distortion (*THD*) and the odd order harmonic components, e.g. 150 and 650Hz, were significantly correlated with the contamination condition of the insulator surfaces. Besides, a new characteristic parameter *IMR*， defined as the product of the peak values of leakage current by the ratio of the 3rd order harmonic components to the 13th order harmonic components, is introduced to evaluate the contamination condition on the insulator surface.

0 Introductions

The insulator flashover is one of the major problems facing power engineers throughout the world. Therefore, it is of great importance to estimate the contamination condition of insulators surface so as to predicate the flashover occurrence on the transmission lines [1-3].

The leakage current is a very important parameter for the on-line detection of polluted insulators, which leads to a lot of research on the measurement and analysis of leakage current waveforms. In [4], the conclusions is drawn that the Total Harmonic Distortion (*THD*) of the leakage current was significantly correlated with the condition of the insulator surfaces, the *THD* varied in 20~35% before flashover. In [5], it is pointed out that the possibility of flashover occurrence becomes higher when the magnitudes and prominent harmonic contents of the leakage current on the single suspension insulator exceed a particular threshold. [6] pointed out that, if the moist of the contaminated surface is not saturated, the 2nd harmonic components (100Hz) are remarkable, this is an important characteristic used to distinguish the arcs between saturated moist and other relative humidity. Based on the above mentioned, there are some divergences on the relation between frequency characteristic of leakage current and contamination condition. So it is necessary to do further investigations on the correlation between the pollution condition of insulator surfaces and the leakage current.

In this paper, three unit of IEC standard suspension insulator was tested in the multi-function artificial climate chamber, the correlation between the contamination condition of insulator surfaces and the peak values of the leakage current and the frequency characteristics of the leakage current are analyzed and discussed, a new characteristic parameter *IMR* is introduced to estimate contamination condition on the insulator surface.

1Test facilities and procedures

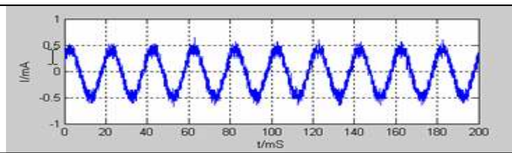
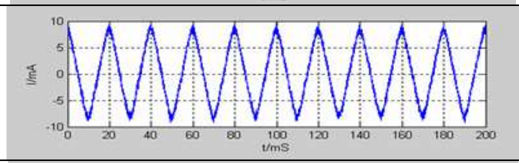
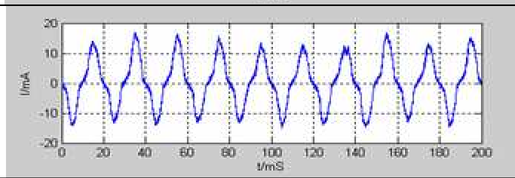
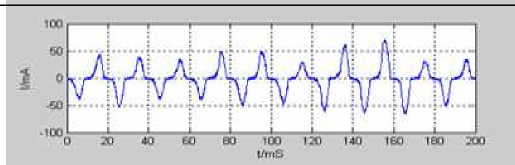
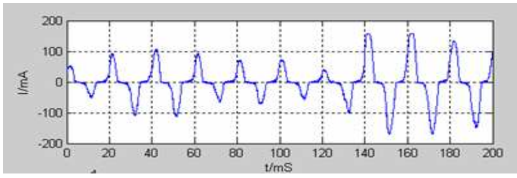
The test circuit of the artificial contamination test is same as [2]. The power supply is leaded in through a wall bushing. An ac high voltage of up to 150 kV is supplied by a testing transformer, which ensures a dynamic voltage drop of less than 5% when the load current is 6A. The test power supply satisfies with the requirements commended by references [7-11].

The tested insulators are IEC standard suspension insulators. Referred to the IEC standard [7-9], the test was carried out by solid-layer method. The Non-Soluble Deposit Density *NSDD* (in mg/cm^2) was $2.0mg/cm^2$, the Salt Deposit Density *ESDD* (in mg/cm^2) were 0.05, 0.10, 0.15 and 0.20 mg/cm^2 respectively. The polluted sample was suspended on the hook of the artificial climate chamber. The pressure of the chamber keeps constant, which is equal to the atmospheric pressure 99.5KPa at the laboratory. The indoor temperature is about 26℃. The *Rh*% is controlled by the fog generator and the desiccant. When the *Rh*% is controlled well, a 20 kV ac voltage was applied to the insulator string, which is the average voltage on insulator string in 35 kV power systems. At the same time the leakage current was sampled at a rate of 20000 samples/s, and the sampling length is 0.2 second (10 cycles).

2 The typical characters of leakage current

The *ESDD* is usually used to evaluate the contamination condition of insulators surface in Europe and China. However, experimental investigations in [5, 6, 12-14]shown that, not only there was a relationship between *ESDD* and the contamination level, but also the environment *Rh*% is significantly correlated with the contamination level of insulator surface. According to the artificially pollution test results, it was found that there were five typical discharge phenomena before flashover. Through in-depth analysis, it can be found that the five typical discharge phenomena correspond to five kinds of leakage current waveforms before flashover on different contamination condition which was shown in table 1.

Table 1. The Leakage Waveforms and the Typical Discharge Phenomena

No.	The typical discharge phenomena	The waveforms of leakage current
A	There is no visible discharge on the insulator surface under dry condition of low *Rh*%	
B	The dirty layer gets wet, the purple silk discharge or small arcs can be seen on the porcelain surface around the pin, and the discharge noise can be heard.	
C	The yellow short intensive arc appears on the rim of cap and around the pin, keeps on and the discharge noise is very loud.	
D	The very low frequency and obvious enlargement yellow arc appears, the arc length can reach the 1/3 of leak distance	
E	One or a few bright yellow main arcs appear on the top and bottom of shed, the length almost attains the edge of ship, the intensive small arc appears inside groove.	

3 Relationship between leakage current and pollution condition

Reference [15] put forward that the contamination condition can be estimated by the peak values of the leakage current on the insulator surface. This method is easy and feasible. However, the peak values of the leakage current at any chosen time are statistically random, it is not sufficient to estimate the pollution condition only by the peak values of the leakage current [3]. Frequency components provide more information about insulator performance than just the instantaneous peak values [3-6]. That is to say, both the peak values of the leakage current and the frequency components are related with the contamination condition of the insulator surfaces.

The distinguishing features are only at frequency less than 1 kHz in the presence of local arc [5]. So the frequency components of leakage current at frequency less than 1 kHz are analyzed in this paper. Several parameters are defined to quantify the harmonic content of the leakage current, which are *HD*, *THD*, HD_3 and HD_{13}.

$$\begin{cases} HD = \sqrt{\sum_{n=2}^{\infty} I_n^2} \\ THD = HD / I_1 \\ HD_i = {I_i}/{HD} \end{cases} \quad (1)$$

Where, *HD* is defined as the total harmonic components, I_n is the n^{th} order harmonic for n=2, 3… 19 (frequency <1kHz), *THD* is defined as the ratio of the *HD* and the fundamental, I_1 is the 1st order harmonic (fundamental 50 Hz), HD_i is defined as the ratio of the ird harmonic and *HD*.

The FFT off-line analysis is used to obtain the frequency signal of leakage current under different *ESDD* and *Rh*%, the result is shown in the Table 2.

Table.2 Results of FFT for the leakage current

Test No.	Group.	*EESDD* /mg/cm^2	*Rh*%	*THD*	HD_3	HD_{13}	$\frac{HD_3}{HD_{13}}$	I_h/ mA	Discharge phenomena	*IMR*/ mA
1	1-1		49%	11.20%	0.00%	68.93%	0	0.4		0
2	1-2		64%	15.21%	0.00%	70.62%	0	0.34	A	0
3	1-3		80%	16.47%	0.00%	76.03%	0	0.38		0
4	1-4	0.05	85%	18.08%	93.44%	5.93%	15.76	6		94
5	1-5		90%	26.41%	95.36%	6.38%	14.94	10.4	B	155
6	1-6		87%	25.90%	98.49%	10.25%	9.61	8		76
7	1-7		97%	30.35%	98.58%	9.14%	10.78	17	C	183
8	2-1		57%	12.19%	13.23%	68.77%	0.19	0.44		0.08
9	2-2		63%	13.93%	6.30%	45.69%	0.13	0.36	A	0.05
10	2-3		70%	12.23%	6.34%	65.75%	0.09	0.52		0.05
11	2-4	0.10	77%	2.97%	22.85%	63.11%	0.36	1.44		0.5
12	2-5		83%	29.05%	99.65%	4.17%	23.9	11.3	B	270
13	2-6		90%	38.38%	98.23%	4.61%	21.33	23	C	490
14	2-7		100%	48.77%	95.58%	2.73%	35.04	28		981
15	3-1		53%	15.80%	5.96%	58.07%	0.1	0.32		0.03
16	3-2		62%	15.77%	6.91%	59.03%	0.12	0.38	A	0.04
17	3-3		75%	8.79%	0.00%	74.66%	0	1.83		0
18	3-4		82%	17.56%	96.63%	7.85%	12.31	6	B	73
19	3-5		86%	32.19%	92.79%	4.04%	22.98	11.2		257
20	3-6	0.15	88%	51.06%	95.86%	3.64%	26.3	19.6	C	515
21	3-7		91%	48.40%	96.63%	4.32%	22.34	33.2		741
22	3-8		93%	42.94%	96.37%	6.34%	15.2	42	D	638
23	3-9		98%	42.98%	94.50%	2.29%	41.2	121	E	4988
24	3-10		99%	56.95%	99.06%	3.91%	25.3	134		3392
25	4-1		68%	8.65%	0.00%	74.53%	0	0.56		0
26	4-2		64%	11.53%	0.00%	65.67%	0	0.42	A	0
27	4-3		71%	3.74%	13.41%	80.09%	0.3	1.12		0.3
28	4-4		75%	2.07%	78.71%	35.07%	2.2	8		18
29	4-5		80%	2.16%	78.13%	30.05%	2.6	6.7	B	17
30	4-6	0.20	83%	15.06%	95.03%	5.96%	16	12		191
31	4-7		87%	49.83%	95.38%	2.43%	39.2	29.6	C	1159
32	4-8		85%	47.81%	93.95%	5.62%	16.7	24.8		414
33	4-9		91%	50.85%	95.99%	3.09%	31.1	68	D	2112
34	4-10		95%	52.96%	96.28%	2.44%	39.5	141	E	5572
35	4-11		99%	56.70%	98.10%	0.43%	229.3	190		43566

3.1 Relationship between leakage current and *Rh%*

According to test results, the peak values of leakage current increase with the increase of relative humidity. It is also seen that, under dry condition with *Rh*% of 50%~70%, the peak values of leakage current is less than 0.55 mA, and they are similar under different *ESDD.* With the increase of relative humidity, the discharge will be observed. But the visible discharge appears in different *Rh*% under different *ESDD*. When *ESDD* is 0.05 mg/cm^2, the visible discharge appears in *Rh*% of 85%, while *ESDD* is 0.10 mg/cm^2, 0.15mg/cm^2, 0.20 mg/cm^2, the visible discharge appears in *Rh*% of 83%, 82% and 75% respectively. It shows that *Rh*% should be taken into account as well as *ESDD* when estimating of the condition of insulators.

3.2 *THD* in different *Rh%* and *ESDD*

It can be seen from Table 2 that, the *THD* increases with the increase of relative humidity. The *THD* is about 10% in lower *Rh*% (dry condition) at different *ESDD*, and seems to have no correlation with the *ESDD*. As to the reason, it may because that the random environmental noise leads to the distortion of leakage current waveform under dry condition.

Form table 2,it can be also seen that the *THD* has a suddenly decrease in *Rh*% of about 80%. When *Rh*% is less than 80%, the distortion of leakage current waveform is caused by the random environmental noise. When the peak values of leakage current is about 0.4 mA (in test No.1~3, No.8~10, No.15, No.16, No.25 and No.26), the distortion may be comparatively with the leakage current, so the *THD* is about 10%. While the peak values of leakage current increases to about 1.4mA (in test No.17, No.17 and No.27), the distortion can not be comparatively with the leakage current, so the *THD* has a suddenly decrease.

The effect of *ESDD* is obvious in high *Rh*% or saturated moist. The peak value of the leakage current will increase with the increase of *ESDD.* The distortion of leakage current is caused by discharges on the surface of polluted insulators, so the *THD* increase with the increase of *Rh*% and *ESDD*. The maximal *THD* is 30% at *ESDD* of 0.05mg/cm^2, which increases to 56% at *ESDD* of 0.15mg/cm^2 and 0.20mg/cm^2.The conductivity of insulators surface is more excellent and the peak values of leakage current become higher when *ESDD* is higher, the discharges is more obviously, which results in the serious distortion of the leakage current.

3.3 HD_3 and HD_{13} in different *Rh%*

Based on the analysis results in Table.2, the HD_3 increases with the increase of the *Rh*%, while the HD_{13} decreases with the increase of the *Rh*%. When the *Rh*% is lower, the HD_{13} is higher than 60%, while the HD_3 is about 10% or to 0%.This may because the 13th order harmonic is main component of random environmental noise, which is the reason for the distortion of leakage current waveform in low *Rh*%. When the *Rh*% is higher, discharge on polluted insulator surface is the main reason for the distortion of leakage current waveform, the HD_3 is much higher than HD_{13}, and the 3rd order harmonic is main component of *HD* correlated with the distortion of leakage current waveform. This implies that insulators condition may be estimated based on HD_3, HD_{13} and the peak values of leakage current.

3.4 Method to estimate contamination condition

Based on the above analyzed results, it can be concluded that the peak values of the leakage current as well as HD_3 and HD_{13} were significantly correlated with the contamination condition of the insulator surfaces. So in this paper, a new characteristic parameter *IMR* is introduced to estimate contamination condition on the insulator surface. *IMR* (mA) is defined as the product of the peak values of leakage current and the ratio of the 3rd order harmonic components to the 13th order harmonic components, which can be expressed as:

$$IMR = I_L \bullet \frac{HD_3}{HD_{13}} \tag{2}$$

The calculated results of *IMR* are shown on the Table.2. If the *IMR* is lower than 2mA, there is no discharge on the insulator surface, the contamination condition is safe. If *IMR* is 20~300 mA, there is visible faint discharge on the insulator surface, the contamination condition is light. If *IMR* is 300~2000 mA, there are arcs on the insulator surface, the contamination condition is moderate. If *IMR* is higher than 3000 mA, there are a few main arcs on the insulator surface, the contamination condition is heavy. For example, as to the test No.10, the *IMR* is lower than 2 mA, so the contamination condition is estimated as safety; the fact is that there is no charge on the insulator surface at *ESDD* of 0.10 mg/cm^2 in *Rh*% of 70%, which is accordant with the estimated result. As to the test No.24, the *IMR* is higher than 3000 mA, so the contamination condition is estimated as heavy; the fact is that there are a few arcs on the insulator surface at *ESDD* of 0.15 mg/cm^2 in *Rh*% of 99%, which is accordant with the estimated result.

4 Conclusions

Based on the above test and analyzed results for an IEC standard suspension insulator, the following conclusions could be obtained in this paper:

(1) The influence of *ESDD* is small under dry condition with *Rh*% of about 50%-70%. The visible discharge appears in different *Rh*% at different *ESDD*. *Rh*% should be taken into account when estimating the pollution condition of insulators.

(2) A new characteristic parameter *IMR* (mA) is defined as the product of the peak values of leakage current and the ratio of the 3rd order harmonic components to the 13th order harmonic components can be used to estimate the contamination condition on the insulator surface.

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