Harmonic Components Analysis of Leakage Current for Standard and Anti-Fog Suspension Insulators under Humidity Conditions

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***Abstract**: Porcelain Suspension Insulators are widely used in overhead transmission lines. During operation, the outdoor insulators are subjected to environmental stresses such as ambient humidity continually which may reduce their performances such as surface resistance. Under these conditions a large leakage current (LC) may flow on the surface and degradation may take place. In long term the degradation may lead to the flash over of the insulators and serious damages.*

This paper describes an investigation on the leakage current harmonic components of standard and anti-fog porcelain insulator strings under humidity conditions. The insulator string samples were put in a test chamber with controlled humidity conditions. AC voltage with different levels and frequency of 50 Hz were applied. The tests were conducted in high voltage laboratory of Babol University of Technology and the LC waveforms were measured. Leakage current characteristics such as peak value, the harmonic content magnitudes and also the 5^{th} to 3^{rd} harmonic ratio in different voltages and humidity conditions were analyzed.

Key words: *Insulator, leakage current, humidity.*

1. Introduction

Insulators of transmission lines are exposed to different conditions such as over-voltages of switching, lightning, surges and environmental pollution and its consequences. They have high surface resistance in order to prevent electric currents in unexpected paths. During service time, these devices are exposed to different climate and geographical conditions and also pollutions and humidity. These factors lead to electric surface discharge on the insulators and consequently increase of leakage current and in some cases sparks will occur [1-3]. This process usually depends on several parameters, such as material, leakage distance and insulator profile [4,5]. Leakage current data provides important information about the behavior of insulators in various conditions [6-9]. Therefore, control of insulators' performance in different humidity prevents unpredicted outage of electricity from the grid. In order to analyze the behavior of leakage current of insulator string in different humidity condition, experimental tests are carried out on the sample string (standard porcelain and anti-fog porcelain) in clean condition and without pollution. Also leakage current waveforms of sample string are measured under different humidity.

The test results are investigated in time and frequency domain and effect of leakage current parameters such as peak value, harmonic contents, and also fifth harmonic to third harmonic ratio in analysis of insulators' behavior is also evaluated in different voltage and humidity levels.

2. TEST PROCEDURE

2.1. Test Setup and Sample Insulators

The tests were performed in a fog chamber (volume 400 ×400 ×370 cm height) in the high voltage laboratory of Babol University of Technology. A single phase, 220 V/100 KV, 5 KVA, 50 Hz transformer is used as a power supply. The rated current of transformer is 50 mA with maximum short circuit of 1.25 mA. The H.V supply was connected to the test chamber through a bushing. The power supply is leaded sample insulator string through a resistance .The test circuit is shown in figure 1. The high voltage supply is connected to tested insulator string through a 245 Ω protective resistance (R_p). Also, the H.V supply is connected to a capacitor voltage divider (C.V.D) that the divider ratio is 500:1. AC voltage up to 132 KV ÷ $\sqrt{3}$ = 76.2 kV was applied to the sample insulator string. Digital oscilloscope (D.O) acquired the voltage waveform from the low voltage of C.V.D. In order to perform the experimental tests, the setup has been prepared according to IEC60507 as shown in figure 2. The leakage current waveform is measured from voltage drop across a specific resistor R_1 (470 Ω) by D.O. All of the waveforms and their FFT are recorded and stored by D.O.

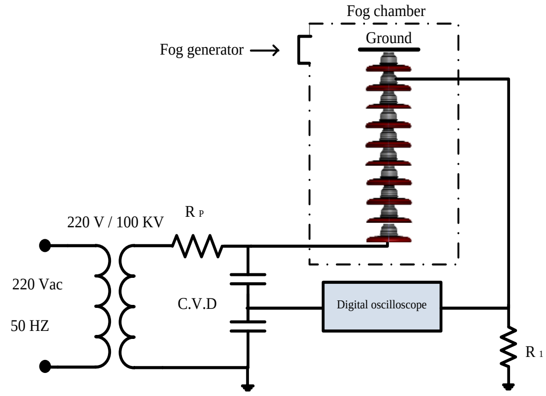

Figure 1. Schematic diagram of test setup

Figure 2 .Experimental setup

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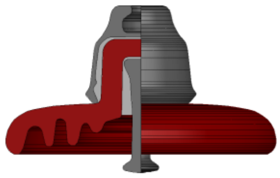
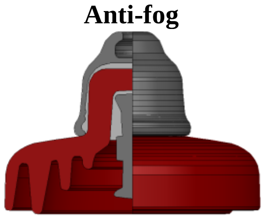
Two sample insulator strings (standard porcelain and anti-fog porcelain) was used for the experiments includes 9 porcelain suspension insulators to simulate 132 kV overhead transmission lines. The unit profile and its parameters are shown in table 1

Table 1. Characteristics of Tested Insulators

Data of sample insulators	material	Disc diameter (mm)	Creepage distances (mm)	Mechanical tension strength (KN)	Height (H)
standard 	porcelain	254	295	120	146
Anti-fog 	porcelain	254	432	120	146

2.2. Wetting the Insulators

Sample insulators strings are placed in the chamber of fog and then fog-making device is turned on until the humidity of the chamber reaches to the desired value. The experimental tests were carried out in four relative humidity levels, at first 66% (natural environment humidity) and three humidity levels 80%, 90% and more than 95%. Humidity of the fog chamber is controlled via two humid-meter devices. After reaching to desired humidity, high voltage is applied to sample insulators and leakage current is measured for different humidity. Figure 3 shows an example of waveform and harmonic spectrum of leakage current and also applied voltage waveform recorded by D.O.

It is noted that after each stage of wetting, residual humidity in the chamber is reached to the natural humidity and also humidity on the surface of the insulators are captured using a clean tissue. In other words, test conditions for next measurement are the same as previous one.

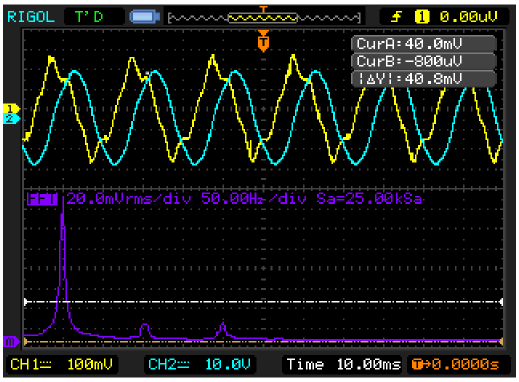


Figure 3. Waveforms recorded by oscilloscope

2.3. Process of Experiment

In these experiments, two conventional types of porcelain insulator string consisting of 9 units are used. These insulator strings are standard and anti-fog types. Aim of experiment is to investigate and analyze the behavior of leakage current of high voltage insulators used to transmission lines under different humidity conditions. For this purpose, first sample string are tested in dry condition (natural humidity,66%) in chamber without artificial fog in nominal voltage and then it is tested with fog which is made artificially in different humidity (80%, 90% and more than 95%) in nominal voltage. In each stage, data of leakage current in time and frequency domain is analyzed.

It is noted that above experiments are carried out in different voltage levels in addition to nominal voltage and in mentioned humidity.

3. Experimental Results and Data Analysis

3-1- Analysis of Leakage Current in Time Domain Using (I_m) parameter

Peak value of leakage current (I_m) on the insulator surface is one of the most important characteristics for analyzing the behavior of leakage current in time domain [10-12].

3-1-1- Peak Value of LC in Different Humidity

Peak value of LC changes in different humidity. As shown in Figure 4, variation of peak value of leakage current at nominal voltage in string insulators (standard porcelain and anti-fog porcelain) is shown.

It is obvious that with increase in relative humidity, peak leakage current is increased in both insulators. Since there is no pollutions on the surface of tested insulators, peak value leakage current in anti-fog insulator is very close to each other in comparison with standard porcelain insulator.

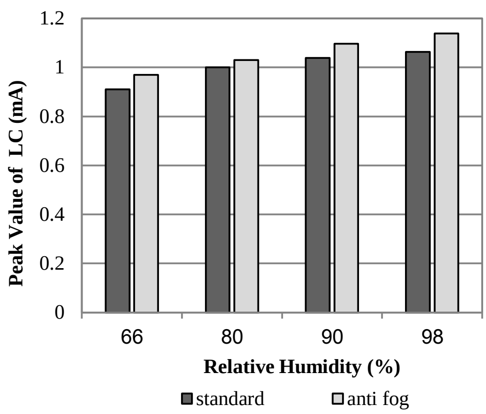
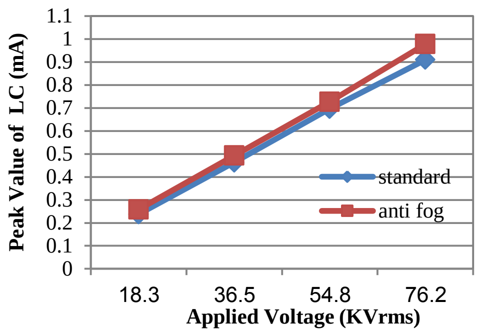


Figure 4 . The variation of peak value of (LC) versus different relative humidity at nominal voltage

3-1-2- Peak Value of LC in Different Voltage Levels

Peak value of LC is evaluated in different voltage levels and above-mentioned humidity.

As shown in Figure 5, by increasing voltage, peak value of leakage current increases smoothly in every string insulator and this means that with increase in humidity, partial discharge may occur and as a consequence flash over is possible in low voltages. This leads to a reduction in reliability of the grid.



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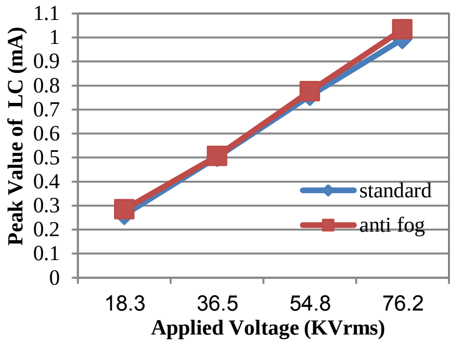

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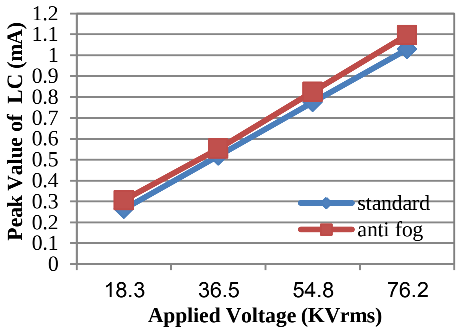

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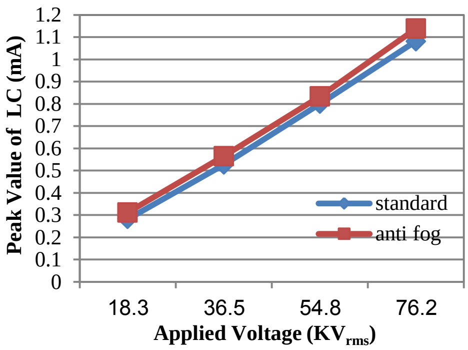


(d)

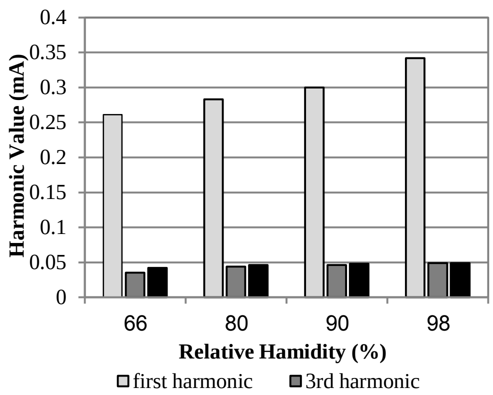
Figure 5. The peak value of LC in different voltage and RH. (a) RH=66%; (b) RH=80%; (c) RH=90%; (d) RH=98%.

3-2- Analysis of Leakage Current in Frequency Domain

3-2-1- Harmonic Components of Leakage Current in Different Humidity

Figure 6 shows harmonic contents of leakage current for sample insulators in different humidity and nominal voltage.

Experimental tests are performed in nominal voltage and different relative humidity and then, behavior of 1^{st}, 3^{rd} and 5^{th} harmonic components are investigated. As shown in the figure 6, increase in humidity leads to increase in amplitude of harmonic components. As shown in the figure 7, increase of humidity in standard porcelain insulator, leads to increase in amplitude of third harmonic and this increase is more than fifth harmonic and consequently it decreases the ratio of 5^{th} to 3^{rd} harmonic component ($K_{5/3}$) which is an important criterion in studying the leakage current. Also Figure 7 shows that $K_{5/3}$ will no change by increase in humidity in anti-fog porcelain insulator in nominal voltage and it is equal to unit. It is noted that in dry condition (natural humidity, 66%), amplitude of 5^{th} harmonic is more than 3^{rd} harmonic and by increase in relative humidity via fog generator, a remarkable increase in 3^{rd} harmonic is observed. Therefore, main cause of remarkable increase of 3^{rd} harmonic component is the increase of relative humidity and consequently increases in the number of partial discharge on the surface of the insulator. Hence, it is concluded that by increase in environment relative humidity, partial discharge increases on the surface of the sample insulators that will lead to extend the leakage current and finally flash over will occur. This causes improper performance of the insulators and increase of failures of lines and damages.



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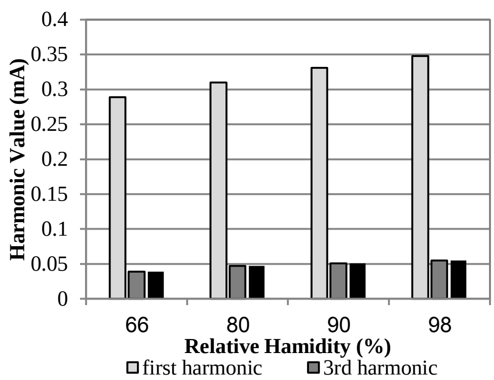

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Figure 6 . Harmonic components of LC in different relative humidity and nominal voltage. (a) standard insulator; (b) anti-fog insulator.

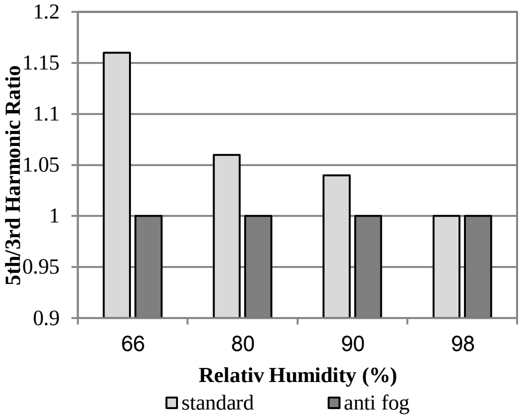


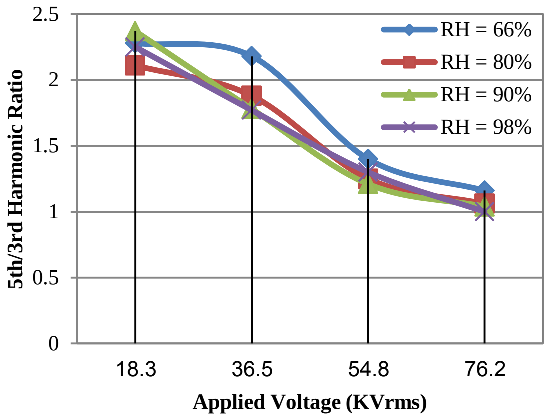
Figure 7. The variation of fifth to third ratio versus different relative humidity for sample insulators at nominal Voltage

3-2-2- Harmonic Components of Leakage Current in Different Voltage Levels

As shown in table 2, increase in voltage level, has a similar behavior to increase in humidity, and leads to increase in amplitude of 1st, 3rd and 5th harmonics especially third harmonic. Therefore, figure 8 show the ratio of 5th to 3rd harmonic component ($K_{5/3}$) also decreases with increase in voltage close to the nominal voltage and reaches to unit.

Table 2. The variation of harmonic components of LC versus different voltage and humidity levels

Relative Humidity (%)	Applied Voltage (kV_{rms})	Sample insulators							
		Standard type				Anti-fog type			
		1st	3rd	5th	$K_{5/3}$	1st	3rd	5th	$K_{5/3}$
66	**18.3**	0.067	0.007	0.016	2.28	0.074	0.008	0.018	2.25
	36.5	0.126	0.011	0.024	2.18	0.133	0.015	0.026	1.73
	54.8	0.189	0.02	0.028	1.4	0.217	0.029	0.035	1.20
	76.2	0.255	0.036	0.042	1.16	0.287	0.041	0.041	1
80	**18.3**	0.075	0.009	0.019	2.11	0.076	0.008	0.017	2.12
	36.5	0.125	0.017	0.032	1.88	0.146	0.019	0.030	1.57
	54.8	0.217	0.032	0.04	1.25	0.223	0.032	0.038	1.18
	76.2	0.293	0.044	0.047	1.06	0.310	0.047	0.047	1
90	**18.3**	0.075	0.008	0.019	2.37	0.081	0.008	0.019	2.37
	36.5	0.151	0.019	0.034	1.78	0.163	0.019	0.034	1.78
	54.8	0.219	0.033	0.040	1.21	0.242	0.033	0.043	1.30
	76.2	0.306	0.046	0.048	1.04	0.331	0.051	0.051	1
98	**18.3**	0.08	0.008	0.018	2.25	0.082	0.007	0.018	2.57
	36.5	0.165	0.018	0.032	1.77	0.166	0.016	0.034	2.12
	54.8	0.240	0.030	0.039	1.30	0.242	0.034	0.045	1.32
	76.2	0.344	0.051	0.051	1	0.348	0.055	0.055	1



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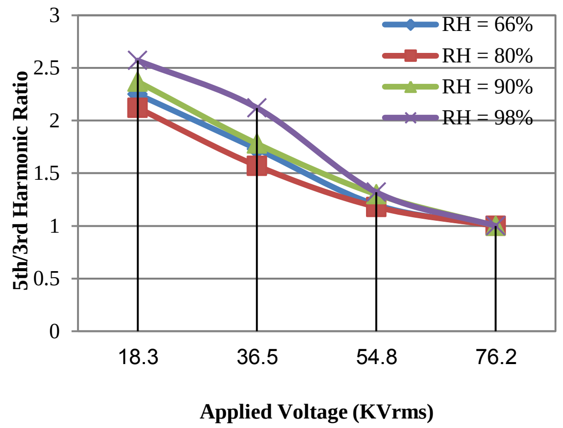

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Figure8. The relationship between $5^{th}/3^{rd}$ harmonic ratio and applied voltage

4. CONCLUSION

In this paper, performance of string insulators (standard porcelain and anti-fog porcelain) has been investigated through monitoring leakage current parameters in different voltage and humidity levels in time and frequency domains. Experimental results show a close relation between leakage current parameters and variations of relative humidity and voltage levels.

With increase in relative humidity, Peak value of leakage current (I_m) is increased in both insulators and since tests are performed in clean condition without pollutions, Diagram of peak value of leakage current in anti-fog insulator is very close to each other in comparison with standard porcelain insulator. Also increase of relative humidity and voltage level leads to increase in amplitude of 1^{st}, 3^{rd} and 5^{th} harmonic component, and because of increase in partial discharge in higher voltage and humidity levels, 3^{rd} harmonic is more than 5^{th} harmonic and consequently it decreases the ratio of 5^{th} to 3^{rd} harmonic ratio ($K_{5/3}$). Obtained results show that the 5^{th} to 3^{rd} harmonic ratio decreases when relative humidity is constant and voltage increase. Therefore, $K_{5/3}$ can be a good criterion in analysis and evaluation of insulators in different humidity and voltage levels.

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