

EVALUATION OF POLYMER HOUSED METAL OXIDE SURGE ARRESTER'S CONDITION IN HUMID AMBIENT CONDITIONS

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Abstract: *The AC leakage current of surge arresters is the most important information for monitoring and the condition assessment process. The ambient humidity can result in the increase of the leakage currents and the variation of harmonic components. The aim of this study is assessment of 20 KV brand new polymer surge arresters in humidity conditions. This paper described leakage current characters of 20 KV polymer housed metal oxide surge arrester in different humidity conditions and voltage levels by using experimental tests. The characteristics of the leakage currents have been investigated under different applied voltage when changes the ambient humidity in an artificial fog chamber. A joint approach of Fast Fourier Transform (FFT) amplitude is used to analyze the leakage currents in combination with the leakage current waveform. Also this paper presents the analysis of the harmonic components of leakage current in different conditions. Finally, a good indicator is introduced for assessment of polymer surge arresters in humid ambient conditions.*

Key words: *Metal Oxide surge arrester, Leakage current, FFT amplitude, Humidity.*

1. Introduction

Lightning and switching surges and also temporary overvoltages are the main reasons for outages in overhead transmission lines, distribution lines and in substations. It is well known that the lightning protection of transmission lines is exclusively relying on their correct initial design. Metal-Oxide (MO) surge arresters is an important overvoltage protection device in power systems [1], that frequently being used in power transmission and distribution facilities for surge protection of equipments.

Today, there are several different types of surge arresters and all perform in a similar manner. Most distribution surge arrester types have polymeric housing and a mechanical structure without spark gaps. MO-surge arresters are composed of a series of stacked varistor blocks, enclosed in porcelain or polymeric housing. Surge arresters are known that nonlinear voltage-current characteristics of metal oxide varistors become degraded due to the continuous application of AC or due to transients with currents larger than the varistors ratings.

In addition MO arresters are inherently faster-acting than the gapped type, since there is no time delay due

to series air gaps extinguishing the current [2]. Surge arresters are an essential part of the insulation coordination design of the power system and therefore must be reliable under steady-state as well as surge conditions.

The MO surge arresters due to passage of surge currents can degrade during its service, moisture ingress, pollution on the external surface, and overvoltages. Thus, is obvious the importance of the arresters' condition monitoring, since this process is capable to guarantee the reliability of the system. However, the monitoring process is expensive, especially for high voltage systems, exceeding in almost all the cases the value of the arresters' installation.

Furthermore, the risk of measuring errors and measurements' misinterpretations is high and might lead to unnecessary arrester replacements, which again produce additional expenses in equipment and working time [3]. All those reasons have as a result the application of sample monitoring procedures in contrast to continuous online monitoring systems from electric companies all over the world, considered as more accurate and cost-effective methods. However, the majority of the monitoring methods (either sample or online monitoring) are based on the resistive leakage current measurement, which is a good indicator of the arrester's condition [4].

Nowadays, the determination of the condition of gapless MO arresters is achieved using many alternative methods, such as ultrasonic and radio interference detection [5], partial discharge and electromagnetic radiation measurement [6, 7], thermovision methods [8] and certainly the leakage current measurement. The total leakage current of a MO surge arrester consist of resistive and capacitive current components, where the capacitive component is much bigger than the resistive.

MO-surge arresters are known to exhibit an increase in resistive leakage current in relation with the arrester's operating time. Increase of the applied voltage and the increase of ambient temperature, degradation or aging in the arrester results in an increase to the resistive component of the leakage current, while the capacitive part has little change [9-11]. An increase of the resistive current can be considered as an indicator of the arresters condition,

and with the continued operation time it can cause failures or permanent degradation [12]. Therefore it is obvious the importance of the arrester's resistive leakage current measurement for the diagnosis of its condition, since the total leakage current does not contain important information, except from the case of moisture ingress into arrester, which may affect the peak value of the total current [3]. The leakage current measuring procedures can be divided into two different groups, Online monitoring and Offline monitoring [13].

The most common online methods are the measurement of the total leakage current, which is based on the fact that the leakage current contains harmonics, due to the nonlinearity of the voltage-current characteristic. When the resistive current increases, the amplitude of the harmonics also increases. Main disadvantage of the method is the fact that the measurement is influenced by the voltage harmonics and the practically unknown temperature of the arrester.

Several leakage current measurements exist in the technical literature performed under artificial pollution conditions [14, 15].

Christodoulou et al. [16] done the measurements under artificial rain and measurements after impulse voltage subjection. No attempt was made to determine leakage current harmonics.

Lahti et al. [17] considered based on measurement results obtained during a 1.5 year laboratory test series conducted for different types of polymer-housed distribution class arresters. This work was done for revealing internal moisture in polymer housed metal oxide surge arresters. No attempt was made to determine leakage current harmonics of brand new surge arrester in different humidity conditions.

Mardira et al. [18] investigated diagnostic techniques for metal oxide surge arresters when subjected to severe lightning strikes in the field. In this

work leakage current harmonics analysis was not attempted as a diagnostic methods.

In this work, the characteristics of leakage current of 20 KV metal oxide surge arrester in the time and frequency domain were measured and analyzed; Fast Fourier Transform (FFT) amplitude of the leakage current is measured. One case for the 20 KV surge arrester with polymeric housing was considered, that is, measurements with brand new arrester, measurements under different humidity ranges and measurements with different applied voltage. It must be mentioned that this work has been focused on tests in humid ambient. The experimental tests are according to IEC60099-4 for surge arresters. The behavior of leakage current's harmonic components during these tests has been presented in detail since moisture on arrester's polymeric housing, plays an important role in arrester's condition. The analysis and the discussion of the produced results can be used from electric utility's engineers in order to easily diagnose arresters' condition leading to more effective schedule maintenance.

The AC leakage current was measured in test specimen every day during the almost 6 month test.

2. Experimental Tests

2.1. Test Facilities

In order to perform the experimental tests, the setup has been prepared according to IEC60507 as shown in Figures 1, 2. The tests were performed in a fog chamber in the high voltage laboratory of Babol University of Technology. This chamber has the volume equal to 200 cm×200 cm×180 cm, as shown in figure 3. The test circuit is shown in figure 1.

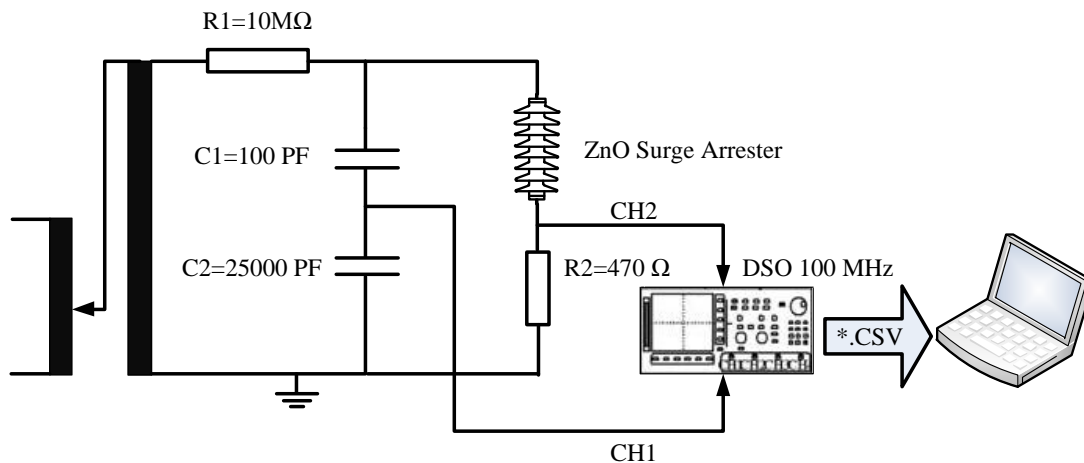


Fig. 1. Circuit for the measurement of the total leakage current of a surge arrester

The high voltage supply is connected to tested surge arresters through a 10 Mega ohm, protective resistance (R1). Also, the HV supply is connected to a capacitor voltage divider (C.V.D) with the ratio of 250:1 (high voltage to low voltage). AC voltage up to $25 \text{ kV}_{\text{rms}} / \sqrt{3}$ was applied to the sample surge arrester. The digital oscilloscope (D.O) acquired the voltage waveform from the low voltage of C.V.D.

The leakage current waveform is measured from voltage drop across a specific resistor R1 (470 Ω) by D.O. All of the waveforms and their FFT are recorded and stored by D.O. Figure 4 shows an example of leakage current and applied voltage waveform recorded by oscilloscope.



Fig. 2. Experimental setup in laboratory



Fig. 3. Fog chamber for experimental tests

2.2. Power Supply

AC high voltage is supplied to 100 kV from single phase transformers 220 V/ 100 KV, 5 KVA, 50 Hz. The rated current of each transformer is 50 mA with maximum short circuit of 1.25 A. The HV supply was

connected to the test chamber through a vertical bushing. The power supply is loaded sample surge arrester through a resistance.

2.3. Sample Surge Arresters

The sample arrester is used for the experiments includes 8 sheds for polymer surge arrester. This surge arrester is used for simulating 20 kV distribution lines. Their parameters are shown in table 1.

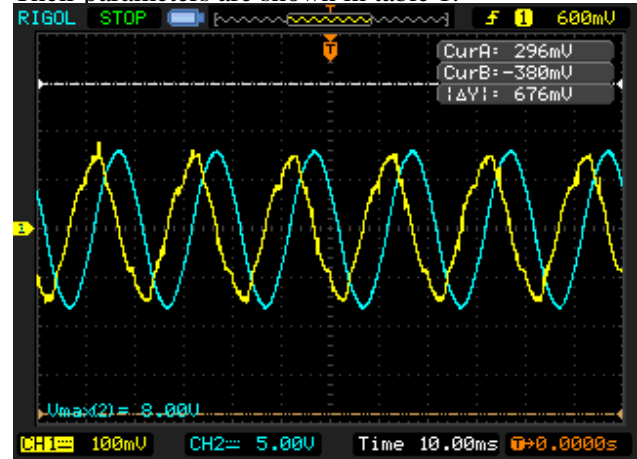


Fig. 4. Example of leakage current and applied voltage waveform recorded by oscilloscope

2.4. Test Procedure

In the current work, the leakage current for 20 kV ZnO polymer housed surge arrester was computed for four humidity different cases in three voltage levels.

Table 1. Electrical and housing data characteristics of the arresters

Parameters	Silicon Rubber
Nominal discharge current (8/20 μ s), kA	10
Residual voltage (8/20 μ s, 10 kA), kV	82
Height, mm	380
Creepage distance, mm	850
Number of sheds	8

In order to measure leakage current harmonic components of surge arrester, the surge arrester was tested in humid conditions. In any humidity level, the surge arrester was energized with three voltage levels in clean fog produced by fog generators.

The relative humidity of the air was kept in four ranges, (55–65%), (65–75%), (75–85%) and (85–95%), respectively. The temperature range of the fog chamber was kept constant, between 20 and 25°C, during test series described below:

For arrester and for each humidity range, five measurements in 11.5kV (corresponds to the continuous operating voltage of the arrester (U_c)), five measurements in 13.2kV and five measurements in

14.4kV (corresponds to the rated voltage of the arrester (U_r)) were performed.

However, in this work, harmonic components of ZnO polymer arrester under different humidity condition are discussed and analyzed. The study of these measurements could be useful in the more effective evaluation of the arrester's condition.

In humid condition, clean fog produced by fog generator and as soon as the arrester surface was wetted for 15–20 min, the operating voltage was applied. In each of the cases, leakage current signals were recorded and analyzed in both time-domain and frequency-domain.

3. Analysis of the Leakage Current

Fourier series provides an alternate way of representing data, instead of representing the signal amplitude as a function of time, was represented the signal by how much information is contained at different frequencies.

The leakage current is a random signal in nature that follows the statistical laws in the time domain and represents the harmonic feature in the frequency domain. The FFT analyzed characteristics of the leakage current can be used as another new approach to explore the influence of relative humidity, on the leakage current.

In laboratory tests, the applied voltage and total

leakage current waveforms were measured with use of oscilloscope, the voltage waveform is considered as reference signal.

4. Result and Discussion

The characteristics of leakage currents in the humidity experiments can be demonstrated by the waveforms, FFT amplitudes plots. The Stored waveforms by oscilloscope are in the form of *.CSV files and they can be used to obtain leakage current frequency spectrum in MATLAB environment. Figure 5 shows waveforms and frequency spectrum of leakage current for polymer surge arrester in 11.5KV voltage level, when the relative humidity was in different humidity ranges.

Table 2 shows the values of 1th, 3th and 5th harmonic components of leakage current in different voltage levels and humidity ranges. These values are average of five measurements. The amplitudes of the harmonic components at the four humidity ranges are presented in figures 6-8. According to this figures, the leakage current peak value in surge arrester increases with increase of voltage. In the FFT amplitude plots, the amplitude of 50 Hz harmonic component grows significantly. That is similar to the growth of the peak value of the waveform in the time domain.

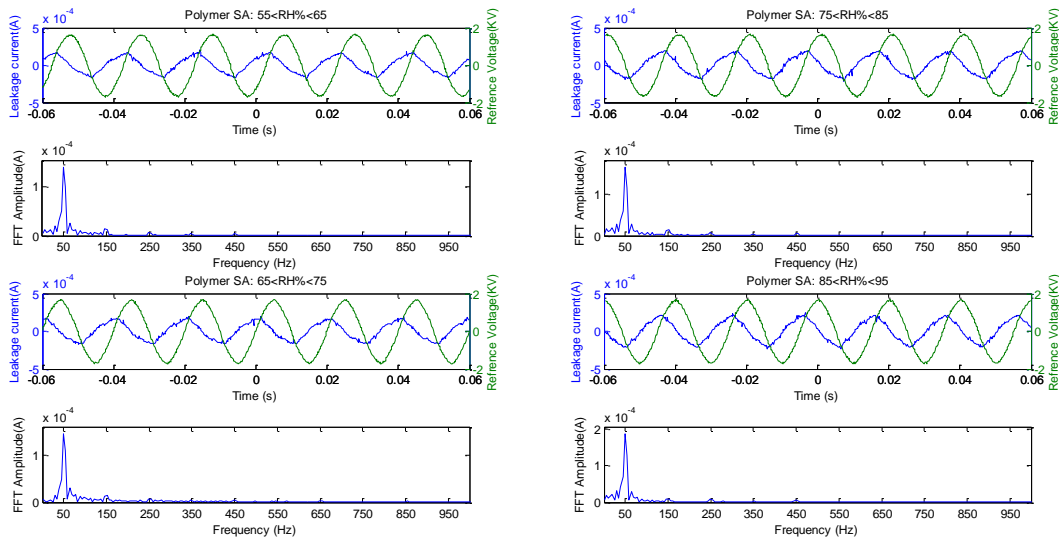


Fig. 5. Waveforms, FFT amplitudes for polymer surge arrester in 11.5 KV level and in different relative humidity ranges (RH%)

Table 2. Average amplitude of leakage current in μA for polymer surge arrester in different voltage levels (rms)

Relative Humidity (RH%)	Applied Voltage (kV)								
	11.5			13.2			14.4		
	1th	3th	5th	1th	3th	5th	1th	3th	5th
55-65%	141.1	14.53	5.98	161.2	12.34	9.48	187.2	13.21	14.32
65-75%	153.6	14.33	7.72	172.3	13.78	15.12	191.6	16.93	11.21
75-85%	166.9	15.8	7.45	175.8	14.97	13.53	200.8	17.21	15.63
85-95%	186.2	9.85	7.43	180.2	18.34	11.79	216.2	19.73	13.29

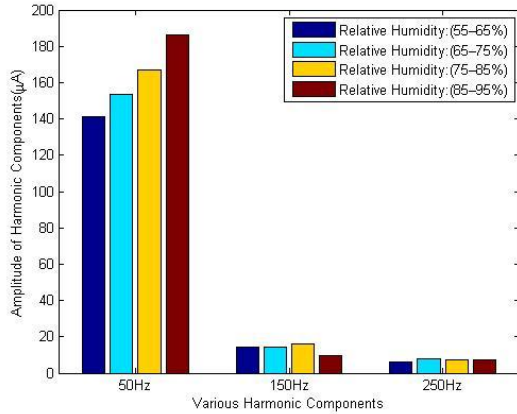


Fig. 6. Amplitudes of the harmonic components in 11.5KV level

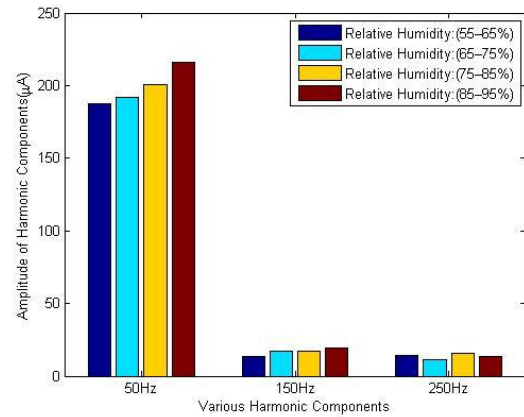


Fig. 8. Amplitudes of the harmonic components in 14.4KV level

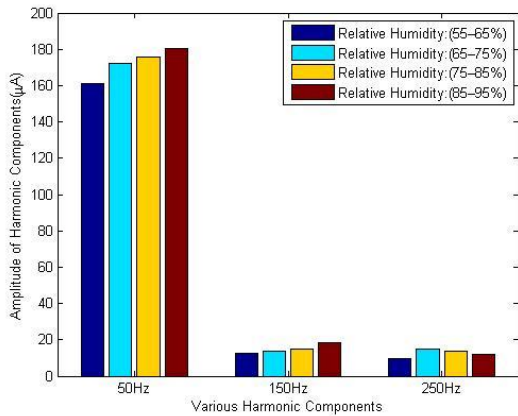


Fig. 7. Amplitudes of the harmonic components in 13.2KV level

However, the increase is not same for the other harmonic components such as, for 150 and 250 Hz. Their analysis reveals that the growth of the 50 Hz harmonic component is the main reason for the increase of the leakage current with relative humidity.

Inspecting the amplitude plots, the smooth lines show that there are only a few pulses during the entire test process. Thus, the reason for the increase of the leakage current is mainly because of the increase of the relative humidity, considering the characteristics of the leakage current from the waveforms, FFT amplitudes.

5. Conclusions

In the present work, the leakage current frequency spectrum analysis for 20 kV ZnO surge arrester with polymeric housing was computed for three voltage levels in four humidity ranges (measurements on brand new arresters, measurements under humidity conditions).

By analyzing harmonic component of leakage current, we find out that, in humid ambient conditions, amplitude of first harmonic order increases with increase in humidity. It is noted that first harmonic order in more sensitive to change in humidity in comparison with higher harmonic order. First harmonic order component of leakage current can be good indicator for evaluating arrester in humid ambient conditions.

It must be mentioned that the future work in this paper field can be the effect of pollution with humidity on the leakage current of polymer surge arresters with experimental tests.

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