International Conference on Lightning Protection
33rd International Conference on Lightning Protection
25 - 30 September 2016
Estoril, Portugal

Experimental study of surge arrester ageing using a high impedance current source

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***Abstract*—Ageing in surge arresters is a topic still under study. This paper proposes a method to study surge arrester ageing employing an Extra High Impedance Current Source. Using this source, it is possible to see the ageing process of the arrester blocks as they are stressed with current impulses. Both, the methodology used to accelerate the ageing process of the arrester blocks and the steps followed for its implementation are presented in this work.**

Keywords:Surge arrester, ageing, current impulse, high impedance curent source.

I. INTRODUCTION

Surge arresters are the most important protecting devices used in both electrical transmission and Distribution systems. In Colombian distribution systems these devices are mainly used to protect distribution transformers.

The surge arrester continuous operation could initiate ageing processes, which could change their characteristics and lead to early failures. Surge arrester failures could indicate damages in distribution system especially in countries with high keraunic level, such as Colombia. Therefore, to anticipate and to predict surge arrester failures, it is imperative to study surge arrester ageing processes.

For the aforementioned reasons, this experimental study was initiated in order to predict surge arrester ageing and failures by examine changes in the low current region (Continuous Operating Voltage - MCOV). To examine the non-linear characteristic of the arrester, the Extra High Impedance Current Source, known in the following by its acronym ETHICS, was used. ETHICS was developed by Roman [1] and it is used to study semiconductor materials, such as varistors.

ETHICS is a current source which uses corona discharges in air generated in the low curvature electrodes of a coaxial electrode configuration feed by a high voltage DC source. When corona discharges are initiated in the low radius of curvature internal electrodes of a coaxial arrangement, a corona current appears. This corona current flows to the external coaxial electrode and to the earth through a series connected load, as it can be seen in Figure 1.

The surge arrester test probes are aged by applying 8/20 μs lightning current impulses, while they are energized to its operating AC voltage. ETHICS was used to reproduce the voltage-current characteristic up to a few milliamps of every single surge arrester, before and after the ageing process was performed. The hypothesis in this study is that this voltage-current characteristic could clearly show the surge ageing process.

To demonstrate the proposed hypothesis following activities were performed:

- Definition of the test procedure.
- Overview of the proposed method.
- Selection of surge arrester prototype to be tested.
- Selection of both the impulse current 8/20 μs amplitude and the AC voltage level for testing.
- Construction of an experimental setup for the simultaneous application of both lightning impulse currents and AC voltage
- Construction of the measurement system.

The previously mentioned elements used to age the surge arresters are described throughout this document.

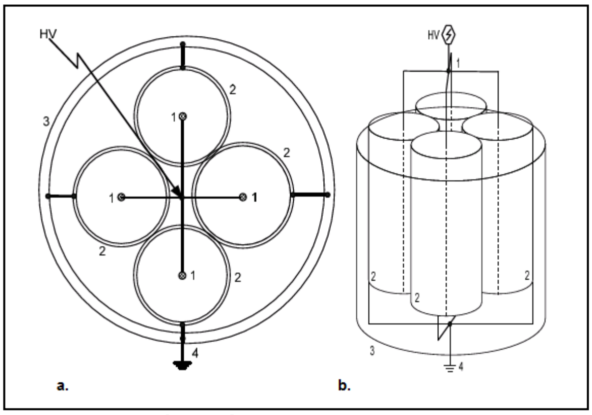

Figure I. Extra High Impedance Current source ETHICS. a) Upper view of the four coaxial cylindrical arrangements, b) Isometric view. 1 are the corona wire electrodes, 2 are the earthed external cylindrical electrodes, 3 is a container and 4 is the earth connection [2].

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II. PREVIOUS STUDIES

Three ageing methods used in previous studies are presented and discussed in the following. The method proposed in the present paper is based in some of these works.

A. Ibañez's method [3]

One of the first research works performed in Colombia about Zinc Oxide blocks degradation was performed by Ibañez [3]. In Ibanez method AC voltage is applied while AC current and temperature are measured in the test probes.

B. Standar IEC 60099-4 [4]

The IEC 60099-4 standard established an accelerated aging method consisting in a surge arrester heavy-duty test performed in several steps.

The surge arrester initial condition is evaluated at the test initiation by performing initial measurement of some of its characteristics. Afterwards the sample is conditioned at a temperature above 100 °C for 1000 hours while it is energized with AC voltage.

Thereafter, a series of 8/20 and 4/10 µs current impulses are applied. As a result, the residual voltage variation measured before and after the test, should not be greater than 5%.

C. Lee, Song, Kim, Lee B.S.,Kwon 's method [5]

In this method a constant voltage is applied to the surge arrester while it is immersed in a chamber, while temperature, humidity, salinity, rain and UV radiation conditions are varied to simulate summer and winter conditions. The measured variable along the test is the leakage current.

D. Poveda's method [6]

Poveda proposes to apply 8/20µs current impulses at a rated amplitude while the maximum continuous operating voltage (MCOV) is applied at the surge arrester. Both residual voltage and AC leakage current are measured.

III. PROPOSED METHOD

The proposed method in this research work is mainly derived from Poveda's method:

8/20 µs current impulses are applied while the surge arrester is energized at its maximum continuous operation voltage - MCOV.

After each current impulse, the AC leakage current is measured and the DC voltage-current characteristic is obtained by using ETHICS.

Lighting current impulses are applied until the surge arrester fails. What it is expected to be observed is changes in some of the surge arrester characteristics such as leakage current or in the DC voltage-current characteristic.

IV. SURGE ARRESTER SELECTION

Present work is focused in the surge arresters used in 11,4 kV and 13,2 kV Colombian distribution systems. The surge arrester characteristics of the selected test probes are presented in Table I.

TABLE I. Characteristics of Surge arrester selected

	Rated Voltage [kV]	***Rated Discharge Current [kA]***	***MCOV [kV]***
Surge Arrester	12	10	10,2

Another important point is the selection of surge arrester model employed to perform simulations with the respective impulse current generator circuit. The simplified Pinceti P. and M. Giannettoni model [7] was selected. Tests are performed on six surge arresters samples of the same characteristics. The circuit element values are calculated by using the factory data.

Figure 2 shows the components of simplified Pinceti P. and M. Giannettoni models. The R resistance value is 1 MOhm. The values of L0, L1, A0 and A1 are calculated by using the factory data and the model's equations. Table II and Table III show the values of model's parameters used. Fig 3 shows Voltage-current characteristic curve of surge arrester implemented in the EMTP-ATP Simulation.

V. SELECTION OF IMPULSE CURRENT AMPLITUDE

Knowing that the definition of the impulse current amplitude is one of the most important parameters of the ageing methodology proposed in this work, it was decided to simulate a real Colombian distribution example. A medium voltage circuit located in La Palma – Cundinamarca, one of the Colombian regions with the highest lightning activity, which was studied by Gonzalez et al. [8] was modelled.

The selected circuit was a 12,5 km length and 13,2 kV transmission line, with a shielding wire, which was simulated with the EMTP/ATP transients program. The transmission line was divided in five sections and in each one a distribution transformer was installed. These transformers, which were loaded with 75% of its total power, were located every 2,5 km along the line and protected with surge arresters in the medium voltage side.

Simulations of the transmission line conformed by surge arresters, transformers and shielding wires, were performed by injecting 20kA, 10/350µs lightning current impulses in the shielding wires. This lightning current amplitude was chosen according to the Colombian lighting protection standard as a lightning current with probability greater than 80% [9]. As a result of the simulations, the current injected in each individual surge arrester of every section was calculated.

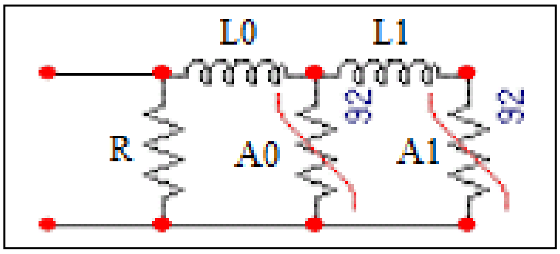

Figure 2. Surge Arrester Model according to Pinceti P. and M. Giannettoni model [7], which was used in the simulations.

TABLE II. R, L0 and L1 parameters

Surge Arrester Model	*R [MΩ]*	*L0 [μH]*	*L1 [μH]*
	1	0,114	0,038

TABLE III. A0 and A1 parameters

Current [kA]	Voltage [p,u] of Vr8/20		Voltage @ Vr8/20	
	A0	A1	A0	A1
0,00001	0,84	0,65	27,72	21,45
0,0001	0,86	0,68	28,38	22,44
0,001	0,90	0,72	29,70	23,76
0,01	0,94	0,75	31,02	24,75
0,1	0,97	0,79	32,01	26,07
1	1,05	0,87	34,65	28,71
10	1,20	1,01	39,60	33,33
20	1,28	1,10	42,24	36,30

Figure 4 shows an example of the currents flowing in each individual section when the lightning current was injected in section 4. It was observed that regardless of the point of lightning current injection point, current was flowing across each individual surge arrester in the circuit. In addition, the highest current amplitude was observed in the surge arrester located in the neighborhood of the impact zone.

Notice the maximum lightning current amplitude in the surge arrester in section 4 and how all surge arresters conduct lightning current, independently of its location in the circuit.

The final result of the 75 performed simulations involving all sections; a mean current value of 700 A, 10/350μs was obtained in each arrester. This calculated current was converted into an equivalent 8/20 lightning current waveform by using the recommendations given in [10] and [11]. As a result, it was obtained a 7 kA, 8/20 lightning current impulse.

VI. Test circuits

To perform this investigation, two experimental circuits are proposed. The first experimental circuit uses ETHICS as a high impedance source to inject DC current to the test objects. The second experimental circuit is an experimental set-up to simulate the injection of lightning impulse currents to the surge arresters while they are connected to an AC source.

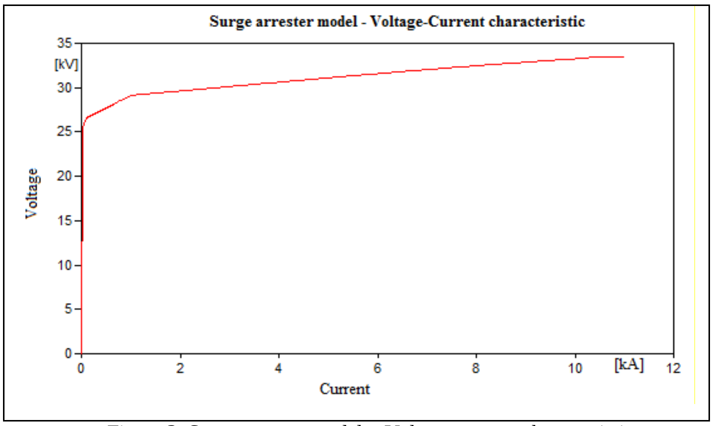

Figure 3. Surge arrester model – Voltage-current characteristic.

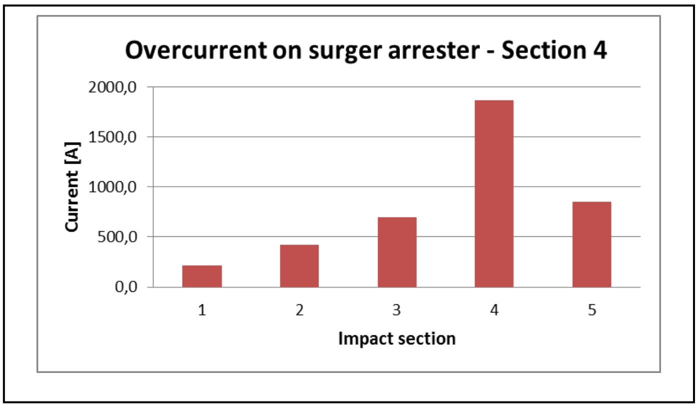

Figure 4. Calculated current in each section when the lightning current is injected in the shielding wire in section 4.

A. *The ETHICS DC experimental circuit*

ETHICS is a DC source with an internal impedance in the order of 1GΩ [1]. Therefore, with this source it is possible to obtain V-I characteristics of semiconductor materials, such as varistors. For this reason, ETHICS is used to obtain the variations in the V-I characteristics of surge arresters. In the present research work a DC current is forced to circulate across the complete surge arrester, while both voltage and current are measured to get its V-I characteristic. The idea behind the use of this source is to register fine changes in the V-I characteristics of the test probes after the application of each 7kA, 8/20 current impulse. Small changes in the V-I characteristics could indicate the initiation of the ageing process.

The ETHICS experimental setup is shown in Fig 5. In this setup voltage is measured with a resistive divider, while current is measured in a series shunt resistor.

B. *AC and impulse circuit*

To perform the ageing procedure an Impulse Current Generator, which is used by the Electrical Industrial Testing Laboratory (LABE) of the Engineering Faculty of the Universidad Nacional de Colombia is used. This generator is able to generate a maximum current of 40 kA, 8/20μs

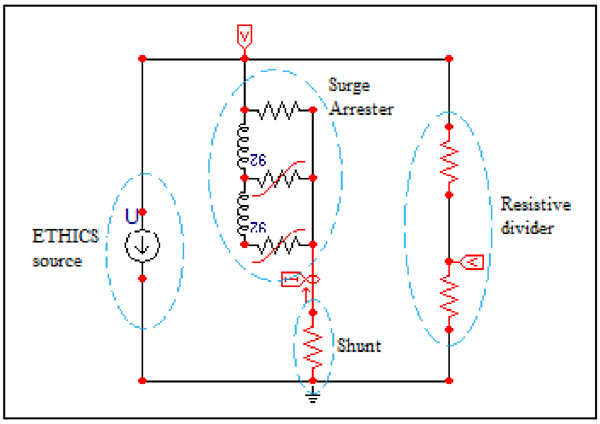

Figure 5. ETHICS DC experimental circuit. Notice the resistive divider and the shunt resistance to obtain the V-I characteristics.

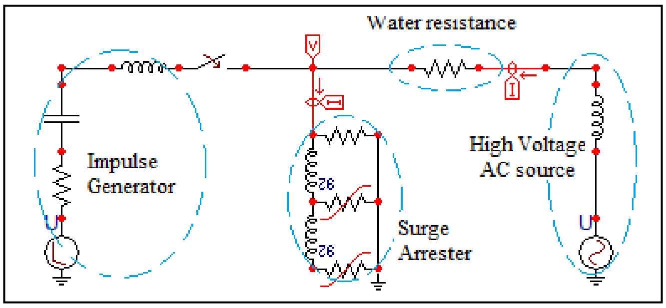

Figure 6. AC and Impulse experimental circuit to age surge arrester. Notice the water resistor used to disengage the AC source from the Current Impulse Generator.

Nevertheless, the impulse generator wasn't designed to work simultaneous with an AC source feeding the test probe. Therefore, a water resistor was added to disengage the AC source from the impulse current generator, following the previous work performed by Poveda's [6]. The equivalent circuit is shown in Figure 6.

The water resistance was able to let the AC current circulate across it to feed the test object, but thereby impeding the current impulse to reach the AC source, a high voltage transformer. The resistance value of the water resistor was approximately 100 kΩ.

A test was performed to identify a possible influence of the intrinsic inductivity of the water resistor. The proposed hypothesis was the following "if there is an inductive effect of the water resistor, there must be a phase lag between both voltage and current signals".

AC voltage was applied at water resistor. Voltage and current signals were measured with an oscilloscope. After various tests and data analyses, no appreciable phase lag between the voltage and current signals was observed. Therefore the water resistor inductive effect are negligible.

Another part of the experimental test circuit was an isolated structure used to support six test samples. A pneumatic system was constructed to allow the selection of a specific test object between six samples. The impulse current is applied to the selected sample, while the others are energized at its maximum continuous operation voltage –MCOV–. In this way, the pneumatic system performs a safe switching for people and equipment between test objects.

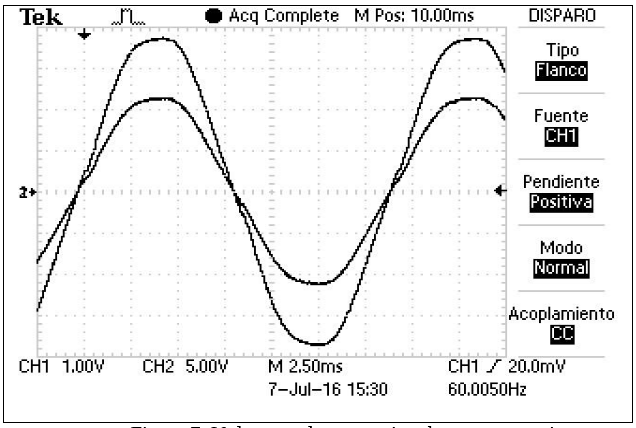

Figure 7. Voltage and current signals on water resistor

Figure 8. Isolated structure and pneumatic system

Voltage and current were respectively measured by a capacitive divider and a shunt resistor. Both residual and alternating voltage are measured in a Tektronics oscilloscope model TDS1012B.

In the second channel of the previously mentioned oscilloscope the current impulses are measured. To perform the current measurements, the current voltage drop on the shunt resistor is attenuated and sent to the oscilloscope through 75 Ω matched coaxial cables to avoid reflections.

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VII. Preliminary Results

The previously described methodology was tested in one surge arrester and results are presented in Fig. 9. The sample results shown in Fig. 8 allow us to adjust the current impulse amplitude and the measuring systems. The first step in this methodology is the registration of the voltage-current characteristic of the sample when is new. Afterwards, several current impulses are applied to the tested surge arrester. Immediately after, the voltage-current characteristic is registered again.

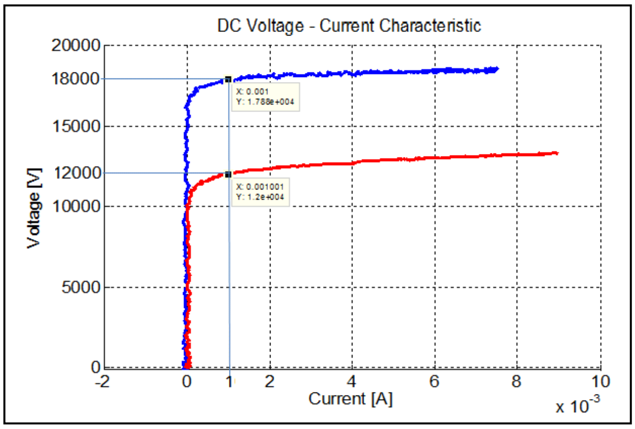

Figure 9. DC Voltage-current characteristic a) for a new surge arrester, blue line, b) for an aged surge arrester, red line. Notice the referent voltage changes at 1 mA in both blue and red characteristics.

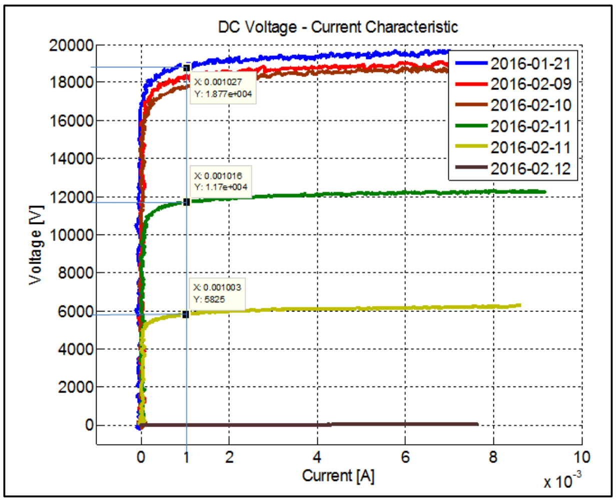

Figure 10. DC Voltage-current characteristic. S-4 sample. Notice the reference voltage changes at 1 mA for each one voltage-current characteristic.

Examples of the degradation processes are presented in Figs. 9, 10 and 11. In Fig. 9 an important change on V-I characteristic of a tested surge arrester is observed. Fig. 10 it can be observed a dramatic change in the V-I characteristics before and after the test procedure. The blue upper characteristic is obtained for a new surge arrester and the red lower characteristic was obtained for the same surge arrester after the ageing procedure. The reference voltage measured at 1 mA shows a dramatic reduction after the ageing procedure: For the new sample (blue line) the referent voltage value measure at the referent current (1 mA) is 18 kV while for aged sample the referent voltage value is 12 kV.

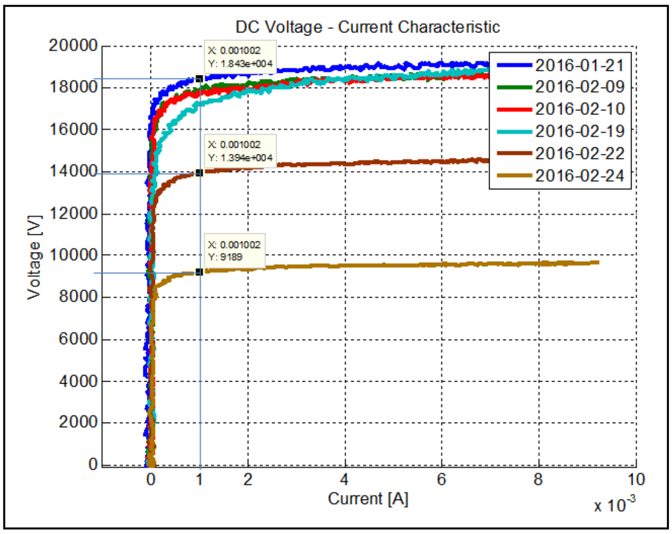

Figure 11. DC Voltage-current characteristic. S-6 sample. Notice the reference voltage changes at 1 mA for each one voltage-current characteristic.

After adjustment of the impulse current generator, tests were performed in six samples called S-1, S-2, S-3, S-4, S-5 and S-6. Figs. 10 shows the observed changes in the V-I characteristics of sample S-4. These samples failed after some current impulses. The behavior of sample S-4 shows how the referent voltage measured at 1mA decreases dramatically. The initial value was 19 kV, but after several days it reduces to 5,8 kV.

In the case of sample S-6 shown in Fig. 11, it can be observed how the V-I characteristic is changing just after the first applied impulse. After 21 impulses the referent voltage was reduced to 9 kV.

The ageing process of the test sample S-4 and S-6 are summarized in Table IV.

TABLE IV. Summary results

Sample	***Current impulses***	***Initial Referent Voltage [kV]***	***Final Referent Voltage [kV]***
S-4	6	18,7	5,8
S-6	21	18,4	9,2

VIII. Conclusions

It was possible to examine the degradation process of some complete surge arresters commonly used in the Colombian distribution networks. The V-I characteristics obtained with the High Impedance Current Source ETHICS developed by the EMC-UNC group.

A method and an apparatus to age surge arresters was tested. This system simulates some real operation conditions like AC voltage and the presence of lightning current impulses.

A Pneumatic system was implemented to allow multiple tests almost simultaneously. Its operation principle reduces thetime to perform several ageing tests.

Acknowledgment

Department of Science, Technology and Innovation – COLCIENCIAS.

Authors would like to thank Universidad Nacional de Colombia, Hermes project, code 28372.

Support and assistance provided by Electromagnetic Compatibility Research Group (EMC-UNC).

By collaboration Industrial Electrical Testing Laboratory (LABE).

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