DEGRADATION OF METAL OXIDE SURGE ARRESTERS UNDER SIMULATED NATURAL CONDITIONS

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ABSTRACT

The degradation of metal oxide surge arresters (MOSA) under continuous operating voltage (C.O.V), with time, is a well known fact. But the contribution of transient overvoltages in the form of lightning surges, switching surges etc., against which the arrester is used as a protection device, to the arrester degradation has not been studied much. The simulation of a situation, wherein the arrester is kept under C.O.V and different surges are applied on it, is somewhat complex. A method for simulation of field operating conditions of an arrester in the laboratory is presented in this paper. Results of two separate degradation studies on different samples under A.C, and D.C excitations with superimposed transient stresses are given. A comparison of observed data with calculated ones is also made.

1. INTRODUCTION

Developments in material technology have spurred quantum advances in power system equipment protection within the past two decades. Ever since its advent, around 1970's, metal oxide based surge arresters have emerged as the most reliable device against power system transient overvoltages. It is being increasingly used in surge protection due to its superior nonlinear characteristics and greater energy handling capabilities. But, due to the absence of any series isolating gaps, the surge arrester elements are continuously stressed by the system voltage, which causes the flow of a small leakage current (about 50µA or so). This current as well as the energy absorption at the time of impulse discharges, cause gradual degradation of the elements. In order to predict the period of reliable operation of a metal oxide surge arrester, or its life, the degradation phenomena is studied the world over. Still, a definite procedure is yet to be postulated to assess degradation under both A.C and D.C excitations. Here we present the results of work done in our laboratory to study the degradation of surge arrester elements under simulated natural conditions.

2. EXPERIMENT

2.1 Scheme of experiment

The representation of the service conditions is achieved by estimating the stress cycle per year. This cycle is then applied to the surge arrester element over one day, to simulate the electrical stresses coming upon the arrester under field conditions. A typical transient stress cycle over one year has been broadly estimated as follows:

(i) Lightning transients

- (a) direct stroke, simulated by a surge current of 4/10µs, 50kA postulated to occur once every 5 years,
- (b) indirect strokes, simulated by surge currents of 8/20µs duration and magnitudes 5, 10 and 20kA occurring respectively; at frequencies of roughly 18, 5 and 2 times a year.

(ii) Switching transients simulated by a rectangular current pulse of 1kA magnitude and 2.4µs pulsewidth, occurring once in a year.

While the above transients are applied the arrester is kept under continuous operating voltage (C.O.V) at a

temperature of 60°C. Experiments were carried out with D.C and A.C excitations applied to the arrester elements. The elevated temperature of 60°C simulates the maximum probable element temperature in field service, taking into account the influence of ambient temperature, solar radiation and influence of pollution on the arrester housing [1]. Further, one year field life of the arrester is simulated within one day following the accelerated aging procedure described in clause 61.2 of IEC TC 37 WG-4 AUGUST 1988 document for MOSA. Accordingly, after the application of surges the sample was heated to a

temperature of $115 \pm 4^\circ\text{C}$ and kept at that temperature with the C.O.V across it, till the start of the next aging cycle. A 20 day simulation on the above lines was carried out with minimum interruption of the A.C operating voltage across the arrester element. Another 10 day experiment with D.C operating voltage on a different sample was also conducted.

2.2 Instrumentation

The lightning impulse currents were generated using a capacitor discharge. One generator was capable of giving upto 40kA, 8/20 μs and another generator of 200kA, 4/10 μs . The switching impulse current was obtained from a 8 stage ladder network transmission line model. It had a surge impedance of 3.6 ohms and the output pulse width was 2.4ms. The A.C/D.C excitation for the arrester elements was obtained from a 230V/3.6-0-3.6kV, 0.5kVA, oil filled transformer and half-wave rectifier & filter capacitor arrangement. The arrester element was kept inside a temperature controlled oven to maintain the elevated temperatures. The oven had a maximum temperature capability of 300°C with a $\pm 2^\circ\text{C}$ regulation.

The measuring instrumentation comprised of a 17.5m Ω co-axial current shunt with Gould 4074 100MHz Digital Storage Oscilloscope, for measuring impulse currents and a resistance potential divider to monitor the residual voltage across the arrester as well as the C.O.V. Typical 8/20 μs lightning impulse current and 2.4ms switching impulse current waveforms, obtained using the above arrangement are shown in Fig.1. The leakage current through the arrester element was monitored using a series resistance-digital multimeter scheme. The capacitance and tan delta variation with aging was measured using GENRAD RLC Digibridge Type 1657.

3. RESULTS

The variation in the different degradation indices monitored are graphically depicted in Figs. 2 to 10 as a function of the aging cycles. Eventhough the leakage current and barrier height were the main indices monitored, capacitance and tan delta variations are also shown.

3.1 Leakage current:

In spite of the scatter observed, the leakage current shows significant overall increase after successive aging cycles under both A.C and D.C operating voltages. Since the a.c leakage current is found to stabilise somewhat after 10

cycles of aging, a comparison between the A.C and D.C leakage current variations for a 10 year period of simulation can be done. This is depicted in Fig.2 in the form of normalised curves (normalised with respect to the initial leakage current values under A.C and D.C respectively). While the increase in leakage current is about 5 fold in case of A.C voltage (after a period of 20 year simulation), that in the case of D.C excitation is roughly 4 times (after 10 days = 10 years, accelerated aging). It is also observed that the magnitude of leakage currents in case of D.C is more than double that under A.C [Figs.3(a) & 4(a)].

3.2 Barrier Height:

The barrier height is calculated from the low voltage D.C characteristics of the arrester element after each cycle of aging. The calculation is based on the following equation:

$$\rho = \rho_0 \exp(\Phi_b/kT)$$

where ρ - resistivity in $\Omega \cdot \text{m}$
 ρ_0 - constant
 Φ_b - barrier height in eV
 k - Boltzman constant, $8.625 \times 10^{-5} \text{ eV/K}$
 T - temperature in K

The variation in barrier height is found to be quite small initially under both A.C and D.C voltages. But, after about 6 to 8 cycles of aging a significantly abrupt decrease is observed in both cases [Figs. 5 & 6].

3.3 Capacitance and Tan delta:

The capacitance and tan delta measurements were made at 1kHz without any external bias voltage. The capacitance values show general decreasing trends under both D.C and A.C operating voltages. On the otherhand measured tan delta values at the end of each cycle of aging show a randomly varying spread, which is hard to explain. While it exhibits a shifting spectrum of values, with overall increase, in case of D.C, the variation is highly erratic, with some peaks, in case of A.C.

4. DISCUSSION

As a real life simulation of MOSA under field conditions, it is felt that much more need to be done to have a good representation of the operating atmosphere. Even then, the present scheme offers a guideline on how to plan a laboratory simulation of MOSA field life, to study the complexities of real life stress degradation.

The leakage current seems to be the best index of degradation, showing a predictable variation with successive cycles of aging. The values of expected

leakage currents were calculated based on an expression given by Y.Fujiwara et al[2].

It is observed that the calculated values of leakage currents show matching trend with the observed values, even though slight deviations are present. The following features could be observed from the calculated and observed graphs [Figs. 3(b) & 4(b)]:

- (i) While the calculated values are more conservative than the observed values in case of D.C voltage aging, it is reverse in case of A.C voltage aging.
- (ii) The leakage current variation with respect to number of aging cycles is determined by the surge current density, element temperature and number of absorbed surges - which were used to compute the theoretical values under both A.C and D.C voltages.
- (iii) While the effect of surges on degradation is found to be pronounced at the elevated temperature and operating voltage, the contribution of the thermal stress to aging is less than that of the former.

Considering the barrier height variation, the almost steady value and then the sudden drop evident from the Figs. 5 & 6, indicate that irreversible changes in the microstructure of the MOSA material happen only after some cycles of aging. In the present case it is observed that such a change happens after about 8 cycles of aging in case of D.C & 6 cycles of aging in case of A.C. But it is notable that the order of change in case D.C is far more than that in case of A.C. This clearly indicates the polarization effects come into play in case of an unidirectional excitation [3].

The decreasing capacitance values with number of aging cycles might be the result of microstructural changes happening at the depletion region near the ZnO grain-grain interfaces, in the arrester material. This as well as the erratic nature of tan delta variation will have to be explained based more on the material characterisation after aging and associated changes in quantum mechanical phenomena, which were outside the scope of the present work. Hence the decision to consider the leakage current and barrier height as the main indices of aging.

5. CONCLUSIONS

A simulation of the field conditions under which surge arresters are supposed to operate has been achieved to a fairly good extent in the laboratory. The leakage current through the arrester is

found to follow a predictable variation opening up possibilities of life prediction on the basis of the order of its variation. Even though the general trends of variation in degradation indices is similar under both A.C and D.C voltages, evidence of probably different phenomena of aging is observed from the tan delta and capacitance variations.

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Fig.1 : (a) Typical lightning impulse current wave form
(b) Typical switching impulse current wave form

Fig.2 : Comparison between ac & dc observed leakage currents at continuous operating voltage (normalised).

Fig.3 : (a) A.C leakage current at C.O.V (measured at 60 C)
(b) Normalised ac leakage currents (observed & calculated)

Fig.4 : (a) D.C leakage current at C.O.V (measured at 60 C)
(b) Normalised dc leakage currents (observed & calculated)

Fig.5 : Barrier height variation after aging under ac excitation.

Fig.6 : Barrier height variation after aging under dc excitation.

Fig.7 : Capacitance variation after aging under ac excitation.

Fig.8 : Capacitance variation after aging under dc excitation.

Fig.9 : Tan delta variation after aging under ac excitation.

Fig.10 : Tan delta variation after aging under dc excitation.