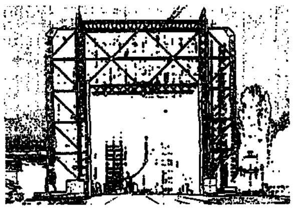

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INTERNAL ARCING TEST ON POLLUTED HIGH VOLTAGE SURGE ARRESTERS

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Abstract - A test to prove the performance of extremely non-uniform polluted single unit metal oxide (MO) and gapped arresters (SiCA) is presented. The test procedure used represents the worst case condition which can occur especially under a small wetting rate and at severe polluted arrester housings. The resulting temperature increase of metal oxide or silicon carbide varistors was measured. Internal partial discharges or internal arcing during the test were also investigated. Currents, power dissipation, voltage distribution along varistors and pollution layer and lightning sparkover voltage were measured or have been calculated.

1. Introduction

It is a well known fact that gapped arresters may have a reduced sparkover voltage under polluted conditions. The highest reduction of sparkover voltage was found to occur during the process of dry band formation. During this time dry zones or bands are formed on the arrester housing which lead to a non-uniform voltage distribution along the arrester porcelain and to increased potential differences between the internal arrester construction and the outside porcelain housing. Due to capacitive coupling the internal voltage distribution along the gaps can be disturbed. To limit this nonuniform voltage distribution the gapped high voltage arresters are equiped with capacitive or resistive grading elements in parallel to the gaps.

The gapless MOAs consists only of stacked varistor elements, which have a uniform voltage distribution in the case of a clean arrester housing. Unfortunately, in the presence of pollution and dry bands on the arrester housing, high radial electric fields can cause ionisation and partial discharges inside of the arresters [1]. If these partial discharges develop to internal arcs which form a partial breakdown between the internal surface of the housing and the varistor column, a dangerous situation can occur. These internal discharges may damage the metal oxide elements if they are not adequately coated and may cause a total destruction of the arrester. The degradation of a ZnO varistor under partial discharge conditions in air may be caused by both the erosion of the arrester surface and the influence of some gases generated by the discharges due to the sealed internal construction [2].

Due to capacitive coupling between the polluted housing and the varistor column or galvanic coupling through flanges in the case of multi unit arresters the temperature of internal varistor elements increases. A lot of work was done to study the temperature behaviour of multi unit arresters and to establish a suitable laboratory standard [3]. Investigations of MOAs pollution performance under natural conditions are very expensive and time consuming therefore there is still a lack of data from different pollution zones, for example from desert type ones.

This paper describes tests to check the behaviour of single unit gapless metal oxide (MOAs) or gapped silicon carbide arresters (SICAs). The test was established earlier on the basis of theoretical studies [1], modified and now extended also to SiCAs.

2. Test arrangement and test procedure

Two types of MOAs with different varistor coatings were tested. All other features were the same. The arrester units used for the investigations have the following specifications:

	MOAs	SiCA	
max continuous operating voltage	68	108	kV
overall length with flanges	1270	1000	mm
core diameter of porcelain	150	155	mm
inner diameter of porcelain	110	115	mm
shed diameter (large / small)	265/235	223	mm
number of sheds (large / small)	17 / 16	14	
leakage distance	3620	1680	mm
diameter of varistor elements	75	110	mm
length of varistor column	1110		mm

To measure the temperatures during the same test at different points small adhesive thermostrips were used which indicate the highest temperature by a change of their colour. The currents were measured via shunts and a digital storage oscilloscope.

The pollution tests were carried out according to the following procedure:

- The MOAs were polluted and dried as described in the solid layer method. The suspension for the pollution of the porcelain housing consisted of 5 g NaCl and 100 g Bentonite per litre of water.
- At the bottom flange of the arrester a dry zone of about 10 % of the creepage length was modelled. This was done to prevent additional dry band formation on the pollution layer during the following test and to prevent arcing across the dry zone.
- Afterwords the air humidity in the test room was increased to about 95 % and the AC test voltage equal to the maximum continuous operating voltage of the arrester was applied for 5 hours.
- The arrester was checked for internal discharges by measuring the internal current at the bottom flange. The internal discharges cause spikes superimposed to the registered AC current signal [1].
- The MOAs were checked for varistor damages by measuring the DC current before and after the pollution test at 95 kV DC.
- The evaluation of the maximum temperature of the varistor elements obtained during this test gives additional information about the thermal stresses occured during the test.

- For SiCA an other type of artificial pollution was used. A graphite film was sprayed on the porcelain housing. The resulting surface conductivity was about 200 µS. The dry band was modelled in the same way as in case of the MOA. The temperature increase of SiC varistors was evaluated at different AC voltages. The lightning sparkover voltage was measured for different clean zone positions. An additional toroid electrode was mounted at the end of the pollution layer to prevent external corona.

3. Test Results

Test Results with metal oxide arresters:

In case of the clean MOA the peak value of the internal current amounts to 1.7 mA at maximum continuous operating voltage of 68 kV. Under clean conditions the peak value of the capacitive component, measured at voltage zero, is dominant and amounts to 1.5 mA peak. Both types of currents, total and capacitive one, increase with an increased length of the pollution layer (fig. 1). With the narrow dry band (10 % of the leakage distance) the total current amplitude is about 2.4 times higher than the capacitive current.

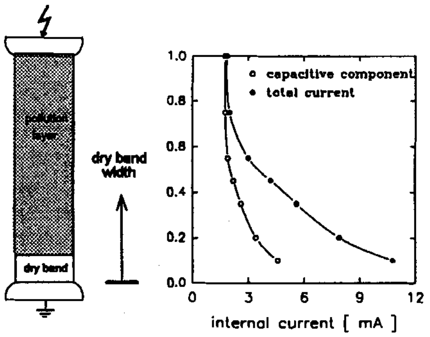

Figure 1: Influence of dry band width on the amplitude of the internal AC current

Due to the coupling capacitance between the external pollution layer and the internal varistor column a capacitive current is coupled in from the pollution layer to the varistor stack. Thus the total internal current increases more and more from the top to the bottom flange. For this reason internal and external currents have also different amplitudes depending on the vertical positions. Knowing the total inernal current from fig. 1 the external current can be estimated on the basis of Kirchoff's first law. With the external current, the surface conductivity (10 µS) and the form factor of the porcelain housing it is possible to evaluate the external voltage drop along the pollution layer. The calculated total voltage drop is only about 4.5 kV (see fig. 2). Thus the full HV potential is present almost all along the pollution layer.

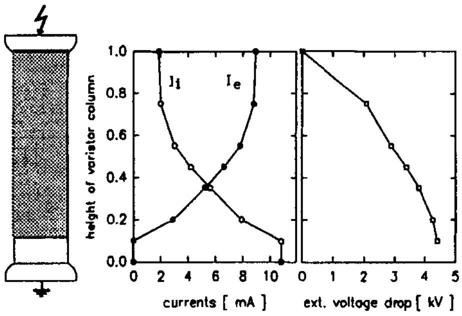

Figure 2: Amplitude of internal, external currents and external voltage drop along the pollution layer

From the oscillogram it is seen (fig. 3) that at the internal current amplitude 11 mA the voltage equals about 82 kV (see fig. 3). With the voltage/current characteristic of the total (clean) MOA and the internal current distribution along the varistor column it is also possible to estimate the internal voltage distribution. This is shown in fig. 4 in form of the voltage gradient along the varistor column. From this figure it can be seen that at the moment of maximum internal current (11 mA at 82 kV) the voltage gradient in the varistor column near to the dry zone is 1.2 kV/cm. This is 1.6 times more than in case of the clean MOA.

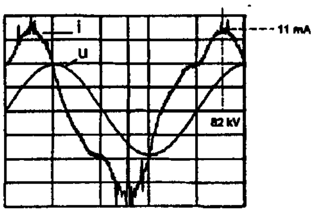

Figure 3: Internal current and test voltage with the dry zone at the bottom flange (current 11 mA peak, voltage 68 kV$_{rms}$)

Multiplying the voltage gradient distribution by internal current density (calculated from fig.1.) the maximum power density (peak value) dissipated along the varistor column can be evaluated (fig.4). In fact the mean value of power density is smaller.

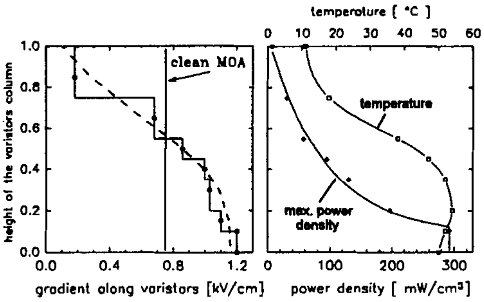

Figure 4: Amplitude of voltage gradient, power density and temperature along varistors with dry zone at the bottom

Figure 4 shows that the max. power density increases rapidly in the range close to dry zone. The non-uniform power dissipation causes obviously a non-uniform temperature increase along the varistor column.

Fig.5 shows the maximum temperature measured along the varistor column with different dry band width after 5 hours of AC testing. For the clean MOA the temperature distribution is nearly linear. The polluted arrester does not show an increased temperature at the top because the heat transport along the varistors is small and the power dissipation at the top is even smaller than under clean conditions. The porcelain at the dry zone warms up and the pollution layer in the neighbourhood begins to dry. Thus the dry zone enlarges gradually. The maximum temperatures are reached a few hours after the beginning of the test.

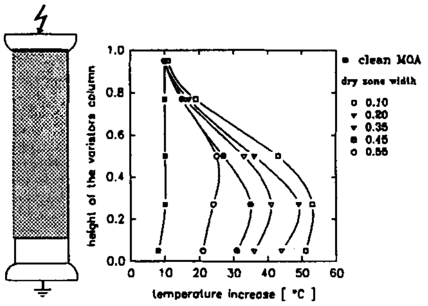

Figure 5: Temperature distribution along the varistor column with different width of dry bands

In case of only one dry zone at the bottom flange of the arrester housing there is a high radial electric field strength between the pollution layer and the varistor elements. This electric field is caused by the full applied test voltage only reduced by a small voltage drop along the outside pollution layer (see fig. 2) and the voltage drop along a few bottom varistor elements. This voltage between the varistor elements and the pollution layer is distributed between the housing and the internal insulation system according to the geometrical arrangement and the dielectric permittivity of the materials used.

A slight corona discharges at the surface of the varistor elements or on the internal insulation housing results in a small apparent charge in the pC range. In this case no spikes on the measured current signal can be seen. However, if there are observed complete flashovers in the insulation system between the porcelain housing and the varistor elements, (internal arcing) the corresponding charge is in the nC range and causes spikes on the measured internal and external current signals. In the case of narrow dry zone at the bottom flange the spike amplitude even in the range of 100 mA can be recorded [1]. With the dry zone at the top flange the measured spike amplitudes are smaller because of the damping caused by capacitance and resistance of polluted arrester.

If the varistor elements are not sufficiently protected against internal arcing a degradation of the varistors can occur. This destruction process increases the resistive internal current which can result in the destruction of the complete arrester. The tested arresters were identically designed, only the varistor coatings were different. After each test the arrester was cooled down and the internal current was measured immediately at 95 kV DC. This current showed a significant increase for the arresters with very thin glass coating (fig. 6). For the arrester with a 1 cm thick varistor coating the internal current was still the same.

This diagnostic check at DC voltage has some advantage. The arrester housing has not to be cleaned for this DC current measurement because the coupling capacitance does not influence the DC signal. Thus the pollution layer can be used for the next test cycle.

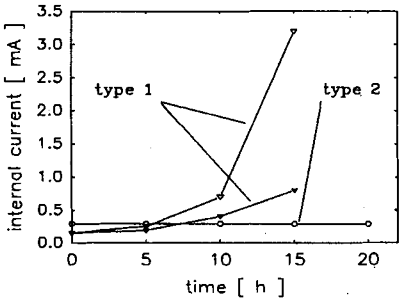

Figure 6: Change of ZnO-current caused by internal arcing

Test results with SiC arresters:

To improve the voltage distribution along the spark gaps the gapped SiCA unit is equipped with resistive grading elements which are connected in parallel to each gap (3 MΩ, 14 mm diameter, 10 mm height). Because of the high coupling capacitance (inner diameter of porcelain 115 mm, only 5 mm smaller diameter of internal construction) and the high grading resistance, the internal current can even be more influenced by dry band position as in the case of MOAs. The grading current measured at the bottom increases 30 times if the dry zone changes its position from the top to the bottom (fig. 7).

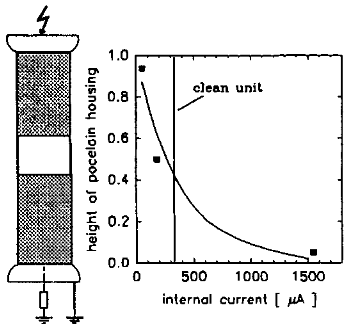

Figure 7: Influence of dry band position on the peak amplitude of the internal AC current

Similar like MOAs the non-uniform polluted SiCA warms up due to the current coupling from the pollution layer to the interal construction close to the dry band. The temperature increase depends strongly on test voltage, testing time and number, position and width of dry zones. The maximum temperature increase at a test voltage of 44 kV with one clean band at the top was about 49 °C (see fig. 8, measured after 8 hours steady state condition).

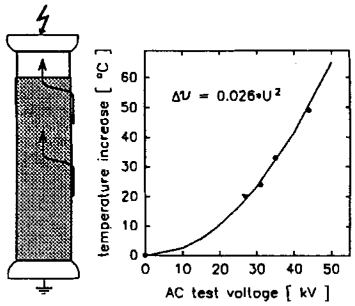

Figure 8: Influence of test voltage on maximum temperature of non-uniformly polluted SiC varistors

Again like with MOAs, a non-uniform temperature distribution along the SIC varistors and the porcelain housing was observed.

As expected also the 1.2 /50 μs lightning sparkover voltage depends on the number and width of pollution zones. The sparkover voltage of the clean arrester is about 150 kV and decreases to 65 kV with one clean zone in the middle of the porcelain housing (fig. 9).

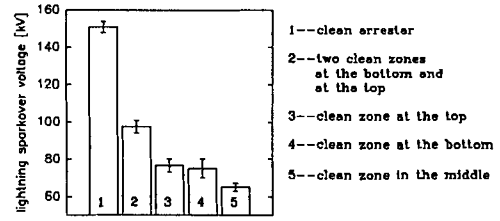

Figure 9: Lightning sparkover voltage of clean and non-uniformly polluted SiC arrester

The onset voltage for partial discharges with one clean band on the porcelain was found to be very low. At 15 kV AC voltage the spikes superimposed on the internal or external current signals were observed. After the test many distinct traces of intensive corona discharges could be detected. The brass parts changed in many places their colour, rust was found on non-stainless steel parts. But surprisingly, such a hardly stressed arrester was still not damaged and did still show normal performance.

4. Discussion

On the first view the internal arcing test procedure used in this paper seems to be a little bit unrealistic. In contrary to well known pollution tests the pollution layer and the wetting of the layer are quite different. In addition the leakage currents flowing on the porcelain housing are very low and also no partial arcs on the housing appear. Nevertheless the proposed test procedure is suitable to check the arresters for internal discharges.

The proposed test procedure is based on two basic assumptions:

- the pollution performance of arresters is strongly affected by capacitive coupling phenomena between pollution layer and the varistor column.
- the stable dry bands or especially one dry band on the arrester unit can occur also under natural condition.

The first assuption has been comfirmed by several papers [1], [2]. Up to now for the second one there are no direct results available which show that stable dry bands can occur on natural polluted insulators in service. There are not sufficient measurement data of leakage currents and temperature available with arresters in different pollution zones. These experiments are expensive, because it takes about two years to collect statistically valuable data.

At the moment results from only two pollution stations located at the seaside are published [3]. Figure 10 shows results from Martigues test station made with two-unit MOA. Each point shows the maximum temperature rise and the corresponding maximum internal charge measured at the bottom unit. No distinct correlation can be seen. The points lying on the left diagram side could be explained by dry band formation at the top flange. In this state the measured internal current (charge) is low, but the temperature increase measured in the middle of the varistor column in our test amounted 40 °C. So at least the above results don't disagree with our results.

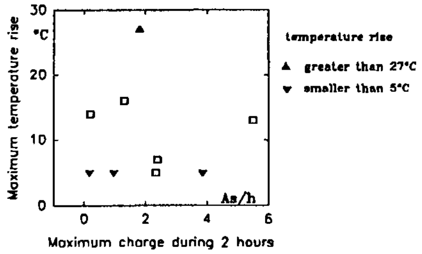

Figure 10: Maximum temperature rise and maximum charge, both measured at the bottom arrester unit at Martigues pollution test station [3]

In laboratory pollution test the existance of stable dry band formation has been demonstrated [5]. Such a phenomena appears often during salt fog tests of porcelain long rod insulators and even of insulators with silicon rubber coating. One dry band can last a few hours at the same position.

In paper [4] is it shown that during solid layer tests with MOAs wetted by steam fog the heating of arrester varistors depends basically on the specific capacitance across the resistors stack and the contamination layer on the cover. It supports clearly our first assumption. Also the influence of dry zone position on the temperature distribution along varistor column was demonstrated.

There are few papers in which results from laboratory test show that the temperature along varistor column is very non-uniform. This can be explained by dry zones randomly formed at different positions and the capacitive coupling to the arrester column.

With one dry band at the bottom flange of an MOA the internal current at close to the bottom flange can increases by a factor of 3 to 4 (fig.1). The increase of internal current depends additionally on the ratio of the conductivities of wet and dry pollution layers. With a clean zone (resistance very high) at the bottom flange a small surface conductivity of the wet pollution layer causes rapid increase of internal current (fig. 11). That means that in the case of heavy polluted MOAs only small wetting could be sufficient to cause a high electrical stress. Due to hygroscopic properties of pollutants such a small wetting can occur during periods of high air humidity [6]. With a small surface conductivity on the insulators the pollution flashover voltage is very high. Thus there is only a small electrical stress for normal insulators. But for MOAs the same condition can lead to a high thermal and dielectric stress. From figure 10 it is seen that nearly the complete increase of internal current occurs in the surface conductivity range up to 5 µS. According to the IEC recommendation areas with such a small contamination are classified to the first zone "no pollution".

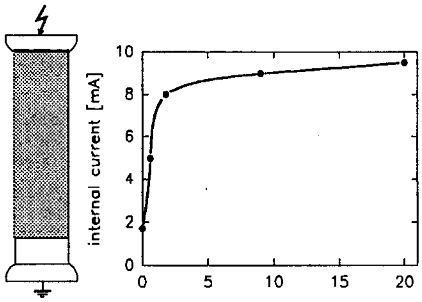

Figure 11: Influence of surface conductivity on the internal current with dry zone at the bottom

The evaporating process on wetted, polluted standard insulator surface is inherently unstable. If any portion of the insulator length tends to dry out faster, then its resistance increases and power dissipation in this portion increases too. The rate of evaporation in this area accelerates further and soon an entirely dry zone all around the insulator is created. With a continuous supply of moisture even with small rates (i.e. high air humidity, fog, but no heavy rain), a stable dry band can exist. If the wetting rate is to small the evaporation develops. If the wetting is to high normally no stable single dry band occurs. The polution layer becomes saturated and several dry bands with partial arcs can develop or the layer can also be washed in case of heavy rain.

On polluted arrester housings the same processes occur. A stable dry band formation was found to occur even more probable in this case. As soon as a single dry zone is formed the varistors near to this place warm up and the heat transferred to the pollution layer supports the evaporation in the dry band.

5. Conclusions

Dry band formation on polluted arresters at AC voltages may results in:

- rise of the internal current (up to 6 times for both MOAs and for SiCA) if the dry band is near to the one of the flanges.
- high local temperatures at the varistor column near to the dry band depending on the size and position of the dry band
- discharges inside of the arrester due to a high radial electric field strength indicated by current spikes superimposed to the internal AC current.

The proposed test modelling worst conditions caused by single dry band formation can be applied to MOAs and to SiCA to check the pollution and thermal performance and the protection of varistor elements against internal discharges.

During the test internal discharges can be detected by measuring the internal current at the bottom flange. The conventional wet pollution can be replaced by a conductive layer sprayed on the insulator. External surface discharges can be avoided by a toroidal electrode at the end of the pollution layer. The test transformer doesn't have to meet the requirement of IEC standard 507 because the currents are in the range of some tens of mA.

The test procedure has a good reproducibility due to absence of external arcs. The electrical stress can be easyly controlled by the applied voltage, dry band width and testing time.

Acknowledgement

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