

Capacitance Changes in Degraded Metal Oxide Varistors

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Abstract: ZnO based ceramics show a highly nonlinear current-voltage (I-V) characteristic due to intergranular layers at the boundaries of ZnO grains. This research indicates that the junctions formed on the border between ZnO grains and the intergranular phase are responsible for the creation of potential barriers which control the flow of current through the bulk of such a ceramic. Having polycrystalline nature and a large number of intergranular barriers, and so a high energy absorption capability, ZnO ceramics are used as active components in overvoltage protection devices. But as a result of charge transport the height of the barriers decreases and varistor degradation occurs. The degradation seems to affect mainly the prebreakdown region of the I-V curve and it results in increased leakage current. This paper presents a part of research aimed at assessing the effect of ageing on the capacitance characteristic of ZnO varistors.

INTRODUCTION

Both in power (transmission) grids and in LV systems it is necessary to protect the equipment against the effects of overvoltages. A source of an overvoltage – a surge in voltage above the operating voltage – can be a process inside the system (e.g. de-energization of a transformer operating without a load) or an external agent (a lightning discharge). For quite some time overvoltage limiters have been used to protect electrical equipment against overvoltages. Their active components are zinc-oxide varistors. The latter are ceramic electronic elements which behave as variable resistors: having high resistance at low voltages (insulators) and low resistance at high voltages (conductors). The varistors consist mainly of zinc oxide (ZnO), bismuth oxide

(Bi₂O₃) and slight quantities of other oxides (Co, Mn, etc.). The technological process of sintering and cooling results in a structure consisting of ZnO grains with admixed atoms of additives [1,2]. The grains are enclosed by an intergranular layer formed during the sintering of molten bismuth oxide. The layer has insulating properties. In this way a lattice of series-parallel intergranular connections forms. The varistor's electrical properties are shaped in the intergranular regions. Because of the existence of surface states on the boundary surface, a depleted charge region forms close to it. In this way a double Schottky barrier builds up on the grain-intergranular layer-grain boundary. Thus the electrical properties of ZnO ceramics are controlled by intergranular conduction [3]. This means that degradation of oxide varistors is caused by changes in the microstructure within the intergranular boundaries. The changes are associated with the migration of charges whereby the shape and/or height of the potential barrier changes. The degradation is manifested in an increase of the varistor conduction current and it affects the low-voltage region.

EXPERIMENTAL PROCEDURE

Varistors installed in a HV overvoltage limiter for the 110 kV network were tested. The varistors were centrally fixed in a porcelain hollow insulator so that there was an air-gap between their lateral surface and the inside surface of the insulator. They were subjected to accelerated aging using the procedure described in [4], which consisted in the generation of a radial electric field sufficiently strong to overcome the local resistance of the air in the gap between the stack of varistors and the insulator and to ignite partial discharges.

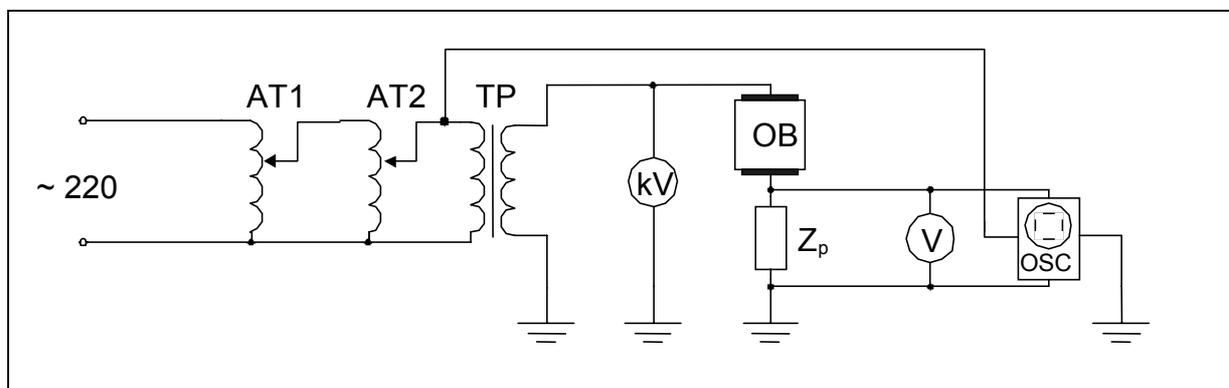


Fig. 1. Varistor testing assembly

The system shown in fig. 1 is used for the testing of varistor characteristic $U = f(I)$ at alternating voltage. The measurements were performed in a test 220V/10kV asymmetric transformer circuit which also included two autotransformers (AT1 and AT2) for precise voltage control, an electrostatic kilovoltmeter for direct measurement of varistor conduction current and a Keithley DMM 2700 digital multimeter measuring the measurement impedance voltage drop of a Tektronix TDS3032B digital oscilloscope used for measuring the resistance component and the capacitance component of varistor conduction current. The limiter conduction current's resistance component and capacitance component were separated by measuring the current as the voltage passed through respectively a maximum and zero. The capacitance of the varistors was measured by a Tettex 2801 bridge at a frequency of 50 Hz.

TEST RESULTS AND THEIR DISCUSSION

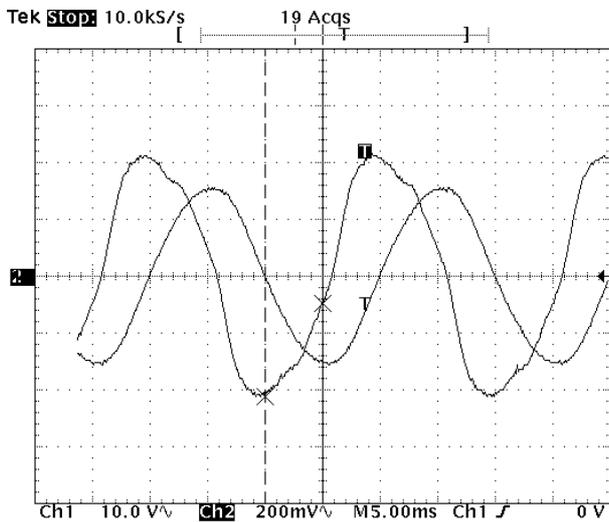


Fig. 2 Varistor current oscillogram

A typical oscillogram used for the separation of the components from the total varistor conduction current is shown in Fig. 2. The oscillogram was obtained for a varistor subjected to partial discharges. The evident distortion of conduction current indicates that the share of the resistance component in the total conduction current has increased. This can be ascribed to the beginning of aging of the varistor. The changes are clearly reflected in the voltage-current characteristics shown in Fig. 3. An increase in the conduction current resistance component is a typical symptom of aging of ZnO ceramics. It has also been found that the capacitance component of their conduction current changes as a result of the effect of partial discharges on ZnO varistors (Fig. 4). Such changes have not been previously reported. To confirm this finding the capacitance of varistors at 50 Hz was measured. The

measurements corroborate the changes in the capacitance of the varistors (Fig. 5).

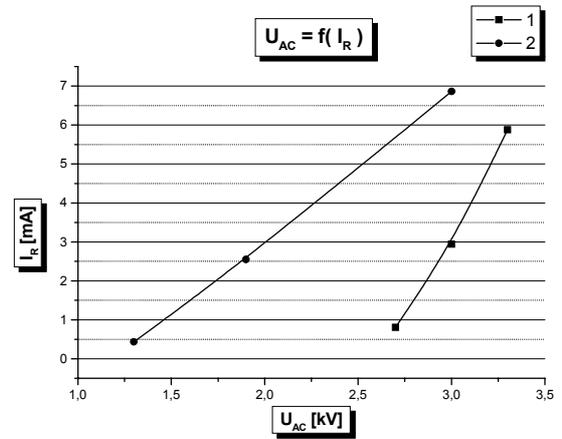


Fig. 3. Resistive component of new (1) and degraded (2) varistor

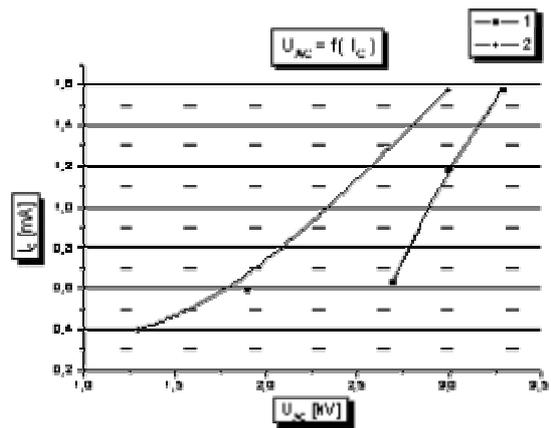


Fig. 4. Capacitive component of new (1) and degraded (2) varistor

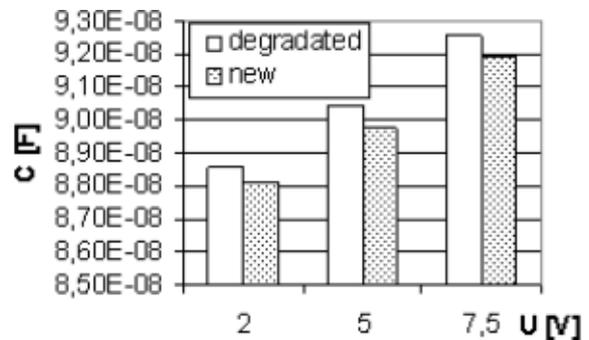


Fig. 5. Capacitance change of new and degraded varistor.

CONCLUSIONS

Ageing of ZnO ceramics is manifested by an increase in conduction current within the U-I characteristic situated below continuous duty operation voltage U_c . It is generally agreed that aging is accompanied by changes in the height and/or shape of the potential barriers on the intergranular boundaries. On a macro-scale this is reflected in changes of the conduction current resistance component whose value is commonly regarded to be a diagnostic parameter. It has also been found that some exposures may cause changes in the microstructure of ZnO ceramics, associated with charge transport and resulting in a change in the capacitance of the whole varistor. The changes are manifested in an increase in the capacitance component of the conduction current of a ZnO varistor subjected to partial discharges.

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