

## DEGRADATION AND DESTRUCTION OF ZnO VARISTORS CAUSED BY CURRENT PULSES

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Although the modern metal oxide elements are resistant to degradation caused by continuous operating voltage the degradation or destruction caused by current impulses, especially lightning currents, is still a serious problem. This phenomenon was the subject of the current study where single zinc oxide elements and 6 kV arresters manufactured in Poland were tested with 8/20  $\mu$ s impulse currents. During our investigation the temperature and changes in current-voltage characteristics were recorded. These results indicate that even varistors that were stressed with high currents could reach saturation state in which following impulses did not cause any further degradation. Both single varistor elements and 6 kV arresters showed only little ageing if stressed with 0,5 kA impulses. The 6 kV arresters composed of 10 elements were able to withstand smaller currents than single varistors. Our findings suggest that a combination of sparking effects and less than optimal contacts are the cause varistor degradation.

**Key words:** metal oxide surge arresters, ageing, lightning impulse current, degradation

### 1. INTRODUCTION

It has been nearly thirty years since the discovery of varistor effect in zinc oxide ceramics. Since then metal oxide surge arresters have almost entirely replaced gapped arresters with SiC varistors. Under continuous operating voltage, current flowing through ZnO varistors of high voltage arresters equals about 1 mA. That is nearly one order of magnitude more than the grading current in gapped type arresters. Degradation changes the voltage-current characteristics of varistors by increasing the current under operating voltage. This phenomenon and related negative temperature factor of resistance can together cause the thermal run away effect. As a result, ageing effects of metal oxide varistors during operating conditions are very important. Degradation of metal oxide varistors can be caused by operating voltage [1, 2], current impulses [1, 4, 5], partial discharges [6], electro-thermal processes [7] or environmental stresses [1, 8].

Degradation caused by operating voltage was eliminated in recent years by improvement of manufacturing processes. In addition, specially-designed housings reduced level of internal partial discharges. Despite those improvements the risk of degradation due to current impulses and not thusofthe the reduce arrester reliability still remains.

Although there is an abundance of experimental data, researches have not been able to develop a commonly accepted varistor ageing model. One of the reasons is that the response of different varistors (different manufactures and/or technologies) to the same stress can be also different. As a result, the comparison of test data obtained on different samples and under deferent test conditions may not produced consistent results.

### 2. EXPERIMENTAL

The diameter and height of varistors used were 25 mm and 7 mm respectively. The experiments were conducted on single varistors and on 6 kV arresters consisting of 10 varistors enclosed in a heat shrinkable housing. The current generator comprised of 30 capacitors (1  $\mu$ F an each) with were equivalent capacitance of 7,5 or 15  $\mu$ F. The impulse currents were a 10 m $\Omega$  shunt.

The samples were subjected to a number of equal impulses applied with a repetition time of 15 to 20 seconds. The number of impulses was chosen in such a way as to not cause any significant temperature increase. The highest temperature of 60 °C was measured on samples stressed with 3,5 kA impulses. The aim of the experiment was not to establish the energy absorption of the varistor but to check the ageing effects caused by current pulses.

After the sample temperature dropped to 20 °C the next series of impulses set was applied. After some tens impulses the reference DC voltages for both polarities at 20 °C were measured. The test was stopped when the next series of impulses caused no change mersurable in the sample U-I characteristics or when the sample was destroyed.

### 3. DEGRADATION AND DAMAGE OF SINGLE VARISTORS

U-I characteristics decrease as a result of impulse currents initiated ageing especially in the region of small current. Currents were measured 5 minutes after voltage application, i.e. after their current value was constant. Due to absorption processes current magnitude continuously decreases after the voltage is switched on [9].

Figure 1 shows varistor currents at a voltage of 600 V as a function of number of applied impulse current pulses. More data are shown in Table 1. The varistor stressed with 4 kA pulses was damaged by cracking. However, the varistors subjected to 3,5, 2,4 and 1,2 kA pulses did not fail in spite of extensive degradation. Their reference voltages measured at the current of 1 mA decreased by 33% and 43% respectively. The known recovery processes were observed. The DC reference current decreased with time. This process is marked in Fig. 1 by a dotted line. Other phenomenon was also observed, not described in the literature. It was observed that the application a subsequent of impulse series can improve U-I characteristics. This abnormal behavior is indicated by two arrows in Fig. 1.

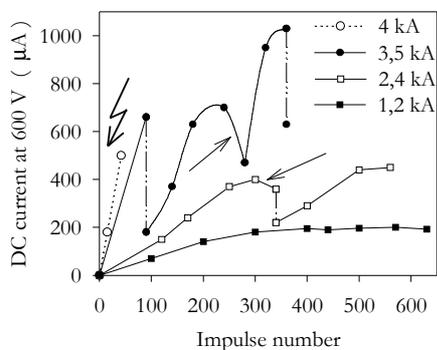


Fig. 1. DC currents changes at 600 V versus number of applied current pulses

The phenomenon described above was also observed during tests with 1,2 kA impulses (Fig. 2). Up to 380 impulses, the current at 600 V increased gradually. On the second and third day a small current decrease was noticed. It was also observed that the subsequent series of impulses did not cause current increase as a result of a saturation state. On 4<sup>th</sup>, 5<sup>th</sup> 6<sup>th</sup> and 7<sup>th</sup> day the currents were greater in the morning than in the evening of the day before. Application of the next impulse set caused current decrease (abnormal behaviour).

Table 1. Additional data for the test series shown in Fig. 1

Current amplitude	Energy of single impulse	Impulse number in a series	Cracks after n impulses	Maksimum temperature	Reference voltage decrease U(1 mA)
4.0 kA	50 J/cm <sup>3</sup>	3	42	45 °C	-
3.5 kA	42 J/cm <sup>3</sup>	8	-	60 °C	43 %
2.4 kA	34 J/cm <sup>3</sup>	10	-	40 °C	33 %
1.2 kA	20 J/cm <sup>3</sup>	10	-	35 °C	18 %

Figure 3 shown that in the saturation state is proportional to the impulse current amplitude. Thus references voltage reduction could be used as a measure of varistor degradation.

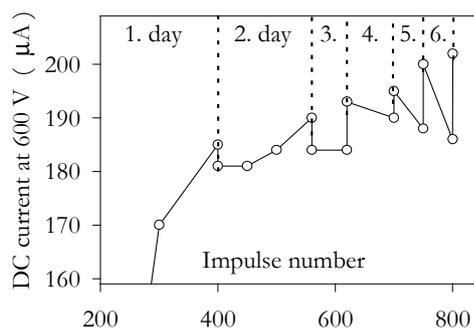


Fig. 2. Effect of 1,2 kA current pulses on the varistor DC

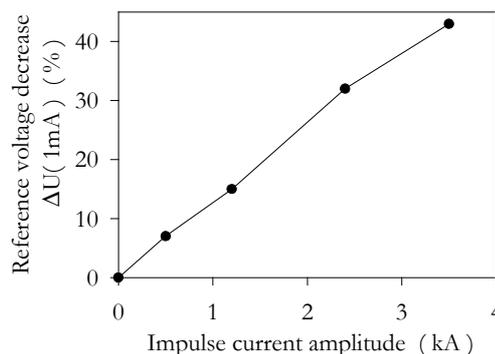


Fig. 3. The reference voltage decrease as a function of impulse current amplitude

#### 4. DEGRADATION AND DAMAGE OF 6 kV ARRESTERS

Relatively small impulse currents of 150 A or 500 A do not lead to any damage of the samples. After application of approximation about 900 impulses of the same polarity the degradation reaches its end point. A DC current measured at 8 kV DC at the apposite polarity to that of the impulse current is higher (Fig. 4). The reference voltage corresponding to a 1 mA decreases by about 7%.

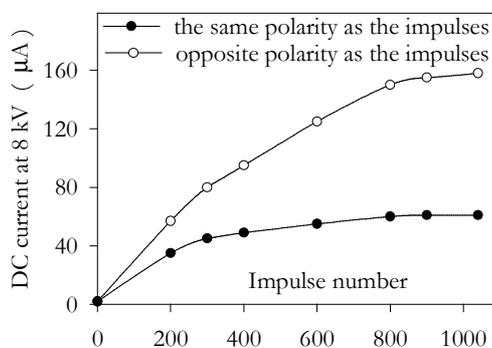


Fig. 4. Current increase measured at the DC voltage of 8 kV as a result of 150 A current impulses with the same polarity. 18 impulses in the set, maximum temperature of the arrester was 50 °C

The arrester stressed by 500 A impulses reached the saturation state (reference voltage decrease of 8%) after 400 shots (fig. 5). During the test the impulse polarity was changed. Therefore the U-I characteristic was symmetrical. Only in one case, directly before the cracking, the small asymmetry was observed.

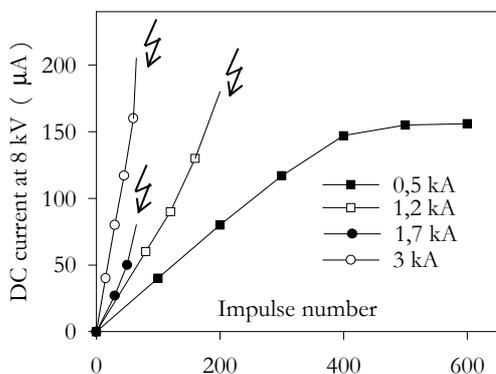


Fig. 5. DC Reference currents number of applied current as a function of the impulse of an alternating polarity

The current amplitude that cause the damage to a 6 kV arrester was three times smaller than that for a single varistor damage. The arrester was destroyed after application of 220 current impulses with the amplitude of 1,2 kA. Flashover along the surface took place and only one varistor was broken into few fragments. The remaining 9 varistors could be used again after cleaning. The damage of the arrester subjected to 1,7 kA impulses was similar.

Table 2. Test data of 6 kV arrester.

Impulse amplitude	Impulse number in the set	cracking after n impulses	Maximum temperature	Reference voltage decrease U(1 mA)
3.0 kA	2	65	50 °C	-
1.7 kA	5	65	55 °C	-
1.2 kA	5	200	48 °C	-
1.2 kA	1	220	30 °C	-
0.5 kA	18	-	50 °C	8 %
0.15 kA	18	-	50 °C	7 %

5. DISCUSSION

Our measurements seem to indicated that the average temperature of the samples (30–60 °C) is not an important ageing factor. Degradation depends on the amplitude and the number of 8/20 µs current impulses, the local temperatures and the varistor ceramics uniformity [3, 10]. To prove that the accelerated ageing procedure by multiple current impulses does not influence the results, two tests with 1,2 kA impulses were carried out. In the first test series of 5 were applied, in the second only single impulses were used. The time between two consecutive impulses was

15 seconds and the resulting temperature 48 °C. The temperature of the varistor stressed by single impulses reached only 30 °C. The U-I characteristics of both varistors were similar and the varistors were damaged after 200 and 220 impulses.

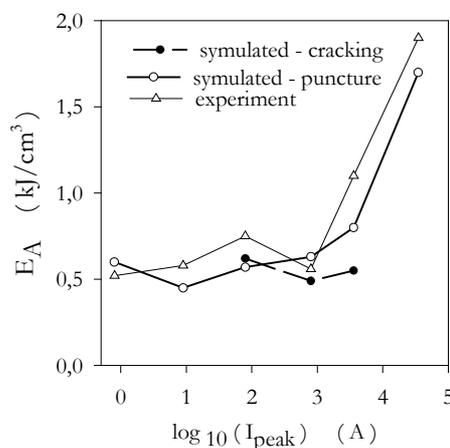


Fig. 6. The calculated and measured energy absorption ability of a varistor stressed by a single impulse as a function of current amplitude [10]

Single varistor stressed by 4 kA impulses and energy density 50 J/cm<sup>3</sup> was damaged after 42 shots. Fig. 6 shows that the energy absorption ability of the varistor stressed by single impulse can be 10 times higher. Results presented on Fig. 6 were obtained on varistors made by a different producer. The large difference could be caused by different procedure of our accelerated ageing. During application of current impulses the degradation of varistor ceramics occurs. Gradually the loss of material uniformity is very pronounced. This non-uniformity can be responsible for low energy absorption ability and varistor cracking after application of only 42 impulses.

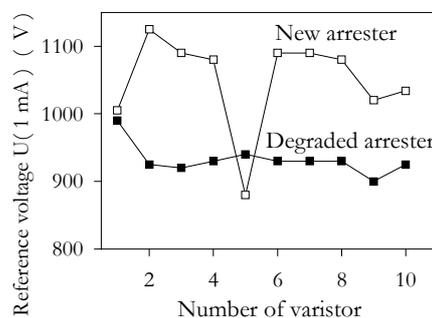


Fig. 7. Reference voltage of individual varistors before and after application of 600, 500 A impulses to an arrester

On the other hand, an smaller energy absorption ability of arrester as compared with a single varistor could be caused by a non-uniform ageing of the arrester elements in the column. The varistors are usually were

selected by the manufacturer to get the similar reference voltage for the whole arrester. However, the reference voltages of individual varistors can be quite different (Fig. 7). The comparison of reference voltages of individual varistors in the arrester before and after ageing is shown in Fig. 7. The arrester was with 600 impulses 500 A. During the test that ended with the arrester failure the differences in reference voltages of particular varistors could gradually increase. Note that the arrester failure was caused by one or two varistors cracking.

It is suggested that smaller energy absorption ability of arrester as compared with a single varistor is caused by sparking. In the case of the whole arrester, the spark traces were observed even for 500 A impulses. For this purpose the housing was dismounted and the sample was observed in darkness. Special washers were used between varistors and as a result, the varistor contact areas were smaller than without washers. Additionally the arrester residual voltage was about 10 times higher than for a single varistor. An intensive sparking could initiate flashover along varistor column.

## CONCLUSIONS

1. In varistors subjected to multiple lightning currents (8/20  $\mu$ s).
  - degradation increases with the number of applied impulses until saturation state is reached.
  - Increasing impulse amplitude reduces the number of impulses required to reach saturation.
  - Varistors that were damaged by cracking have never reached the saturation state.
2. Varistors stressed with 500 A impulses reach the saturation state and the reduction at is around the reference voltage of 8%. Therefore these varistors and arresters can be used for protection of distribution and low voltage systems.
3. A single varistor was damaged by cracking after 42 impulses with the amplitude of 4 kA and energy

density of 50 J/cm<sup>3</sup>. The arrester composed of 10 was damaged after application of 200 impulses with the amplitude of only 1,2 kA.

4. The energy density that caused failure of an varistor after 42 impulses (50 J/cm<sup>3</sup>) was 10 times smaller than the energy absorption ability of a varistor that was stressed by single impulse current (500 J/cm<sup>3</sup> [10])

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