DOI: 10.5604/20830157.1121330

THE IMPULSE CHARACTERISTICS AND ELECTRIC STRENGTH OF VARISTORS PILES DEPEND ON GEOMETRY OF THE ELECTRODES

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Abstract. *The paper describes the results of the impulse characteristics and electric strength measurements of the pile of varistors with modified side surface. Basing on the impulse voltage tests on the surge arresters it was found that one of the reasons of the failures of these devices may be the surface discharge at the varistor - insulating housing phase boundary, through the gas between them. Flashover voltage of power protecting systems can be increase by applying of semi – conducting covers which will carry away the generated surface charge and uniform the distribution of electric field on material surface. Comparing two types of electrodes configuration on varistors, it was found that systems without gap between electrode and side surface of varistor exhibited higher values of withstanding voltage whether their side surfaces were covered or not covered with insulating or semiconducting layer.*

Keywords: varistors, surface discharge, electric strength, flashover voltage

CHARAKTERYSTYKI IMPULSOWE I WYTRZYMAŁOŚĆ ELEKTRYCZNA STOSÓW WARYSTOROWYCH W ZALEŻNOŚCI OD GEOMETRII ELEKTROD

Streszczenie*. W pracy wyznaczono charakterystyki impulsowe oraz wytrzymałość stosów warystorowych o modyfikowanej powierzchni bocznej. Na podstawie wyników pomiarów przy napięciu impulsowym na ogranicznikach przepięć stwierdzono, że przyczyną ich uszkodzeń może być wyładowanie powierzchniowe rozwijające się w szczelinie powietrznej na granicy faz warystor – osłona izolacyjna. Napięcie przeskoku można zwiększyć poprzez zastosowanie warstw półprzewodzących, umożliwiających odprowadzenie ładunku powierzchniowego i wyrównanie rozkładu pola elektrycznego na powierzchni materiału. Na podstawie porównania dwóch konfiguracji elektrod warystorów stwierdzono, że układ bez odstępu pomiędzy elektrodą a powierzchnią boczną warystora posiada wyższą wytrzymałość napięciową niezależnie od modyfikacji powierzchni bocznej.*

Słowa kluczowe: warystory, wyładowanie powierzchniowe, wytrzymałość elektryczna, napięcie przeskoku

Introduction

Surge arresters, in the past called lighting protectors, are designed to protect the electric apparatus against transient overvoltages. Surges can occur when switching on or off of unloaded overhead line or when lightning strikes the line. They can destroy the insulation or other elements of the power system [7, 8]. Surge arresters are relatively expensive that is why they are used to protect only most important elements of the power line, such as transformers or generators.

An introduction to the general use of the modern surge arresters based on metal oxide varistors to the high voltage (above 750 kV) power lines is believed to be the greatest achievement of the electrotechnics of the last quarter of the XXth century [9].

The typical model of the surge arrester designed and produced in the Wrocław Division of the Electrotechnical Institute is shown in Fig. 1.

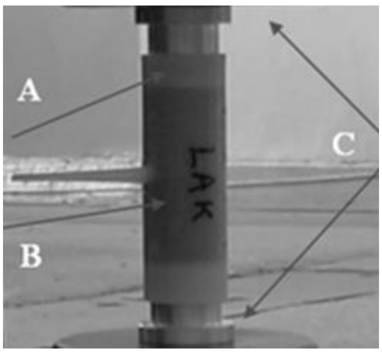

Fig. 1. Metal Oxide Surge Arrester A – insulation housing made from polyamide, B – varistor's pile, C – fittings [6]

As can be seen in Fig. 1 the main part of the surge arrester constitutes the pile of varistors exhibiting with nonlinear I-V characteristics. They limit voltage by changing they resistance and becoming strongly conducting at a breakdown voltage when current increases from the range of few mA to kA [9]. To play properly its role the pile of varistors shall be protected against external factors by covering with an insulating material. The other role of this insulating housing is to make varistors stable affixed inside the surge arrester. Pile of varistors is pressed on the both bottom and top surfaces by the system of fittings which are equipped with electrodes for electrical connection of the arrester to the power system.

As the experience of many research centers, including the authors' own experience, show, the surge arresters can be damaged by the action of voltage impulses, as it happens during voltage impulses tests [1, 2, 6]. What more, the impact of voltage impulses may cause that between the housing and a core, which is a pile of varistors, a gap occurs (Fig. 2).

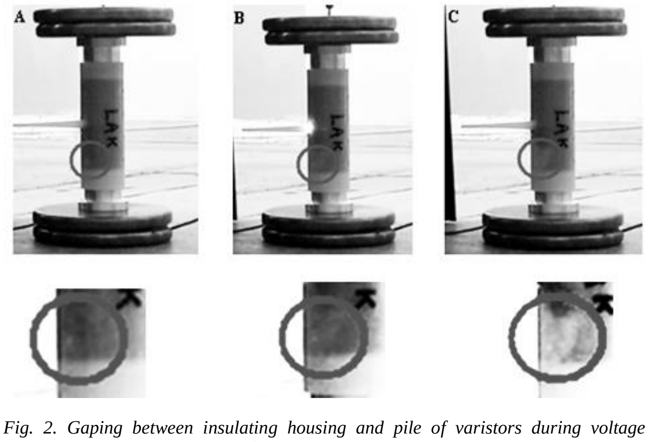

Fig. 2. Gaping between insulating housing and pile of varistors during voltage impulse tests, A – before discharge, B – during discharge, C – after discharge [6]

As a result of the air gap formation during the further testing the surface discharges may occur at the phase boundaries (Fig. 3).

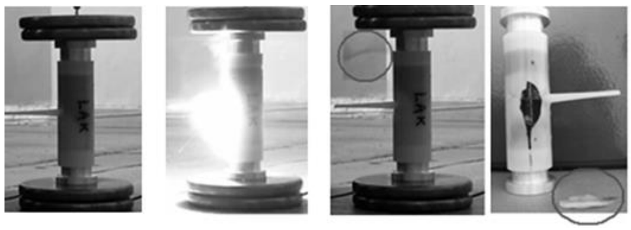

Fig. 3. Surface discharge on the surge arrester and damage of the polyamide housing [6]

The work focuses on the effects of the geometry of the electrodes on the impulse characteristics and electric strength of the piles of varistors constituting the core of the sparkles surge arrester. The most commonly used system of electrodes used in varistors system is an aluminum electrode vapor-deposited on the flat surface of the varistor.

1. Samples

The samples for this research constituted zinc oxide energy varistors, 40 mm in diameter and 25 mm high, with aluminum electrodes deposited in two different fashions: I - an aluminum electrode was applied on the entire flat surface of the varistor sample (Fig. 4A), and II - wherein a gap is left between the electrode and the side surface of the varistor (Fig. 4B)

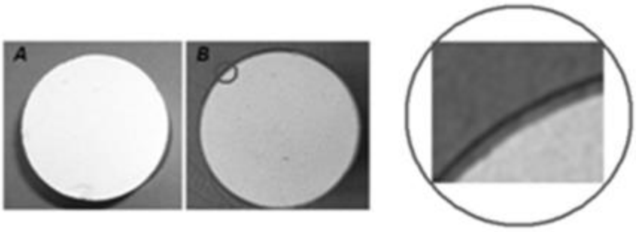

Fig. 4. Varistors without a gap (A) between electrode and side surface with a gap (B)

Additionally to increase the electrical strength of the device the side surface of the varistors was covered with insulating and semiconducting layers what changed the surface properties of the samples. The resistivity surface of the insulating films are shown in table 1.

Table 1. Resistivity surface of the layers

Sample	Surface resistivity of the layers, ρs [Ω]
I	~1011
II	1014 - 1015

2. Measurement

The high voltage tests were carried out using the HAEFELY 700 kV, 35 kJ generator and the measuring system is shown in Fig. 5. Normalized impulses 1.2/50 µs were applied across the varistor electrodes. Flashover voltages were recorded by the control – recording system of the generator.

Fig. 5. HAEFELY generator and measurement system

Diagnostic techniques such as photography and the analysis of recorded images are more and more used in High Voltage Engineering [4, 5], hence also during this voltage testing the discharge images were captured with camera and recorded images were processed graphically.

3. Results

Using the recorded data flashover voltages (Uv) and times of flashover occurrences (Tc) the impulse characteristics (Fig. 6) were determined in correlation with the type of varistors and electrodes applied electrodes as well as with the type of the surface modification.

Note the location of points 3 and 4 (Fig. 6), showing that the flashover on the impulse tale occurs at a peak, and not at the flashover voltage [3].

Impulse characteristics helped to determine which configuration of the electrodes and the materials form a system of more or less homogeneous. The planar characteristics characterize the system with higher uniform field, while steep characteristics say that the tested objects form the system with more nonuniform field.

The impulse characteristics were determined and are showed in Fig. 7 and 8. On the basis of this characteristics one can determinate which electrode configuration and materials create more or less uniform system.

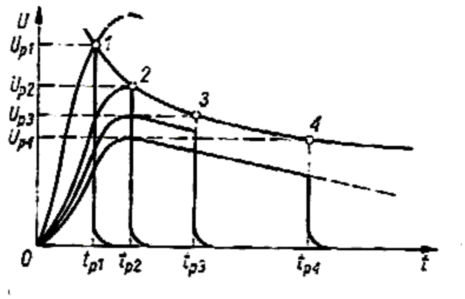

Fig. 6. Impulse characteristic [3]

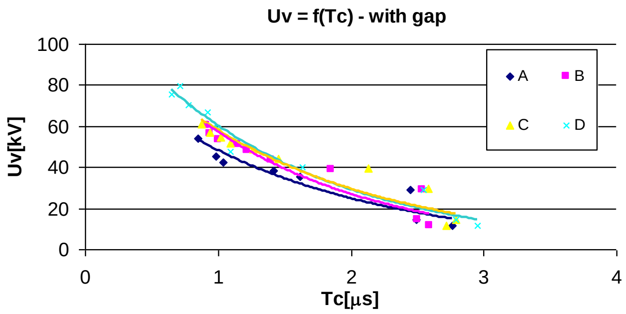

Fig. 7. Impulse characteristics for the waveforms with gap between electrode and side surface of varistor. A – sample with semiconducting layer 10^{14} – 10^{15} Ω, B – sample without cover, C – sample with semiconducting layer 10^{11} Ω, D – sample with semiconducting double layer 10^{11} Ω

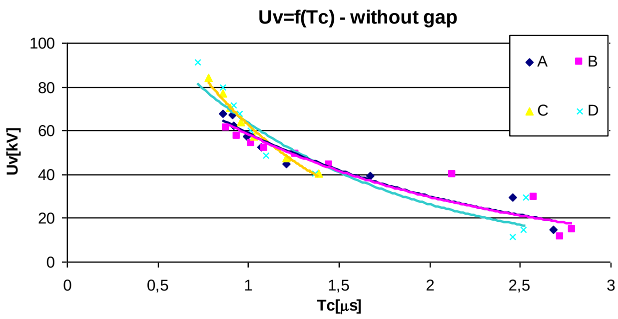

Fig. 8. Impulse characteristics for the waveforms without gap between electrode and side surface of varistor. A – sample with semiconducting layer 10^{14} – 10^{15} Ω, B – sample without cover, C – sample with semiconducting layer 10^{11} Ω, D – sample with semiconducting double layer 10^{11} Ω

Electric strength of the varistors pile was determined by comparing the flashover voltage measurement. The results of voltage and time to flashover, measured on varistors pile for 190 kV from generator were showed in table 2.

Table 2. The results of voltage and time to flashover

Sample	With gap		Without gap	
	Uv [kV]	Tc [μs]	Uv [kV]	Tc [μs]
Without side surface modification	60,2	0,91	61,2	0,88
With modification by layer ~ 10^{11} Ω	61,2	0,88	84,0	0,78
With modification by double layer ~ 10^{11} Ω	75,5	0,65	91,0	0,72
With modification by layer ~ 10^{14} - 10^{15} Ω	54,1	0,85	68,0	0,86

Basing on the results it was found that covering the side of varistors by the semiconducting layers with surface resistivity of about 10^{11} Ω increases their strength on the surface discharges even of 10 – 15% (especially by double covering) – depending on the type of applied varistors.

The withstanding voltage is higher for the systems without gap between electrode and side surface of varistor for both types of varistors i.e. with insulated and not insulated side surfaces.

The latter may lay be explained by the fact that when electrode is not on the all flat surface of the varistor the triple junction points may occur. The triple junction points with relevant electric field may cause the partial discharges and deterioration of varistor properties in the result. If the side surface of the varistors hasn't being modified by the semiconducting layer, the charge generated as a result of the partial discharges occurring can significantly affect the surge arrester work, and later take part in the surface discharge development (Fig. 9). Propagation time of these discharges is much faster then the work time of the nonlinear element - varistor.

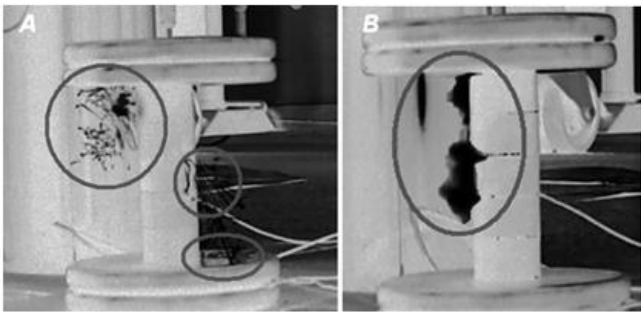

Fig. 9. Images of the discharges during high voltage tests on the varistors pile (5 varistors) without side surface covering A – without gap, B – with gap

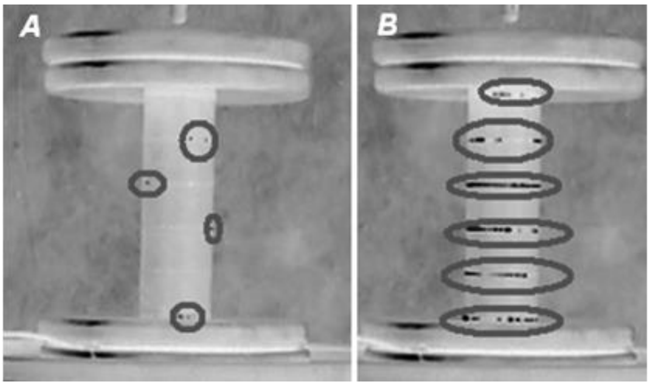

Fig. 10. Discharges images during high voltage tests on the varistors pile (5 varistors) with double side surface cover layer of surface resistivity ~ 10^{11}Ω. A – without gap, B – with gap

Impulse characteristics confirm that the varistors pile without gap between electrodes and side surface of the varistor is characterized by higher electric strength made a system with much more uniform electric field distribution.

During the high voltage tests the discharges on varistors pile were recorded. Results in form of the recorded images are shown in Fig. 9 – 10. The samples after test are shown in Fig. 11 – 12.

The images of recorded discharges show that the character of the discharge may differ, depending on the material used. In the case of the samples without cover on the side surface the intensive partial discharges between varistors and surface discharges occurred over a large part of sample area.

In the case of varistors with semiconducting layers (10^{11} Ω) and without gap between electrode and the side surface of the varistor, the discharge between varistors was not intensive (Fig. 12A). For the same system with gap, also not intensive discharges between varistors were recorded (Fig. 12B). This was confirmed by the results of the withstanding voltages. These samples were characterized by the highest electric strength during impulse voltage tests.

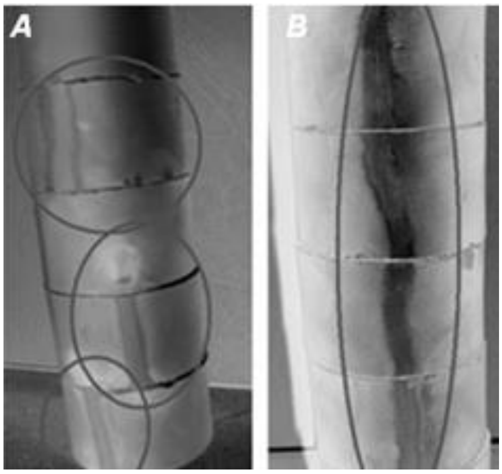

Fig. 11. Samples after impulse voltage test without surface modification, A – without gap, B – with gap

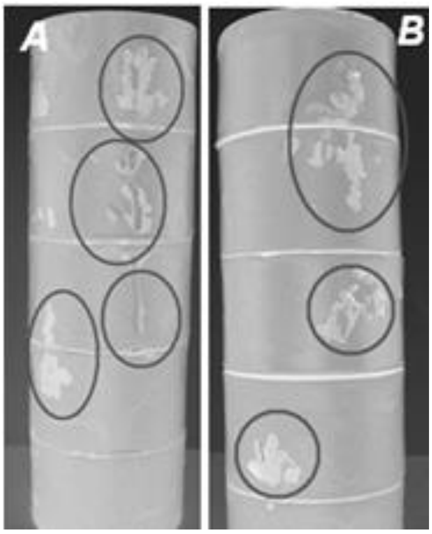

Fig. 12. Samples after impulse voltage test with double side surface layer of surface resistivity ~ 10^{11}Ω. A – without gap, B – with gap

In figures with samples after impulse voltage test it was shown that the varistors pile without surface modification had an evident surface discharges footprint. In the case of samples with double layer with ρs ~ 10^{11} Ω footprint of discharges are slight and doesn't destroy the surface of varistors.

4. Conclusions

Basing on the high voltage tests on the surge arresters it was found that one of the reasons of the failures of these divices may be the surface discharge at the varistors - insulating housing phase boundary, through the gas between them.

On the basis of the measurements results, it was found that, the side surface covering by semiconducting layer of surface resistivity ~ 10^{11} Ω increases their strength to surface discharges even of about 15 - 20% (especially when double cover is deposited) – depending on the type of varistors.

Comparing the two types of electrodes configuration on varistors, it was found that systems without gap between electrode and side surface of varistor (Fig. 4B) exhibited higher values of withstanding voltage whether their side surfaces were covered or not covered with insulating or semiconducting layer.

The reason may lay in the fact that when electrode is not on the all flat surface of the varistor the partial discharges occurring can significantly affect the surge arrester work, and later take part in the surface discharges development. Development time of these discharges is faster then work time of nonlinear element – varistor.

Impulse characteristics confirm that pile of varistors without gap between electrodes and side surfaces is characterized by the higher electric strength and make systems with much more uniform electric field distribution.

The recorded images of discharges show that the character of the discharges can differ, depending on the material used. In the case of the samples without covering on the side surfaces the intensive surface discharges between varistors occur on the large part of samples area.

In the case of the semiconducting layers application to side surface of the varistors without gap between electrode and the side surface of the varistor sample, not intensive partial discharge between the varistors was observed (Fig. 10 A). Also for the same system with electrode not covering the whole flat surface of the varistor, not intensive discharges between varistors were recorded (Fig. 10 B). And these samples exhibited the highest electric strength during impulse voltage tests.

In figures with samples after impulse voltage test it was shown that the varistors pile without surface modification had an evident surface discharges footprint. In the case of samples with double layer with ρs ~ 10^{11} Ω footprint of discharges are slight and doesn't destroy the surface of varistors.

5. Acknowledgements

The research was supported by Wrocław Research Centre EIT+ under the project "The Application of Nanotechnology in Advanced Materials" - NanoMat (POIG.01.01.02-02-002/08) financed by the European Regional Development Fund (Innovative Economy Operational Programme, 1.1.2).

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otrzymano/received: 09.04.2014 *przyjęto do druku/accepted: 12.05.2014*