RESEARCH ARTICLE

Quality Assessment of Low Voltage Surge Arresters

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ABSTRACT Users expect reliable operation of the surge arrester during overvoltages, which may originate from a switching process or a lightning discharge. The necessary conditions to guarantee these expectations are: appropriate construction of the surge arrester, its production being maintained in accordance with technical standards, and a positive results of the type test (as well routine and acceptance tests). The recipient, especially when purchasing large quantities of the product, can check the final quality of the product through selective testing of samples from the market in order to find the best supplier. This manuscript specifies the basic parameters of low-voltage (LV) surge arresters of four manufacturers. Basic electrical parameters, i.e. leakage current and varistor voltage (U_{1mA}) before and after the nominal discharge current (I_n) of 8 μs/20 μs, were determined for 10 randomly selected surge arresters of each manufacturer. Moreover one sample of each varistor batches was aged by fifty 8 μs/20 μs current impulses with I_n. The obtained results of structural analysis indicate that the crystal structure of the varistor materials changes after ageing process, affecting its electrical properties. The proposed research methodology can be employed as a basis for forecasting the stability of the arrester parameters under operating conditions.

INDEX TERMS MOV, leakage current, residual voltage, electrical aging, repeatability of production.

I. INTRODUCTION

The surge arrester is an important part of an electrical installation that protects against overvoltages due to lightning strikes and switching processes. The device is expected to be reliable under typical operating conditions, including extreme situations such as repeated lightning strikes or exposure to high temperatures and humidity. The principle condition to meet these expectations is to ensure the correct construction of the surge arrester and its implementation, confirmed by type tests, in accordance with the requirements of relevant technical standards. In order to meet standardization requirements, manufacturers use high-quality starting materials and appropriate technologies for production. Additionally, the process and final controls applied at the production stage allow for the introduction of products characterized by high repeatability and reliability to the market. The final product

is checked only in the product tests or after the acceptance of a specific set of tests performed on the contractual number of samples according to the contract agreed between the buyer and the manufacturer (acceptance tests). An example of such tests is checking the markings and measurements of electrical parameters, which usually include either residual voltage (U_{res} – crest value of voltage measured between the terminals of arrester due to the discharge current having a current waveshape of 8 μs/20 μs) or leakage current (I_L – current passing through the arrester) tests at the the maximum continuous operating AC voltageU_c. The best practice of manufacturers is verifying each of products by measuring U_{res} and I_L[1].

Wholesale customers are usually interested in more rigorous tests of surge arresters i.e. aging tests performed at the maximum discharge current declared by the manufacturer (I_{max}). The maintenance condition of surge arresters may be also checked by measuring the electric field around these devices. This technique can be a valuable source of

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information about moisture or contamination of the insulation surface [2]. An intriguing alternative to the above mentioned method are simulations performed employing a finite element analysis or artificial neuron network model [3]. Another possibility according to operating duty tests is to test the resistance of surge arresters to aging by three series of 5 current strikes of 8 μs/20 μs each and measure I_{PE} – current passing through the arrester at the reference test voltage (U_{REF} – value from the standard IEC 61643-11) after each of the series [4]. According to common pass criteria (IEC 61643-11 standard) the resistive component of the leakage current (I_{PE}) should not exceed 1 mA or the current value should not change by more than 20% compared to the initial value measured before the test.

The aging process caused by an electric field lead to changes in crystal structure of ZnO- based ceramics [5], [6], [7]. The value of the leakage current I_L or I_{PE} increase in a pre-breakdown (ohmic) region both for a whole varistor as well as for inter-grains contacts during the exposition to a AC or DC conditions. In the breakdown region the I(U) characteristic exhibit a strong nonlinearity, which is a result of a degradation process caused by a tunneling phenomenon between a conduction bands of neighboring ZnO crystallites [8]. This process is promoted by a shrinkage of grain boundaries as a consequence of a redistribution of donors in a space charge area with a reverse bias [9]. Conduction of significant current surges in weakened areas causes shrinkage of ZnO grains and modification of the chemical composition of the interfaces [10], which affects the electric parameters of the varistor [11]. For each type of varistor ceramics, there are critical current and temperature surges above which the degradation process accelerates [10], [12]. The consequences of aging phenomenon are usually determined by I_L or U_{res} measurements [13] .

The rapid development of material investigations techniques such as a portable powder X-ray diffraction method or a scanning electron microscopy has made them more available for industrial purposes. Comprehensive investigations including both electrical measurements and material tests lead to reliable results, that can be useful for assesing the technical condition of surge arresters. Moreover, the application of methods typical for the material science can be helpful in identifying the causes of failure e.g. differences in the concentration of chemical elements may indicate a diffusion process caused by overheating.

The article presents the results of tests of surge arresters manufactured by four manufacturers. In order to evaluate repeatability and reliability of these devices there were performed typical procedures imposed by type-examination standards. The tested samples were additionally checked by observing the effects of the discharge current flow in comparison with the values of the resistive component of the leakage current measured before and after the test. Randomly selected samples were subjected to the effect of multiple current surges in series of 5, 10, 15 and 20 strokes with the observation of the leakage current and, above all, the

physicochemical analysis of the composition of the varistor ceramics. Furthermore we proposed the application of material science methods to investigate properties of ZnO - based varistors. Comparison of the results of electrical measurements and tests of design properties allows to determine the stability of the technical parameters of the surge arrester in operating conditions.

II. EXPERIMENTAL SETUP

In order to analyze the quality of surge arresters, an analysis of the technical condition of surge arresters from 4 different manufacturers (A, B, C, D) with the same nominal discharge current of 5 kA (8 μs/20 μs) was performed. The basis technical data for these samples are gathered in Table 1.

TABLE 1. Rated values for investigated LV surge arresters (U_C – maximum continuous operating voltage, U_P – voltage protection level, I_n – nominal discharge current, I_{max} – maximum discharge current).

Manufacturer	A	B	C	D
U_c [V]	440	440	500	440
U_p [V]	1500	1500	1700	1400
I_n [kA]	5			
I_{max} [kA]	40	30	40	40

The tests were performed according to a standard requirements (see II. A) and then were determined structural parameters and chemical composition following II. B.

A. ELECTRICAL PROPERTIES MEASUREMENTS

The varistor - based surge arrester has a strongly nonlinear current- voltage characteristic, which may be described with a power law equation [14]:

$$I = k \cdot U^\alpha \tag{1}$$

where k is a con stant depending to a geometry of varistor and its synthesis process and α is a nonlinearity coefficient defined as

$$\alpha = [d(\ln I)/d(\ln U)] \tag{2}$$

and usually lays in the range 30 – 100 [15]. The I - U characteristics of the varistors were determined by the estimation of a typical pre-breakdown parameters (U_{1mA} and I_L) and a breakdown parameters i.e. U_{res}. These parameters were performed by means of following measurements:

- varistor voltage U_{1mA} of the v LV limiter, the methodology according to the IEC 61643-331 standard was used, measuring the voltage U_{1mA} at the varistor terminals with a direct current flow of 1 mA - measurement before and after the applied surge,
- limiting voltage U_{res} (IEC 61643-11 standard) at rated discharge current (surge 8/20 μs/μs) measured as it shown in Fig.1,
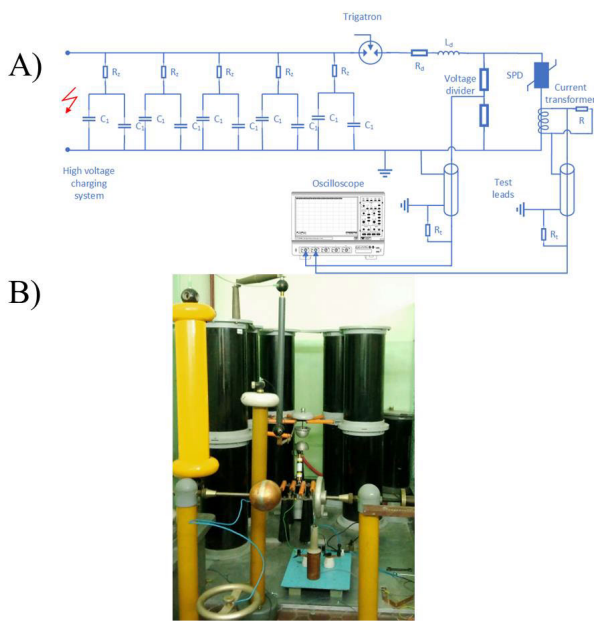
FIGURE 1. Measurement of the residual voltage of varistors with the nominal discharge current flow of 8 μs/20 μs with an amplitude of 5 kA, (a) layout scheme, (b) test stand.
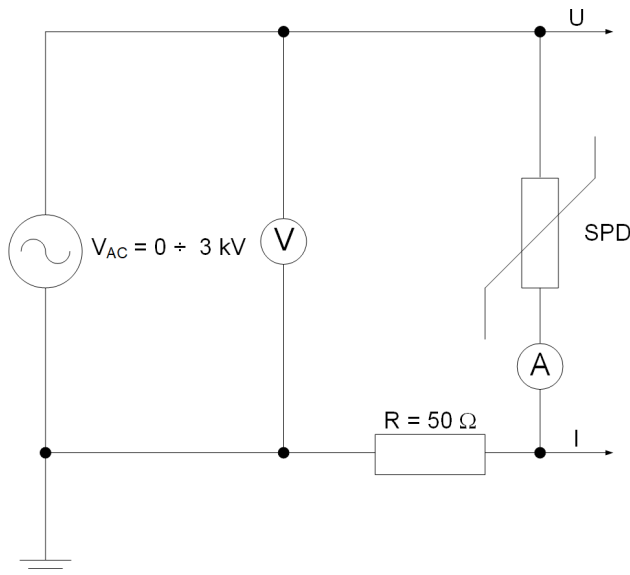
FIGURE 2. A scheme of test stand for leakage current measurements.

- total leakage current I_{LCT} and its resistive component (I_{LCR}) at the highest continuous operating voltage U_c according to Table 1 measured at test stand from Fig.2.

Additionally, an aging process of the arresters was performed for a random samples of each manufacturer (1 out of 10 items). We deliberately applied a series of current surges up to 50 (5 strokes, 10 strokes, 15 strokes, 20 strokes, surge 8/20 μs/μs) following the procedure shown in Fig.3. The duration between impulses was $\Delta t = 30$ s and its maximum current was equal $I_n = 5$ kA. The 24 hour interval between each series of impulses was applied to avoid damage to the
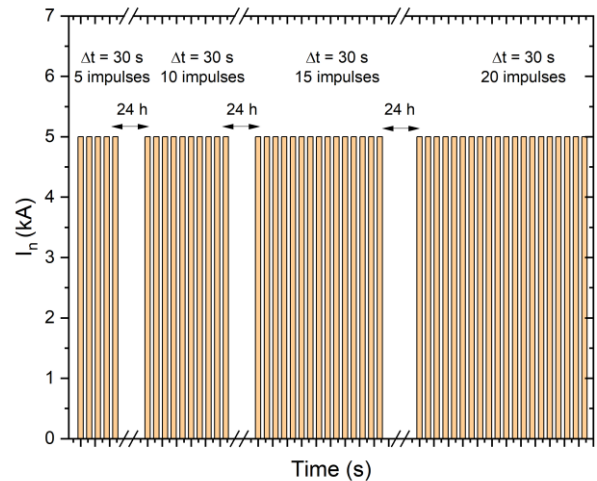
FIGURE 3. A procedure of aging of surge arresters.

surge arresters due to overheating. The electrical parameters of aged samples were checked by measurements of the leakage current (and additionally its active component) and the varistor voltage U_{1mA}.

B. TESTS OF PHYSICAL AND CHEMICAL PARAMETERS
Samples of varistors after 1 and 50 impulses were characterized by structural investigations, which included powder X-ray diffraction method (pXRD) and scanning electron microscopy (SEM). In order to avoid influence of contaminations, each of the samples was cutting on a disc band and then polished. The crystal structure of the analyzed surge arresters was determined employing Bruker D2Phaser diffractometer equipped with XE-T detector (Cu Kα radiation). The TOPAS software was used for LeBail fitting of pXRD data. The microstructural changes of varistors were inspected by means of scanning electron microscopes (SEM) NanoSEM 650 and FEI Quanta FEG 250D The chemical composition of the studied materials was determined by means of energy-dispersive spectroscopy (EDS) method using an EDAX Apollo-X SDD spectrometer integrated into the FEI Quanta FEG 250D SEM. EDAX TEAM software was used to process and fit the spectral data and the element concentration was calculated by means of the standardless eZAF method.

III. RESULTS AND DISCUSSION
A. ELECTRICAL PROPERTIES MEASUREMENTS
Due to the fact that 10 pieces of each type of arrester were submitted for the tests, a basic statistical analysis was performed, which consisted in calculating the mean values of individual parameters, additionally providing the smallest and largest values in the analyzed set of results (Table 2 and 3).

The results summarized in Tables 2 and 3 concern the testing of the surge arrester parameters, respectively, before and after the application of a current impulse with a nominal discharge current of 5 kA and the shape of 8/20 μs/μs (U_{1mA}, I_{LCT}, I_{LCR} columns). Moreover for aged samples was measured U_{res}.

TABLE 2. Statistical parameters of the population of the tested surge arresters before the aging process (the smallest, the largest and the mean value of each 10 -element series of different manufacturers).
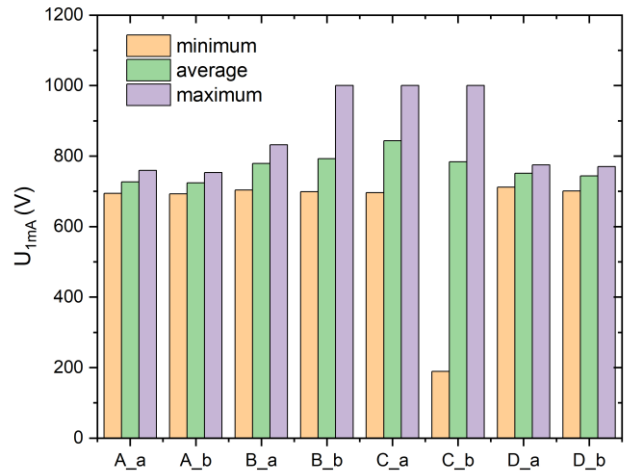
Manufacturer		U_{1mA} [V]	I_{LCT}[μA]	I_{LCR} [μA]
A	minimum	694	313	68,0
	average	727	332,42	91,5
	maximum	759	360	124,6
B	minimum	704	128	14,4
	average	778,9	145,4	29,5
	maximum	832	195,8	66,7
C	minimum	696	159,9	8,6
	average	843,5	202,91	26,9
	maximum	1000	248,1	57,8
D	minimum	712	178	12,5
	average	751,2	194,7	21,6
	maximum	775	226,1	37,4

TABLE 3. Statistical parameters of the population of the tested surge arresters after the aging process (the smallest, the mean value and the largest of each 10 -element series of different manufacturers).

| Manufacturer		U_{res}[V]	U_{1mA} [V]	I_{LCT}[μA]	I_{LCR} [μA]
A	min	1300	693	333,3	66,6
	avg	1334	723,7	355,6	90,8
	max	1400	753	127,0	117,7
B	min	1320	699	145,1	15,0
	avg	1397	792,5	201,8	29,8
	max	1490	1000	159,6	72,9
C	min	1330	189	243,3	9,9
	avg	1551	783,5	613,0	35,9
	max	1970	1000	181,0	109,6
D	min	1350	701	196,2	14,8
	avg	1421	743,7	232,3	24,8
	max	1460	770	309,4	44,4

FIGURE 4. Statistical values of the varistor voltage U_{1mA} (minimum, average and maximum values) for a different samples of LV surge arresters (A, B, C, D) before (a) and after (b) an aging process.
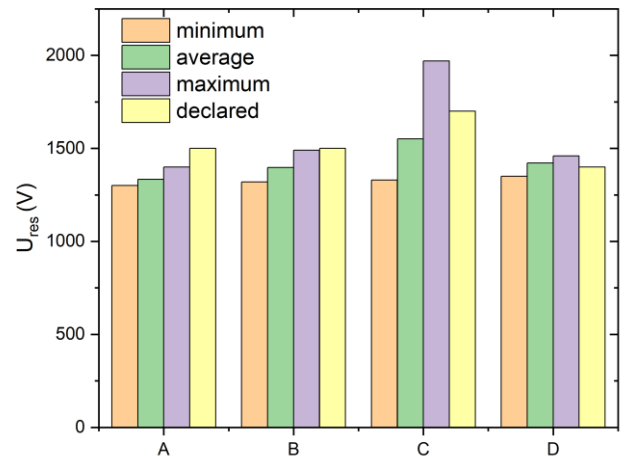
FIGURE 5. Statistical values of the threshold voltage (minimum, average and maximum values) for a different samples of LV surge arresters.

Figure 4 shows the statistical parameters of the varistor voltage U_{1mA} of the population of investigated surge arresters. It can be observed that the A and D surge arresters are characterized by high repeatability, which remains even after an ageing process. An increase of U_{1mA} was observed for one sample of manufacturer B and a drastic decrease in this parameter for one of the varistors C, which means its complete damage. Moreover, the C-surge arresters are characterized by the greatest spread of the U_{1mA} for the investigated population.

Figure 5 shows the results of U_{res} measurements. The largest dispersion of the maximum voltage values accompanying the discharge current flow can be observed again for the C- surge arresters. The remaining companies achieve similar spreads, however it is worth noting that the values obtained for C and D exceed the limits declared by the manufacturers. In this experiment, it can be concluded that manufacturer A obtained the reproducible and lowest residual voltage values. For the products of this manufacturer, the highest of the measured values of the limiting voltage is definitely below the voltage declared by the manufacturer. On the basis of

the above-mentioned test and analysis of other parameters, it can be assumed that in the case of LV surge arresters, the residual voltage test may be the basic method of checking the quality and durability of the surge arresters when performing, for example, a series of repeated current surges with specific parameters.

The analysis of the resistive component of the leakage current, which is presented in Fig. 6 clearly indicates the highest values in the case of product A, which may cause greater heating of this limiter in the steady state and indirectly affect its current-voltage characteristics. The divergence between A samples and others manufacturers products may be a result of a different insulation method of these surge arresters. The analysis of the I_{LCR} value before and after the application of the current surge shows the greatest stability of the B population, where there was a slight increase in the statistical parameters of the resistance component compared to C and D (greater value change). A reverse trend was observed
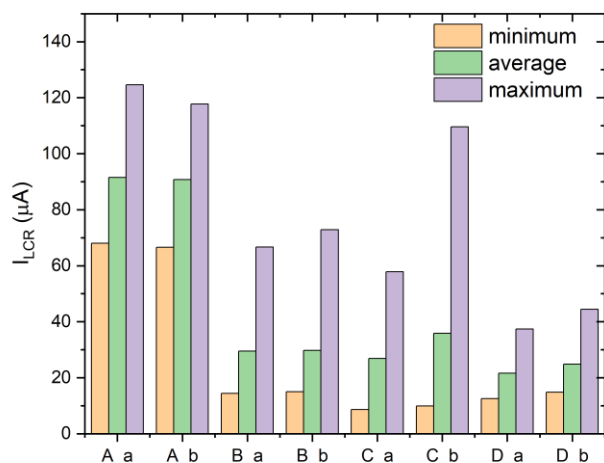
FIGURE 6. Statistical values of the active component of the leakage current (minimum, average and maximum values) for a different samples of LV surge arresters before (a) and after (b) an aging process.

for product A, as the values of the resistance component slightly decreased, which may be due to the stabilization of the parameters of samples with a significant leakage current.

In the next part, the test was performed with current surges of 8 μs/20 μs repeated at intervals of about 50 seconds, during which the residual voltage was measured, and after the established series - the varistor voltage U_{1mA} and leakage current at maximum continuous operating voltage U_c. The strokes were applied in the series of 5, 10, 15 and 20 strokes, so that their total number was N = 50. All selected limiters withstood the application of 50 strikes, which is a good proof of their resistance to repetitive shocks. The residual voltage levels confirm the conclusions obtained for the single stroke tests in Tables 2 and 3 and Figures 4-6. This means that in the case of repeated, multiple current surges, even up to 20 - here, the A and B surge arresters will properly maintain the residual voltage below the value U_p declared by the manufacturer. For C surge arresters, during a series of discharges, an increase in the residual voltage can be expected even to a value exceeding by 400 V the declared voltage protection level of 1700 V. In the case of D- surge arresters, the analyzed exceedance is only 140 V. Changes in the residual voltage, especially during the transition from the N = 5 to N = 10 impulse series, indicate the processes of stabilization of the varistor during its heating to a higher temperature, which is accompanied by the accumulation of current surges (see Fig S1 of the ESI).

B. TESTS OF PHYSICAL AND CHEMICAL PARAMETERS

Fig. 7 shows the room temperature XRD patterns for C varistors after 1 and 50 impulses (plots for other varistors are presented in Fig S2 of the ESI). It is clear that multiple crystalline phases are present in each varistor sample.. In each case the main phase (> 85 mol %) was identified as ZnO, which crystallizes in a hexagonal structure with space group P6$_3$mc (no. 186). Another similarity between these materials is occurrence of δ-Bi$_2$O$_3$ (cubic structure; space group
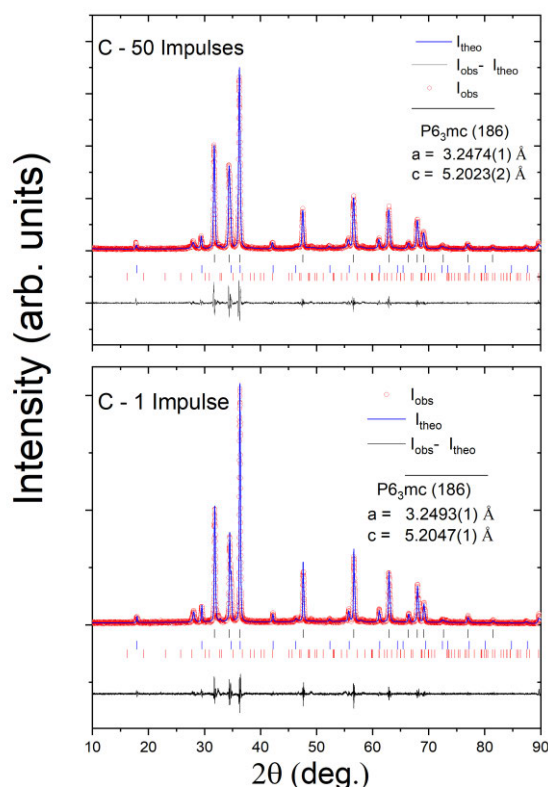
FIGURE 7. Le Bail refinement of powder XRD data for ETI varistors. Observed data and calculated intensity are represented by red circles and blue lines respectively. Black vertical ticks correspond to Bragg peaks for space group P63mc (no. 186); blue to Fd-3m (no. 227) and red to P -42$_1$c (no. 114).

Fd-3m – no. 227) and Sb$_2$O$_3$ (tetragonal structure; space group P -42$_1$c – no. 114). Both of them have a crucial meaning for grain growth process, which was earlier discussed in the literature [1], [2]. Results of the Le Bail refinement are gathered in Table S1 of the ESI. Calculated values of lattice parameters are in a good agreement with reported data. Moreover all of studied varistors contain trace amounts of additional phases, which could not be identified using pXRD method.

Fig. 8 shows results of pXRD measurements expanded in the 2θ region 24° - 40°. It is worth noting that for both samples of A varistors around 2θ $\approx$ 25° one can observe a small reflection, which was not indexed. Similar behavior was not noticed for samples C and D. Furthermore this low angle reflection is present for B varistor treated with 1 impulse but disappears for sample treated with 50 impulses. It is an evidence for differences of composition of tested materials which may be a reason for dissimilarities between their electrical properties. What is more for a chemically pure ZnO intensity of a peak *002* is about 25% smaller than for a peak 001 [16], whilst in studied varistors these reflections are comparable. This phenomenon can be explained by the contribution of additional phases to the peak intensity around 2θ $\approx$ 34°. The shape of this reflection is strongly affected by the ageing process, which is especially visible in the case of

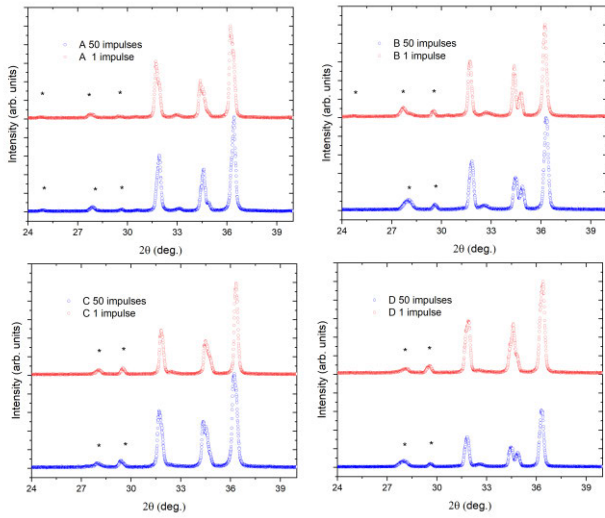**FIGURE 8.** pXRD patterns for selected samples in the 2θ region 24° - 40°.

FIGURE 9. Values of coherent scattering domain for ZnO, Bi_2O_3 and Sb_2O_3 obtained from the line broadening analysis.

sample C. After multiple lightning strikes the crystallinity if the samples is improved, which is probably due to the influence of Joule's heating on structural properties. There are two plausible explanation of this phenomenon. First, exposure to heat may cause phase transition of Sb_2O_3 to a pyrochlore or spinel structure type, during states is partially oxidized from Sb^{3+} to Sb^{5+} [8]. Moreover that the Bi_2O_3 phase is polymorphic, with 4 phases existing in different temperature ranges. Another possibility is a substitution Zn atoms in Bi positions of bismuth oxide. In order to answer this question it is necessary to carry out further investigations e.g. neutron diffraction measurements. The pXRD method was also used to determine microstructural properties of surge arresters employing the line broadening analysis. The methodology of this process was described in [17] and the instrumental profile was approximated by LaB_6 standard measurements results. Obtained values of coherently scattering domain (CSD) for ZnO, Bi_2O_3 and Sb_2O_3 are presented in Fig. 9. It is important to stress out that the CSD size is not directly connected to the grain and crystallite size and is used here only to highlight the evolution of XRD peak shape driven by microstructural changes.

On the basis of these diagrams it may be ascertained that A and C samples have similar CSD sizes after 1 and 50 impulses. In the case of B varistors, a large increase of Bi_2O_3 CSD can be observed, which is consistent with a hypothesis about overheating due to a large resistive component of the leakage current. The substantial differences between D samples can be explained by poor repeatability of these varistors rather than influence of an ageing process. The disproportions in the CSD values indicate on the lack of repeatability of technological processes in the production of surge arresters.

In order to get a better insight into a microstructure of studied varistors, the samples were performed by means of electron microscopy. SEM imaging indicates that all of the samples have a microstructure typical for sintering materials.
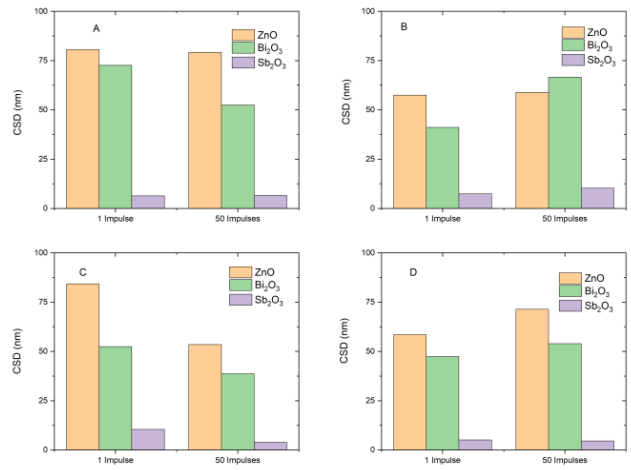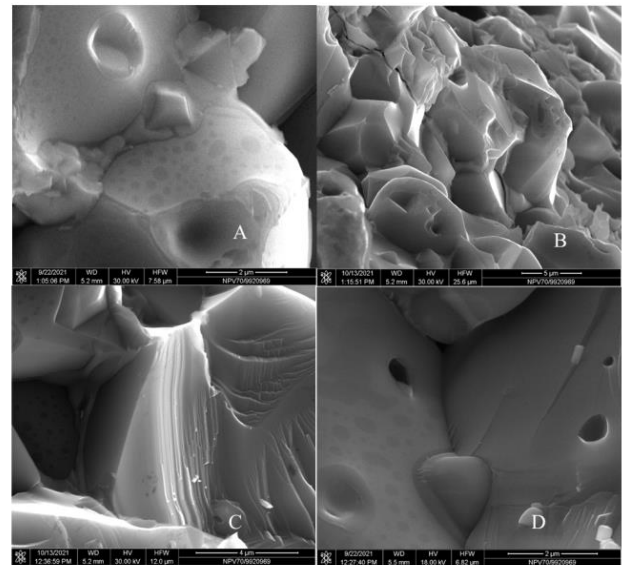

FIGURE 10. SEM images of varistors samples before ageing process.

The surface morphology of samples exhibit the presence of ZnO grains which have various sizes. Within the ZnO grain, submicron pores and traces of other phases can be observed (Fig S3 of the ESI). Images of varistors before an ageing process with higher magnification are presented in Fig. 10.

In each case ZnO grains with insertions of an additional phase are clearly visible. The most important differences between surge arresters can be seen in the interfaces, which are much broader for A and B varistors than for C and D samples. The non-ohmic properties of ZnO based varistors origin from grain boundaries between semiconducting zinc oxide grains [18]. For this reason varistors with broad interfaces may have a better ageing resistance, which was confirmed by electrical properties measurements. Moreover, in B varistor occur single crystalline inclusions with dimensions of approximately few micrometers. The shape of these

insertions suggest a $ZnSb_2O_4$ spinel-like formation. These observations are in line with conclusions from pXRD measurements. It is worth noting that interfaces in the A varistor are cracked, which may result from improper parameters of the sintering process and cause the I-U characteristics to deteriorate.

The chemical composition of varistors after 1 and 50 impulses were checked employing an EDS analysis and obtained results are gathered in Table 4.

TABLE 4. Relative values of chemical elements (excluding oxygen) in varistors after 1 (a) and 50 impulses (b).

Chem. element	A_b % at.	A_a % at.	B_b % at.	B_a %at.	C_b %at.	C_a % at.	D_b % at.	D_a % at.
Sb	2.11	2.51	0.46	1.67	2.44	2.12	2.29	2.18
Cr	1.85	1.92	0	0	0	0	0	0
Mn	1.11	1.16	0.39	1.03	1.30	1.62	1.64	1.59
Fe	0.78	0.76	0	0	0.43	0	0	0
Co	2.24	2.29	0.45	1.30	1.74	2.20	2.25	2.16
Ni	1.84	1.87	0.33	1.06	0.79	1.24	1.21	1.15
Zn	87.21	86.30	97.93	92.35	91.75	91.07	90.79	91.22
Bi	2.86	3.20	0.44	2.61	1.55	1.74	1.81	1.71

The differences between the elemental content are obvious and have a crucial meaning for structural and macroscopic properties of varistors. Only sample A contains the addition of Cr, the positive influence of which on the electrical properties is discussed in [19]. However, an excess of this element impair the potential barrier of grain boundaries, which may led to an increase of the leakage current. The Fe, which occur in some of samples, is not a typical component of ZnO varistors. The presences chemical element is probably a result of a contamination during a production process and may have an impact on the deterioration of nonlinearity of the I-U characteristic. The wide interfaces observed in A and B varistors can be a consequence of the relatively high proportion of a Bi in these samples composition. This phenomenon is promoted in B sample because of the low content of a Sb, which has an opposite role to a Bi [20]. Moreover, samples C and D, which have narrow interfaces are poor in a Bi phase. Fig. 11 shows the multi-element mapping of EDS images of varistors before an ageing process. It can be seen that the most of additional chemical elements are located on interfaces, whilst Mn occurs only in inclusions in ZnO grains. Moreover, Ni, which is commonly added to improve sintering process [21], is evenly distributed in the samples.

The influence of the ageing process on the studied samples was investigated through differences in microstructural properties and changes in chemical. Table 4 summarizes the chemical composition of samples after 1 and 50 impulses. For A, B and C varistors an ageing process cause a decrease of a concentration of a Sb and a Bi, which may be a result of the evaporation of these elements due to a Joule's heat generated during impulses. The potential losses of Bi and Sb result from their volatility and relatively low melting temperatures and may be of great importance for electric parameters of studied
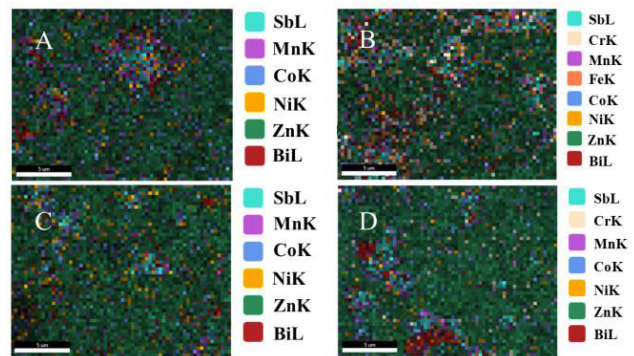
FIGURE 11. Multi-element EDS mapping images of varistors before an ageing process.
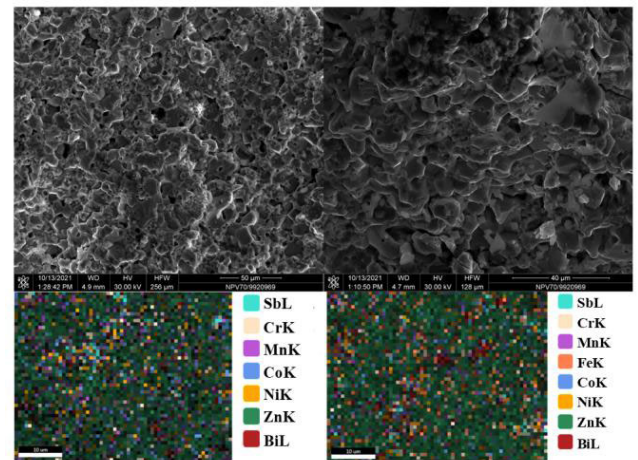
FIGURE 12. Comparison of SEM/EDX images before (left) and after (right) an ageing process for A varistors.

materials. The opposite tendency may be observed in case of D sample, however it is probably a result of inhomogeneity of a precursor mixture. This hypothesis agree with a spread of electrical characteristics of D varistors. In Fig. 12 exhibited the comparison of SEM images and EDS mapping for A sample before and after ageing (data for other varistors are presented in Fig. S4 of the ESI). In the case of sample after 50 impulses the additional elements are more concentrated due to recrystallization process which led to a growth of grain boundaries. Additionally the ZnO grains stay similar to that before multiple lighting impulse currents, which is generally in line with our earlier results.

C. DISCUSSION OF RESULTS

Summarizing the results of the preliminary tests presented in tables 2 and 3, one can certainly point to a poor-quality product of manufacturer C, in which one of the arresters was damaged, characteristic significant dispersions of all parameters and exceeding the declared value of the voltage protection level (despite the highest value in relation to other manufacturers). The obtained results do not clearly indicate the best product among other investigated surge arresters.

The results of the measurements of the varistor voltage U_{1mA} at the flow of direct current and the resistive component of the leakage current at the highest continuous operating voltage U_C suggest greater usefulness and sensitivity of the latter due to the simulation of a typical operating state in conditions similar to those in the power grid.

Similar conclusions can be also be drawn from aging tests. Despite the fact that all investigated samples withstood the application of 50 lightning strikes, there were a non-negligible differences between products of various manufacturers. Manufacturer C surge arresters are characterized by a lower resistance to aging phenomenon than other samples, which can be observed as a significant increase in residual voltage. The increase in this parameter in the case of sample D was about three times smaller, which indicate better tolerance to repetitive lightning strikes. The lowest impact of aging test was denoted for A and B surge arresters, for which the residual voltage did not exceeded the U_p value declared by the manufacturers.

Studies of the properties of materials were a valuable supplement to the measurements of electrical parameters, which allowed for a better insight into the internal characteristics of studied samples. CSD values size estimated from the analysis of pXRD data indicated that the largest changes of the main phase during the ageing process was observed for manufacturer C varistors. The correlation between CSD value for ZnO grains and resistance to lightning strikes was also noted for other investigated samples. It should be also mentioned that the overheating of B samples may be confirmed by the increase of CSD size parameter for Bi_2O_3 grains. Furthermore, a good resistance to aging process of surge arresters from manufacturers A and B is consistent with a wide interfaces observed in SEM images for these samples. This hypothesis is confirmed by the results of EDS analysis, which suggest a higher concentration of Bi in varistors A and B.

IV. CONCLUSION

We proposed a comprehensive method of estimation of technical state of low voltage surge arresters, which include the electrical measurements and the structural investigations. The combination of these measurement techniques lead to a complex overview of properties of ZnO based varistors, which may be useful when checking the quality of new surge arresters. Furthermore the proposed method may be helpful during testing the repeatability of surge arresters and estimate their resistance to the ageing phenomenon.

Our investigations of LV surge arresters certainly point to a poor quality product of the manufacturer C - damage to one surge arrester, characteristic large dispersions of all parameters and exceeding the declared value of the voltage protection level (despite the highest value given in relation to the others). The proposed research methodology indicates a significant, gradual internal changes in varistor ceramics observed during operation process as a result of substantial current exposures (multiple strokes or exceeding the critical load). The observed

scatter of test results indicate the necessity to test at least a dozen samples in order to determine the repeatability of the product.

The results of electric parameters measurements are in a good agreement with a material properties investigations. Both pXRD and SEM/EDS researches confirmed a poor quality of varistor ceramic of C manufacturer. Moreover, there are significant differences in the chemical composition and microstructure of varistors from different manufacturers, which can affect their electrical properties. The impact of aging process on a varistor ceramic is clearly visible and may be investigated by SEM/EDS imaging, which may be useful during identifying the causes of breakdowns of surge arresters.

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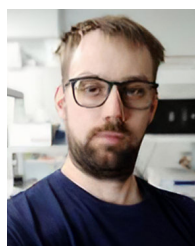
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