130

T. M. Nedić, *et al*.: Efficient Replacement of the Radioactive Sources in the ...
Nuclear Technology & Radiation Protection: Year 2020, Vol. 35, No. 2, pp. 130-137

EFFICIENT REPLACEMENT OF THE RADIOACTIVE SOURCES IN THE GAS-FILLED SURGE ARRESTERS CONSTRUCTION FOR THE INSULATION CO-ORDINATION AT THE LOW VOLTAGE LEVEL

by

Teodora M. NEDIĆ [1*], *Aco J. JANIĆIJEVIĆ* [1],
Koviljka Dj. STANKOVIĆ [2], *and Nenad M. KARTALOVIĆ* [3]

[1] Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia
[2] Faculty of Electrical Engineering, University of Belgrade, Belgrade, Serbia
[3] Institute of Electrical Engineering "Nikola Tesla", Belgrade, Serbia

The possibility of the classical response rate engineering and the long-term deconditioning of the gas-filled surge arresters is considered in this paper. The obtained results are compared with the same results obtained with the gas-filled surge arrester with application of an alpha radioactive source. The work is of an experimental nature. Experiments were performed on the multipurpose gas-filled surge arrester model under well-controlled conditions. The measurement uncertainty of the experimental procedure was less than 8 %. The results were processed by statistical data processing software. To draw impulse characteristics, the law of constancy of surfaces below the impulse voltage in the volt-second area, was used.

Key words: gas-filled surge arrester, low voltage level, insulation characteristic

INTRODUCTION

The increasing contamination of the environment with the high-frequency ionizing radiation and the trend towards miniaturization of electronic, multilayer, densely packed, electronic components extremely highlights the problem of overvoltage protection at a low voltage level. The overvoltage protection at the low voltage level is performed by the drain diodes (a type of Zener diode), the varistors, and the gas-filled surge arresters (GFSA). These components, which are connected in parallel to the shielded electronic component (or electronic structure), have the task of applying an overvoltage (voltage that is higher than the maximum withstand voltage of the protected component or assembly) to the grounded level. For this reason, the overvoltage protection components are sometimes called parallel (voltage) fuses [1-3].

The basic characteristics expected from the insulation co-ordination components at the low voltage level are: the response speed and the stability of the nominal values during the exploitation. Namely, the response speed is the most important characteristic of the overvoltage protection component. It should be

current, *i. e*. it should not allow the entry even of a per mille of the overvoltage in the protected component.

As engineering disciplines do not recognize promptness in the reaction, this problem is, in practice, solved by more flexible approaches to the nominal values of the protected voltage and the operating voltage of the arrester. It is obligatory to provide a certain value of the voltage that the protected element will withstand, even if it is a little higher than the nominal (maximum allowed) value. Stability of nominal values during operation is necessary because the components for the overvoltage protection, especially the semiconductors, are integrated so that their failure means at the same time the failure of the whole assembly [4, 5].

The overvoltage protection components cannot be classified by quality. The drain diode has the fastest response, close to the current value, but it is, unfortunately, the most sensitive to the intensity of the drain power. This means that the drain diode is almost exclusively disposable. The varistor is a component of stochastic characteristics. It consists of a large number of chaotically arranged diodes. It works in such a way as to discharge voltage through the stochastically established Euler path. This, of course, has the disadvantage that after several operations, these paths intersect and interrupt. In addition to such destruction of the varistor, the selected surge protections are not com-

* Corresponding author; e-mail: teodora.nedic@nuklearniobjekti.rs

T. M. Nedić, *et al*.: Efficient Replacement of the Radioactive Sources in the ...
Nuclear Technology & Radiation Protection: Year 2020, Vol. 35, No. 2, pp. 130-137

131

posed of the same number of stochastic diodes with the same characteristics, so the varistor as a surge arrester is not very reliable at low voltage. Varistors for insulation co-ordination are, as an idea, taken from high voltage insulation co-ordination, where under the name zinc oxide arrester, the gas-filled surge arrester is extremely often used, which are also taken from the low voltage insulation co-ordination, have the opposite layout of the disadvantages and of what makes them advisable. Their response speed is their biggest disadvantage, and an almost unlimited number of runs is their advantage. Of course, there is a disadvantage in this infinity of the number of operations in terms of the stability of the operating point. However, with an engineering-acceptable solution, the operating point can be conditionally stabilized. The problem of the slow response is more difficult to solve because the principle of operation of gas-filled surge arresters is based on the mechanism of the electrical discharge in gases (electric breakdown) in which the mobility of ions (or atoms) of the gas plays an active role. Since the mass of ions (or atoms) of a gas is at least 2000 times greater than the mass of an electron, it is logical that the response speed of the gas-filled surge arresters is significantly longer than the speed of the semiconductor surge arresters based only on free or bound electrons. In addition to the slow-motion of the ions, as an important element in the functioning of the gas-filled surge arresters, there is the initiation of the electrical breakdown that will end in a self-sustaining process [6-8].

Namely, in each gas, there is a large number of free electrons, formed by a thermal process or by the collision processes of constitutive gas particles from the high-energy tail of the Maxwell spectrum, or by the collisions of the constitutive gas particles in the interelectrode state. However, free electrons alone are not enough to start the self-sustaining process of gas discharge. In order for it to occur, the free electron should be located in an energetically favorable place, where it can absorb enough energy from the electric field at one mean free path length, to perform ionization in the next collision [9, 10].

A volume that meets this condition is called a critical volume. In order for the process of creating electrons that will start (initiate) the electrical breakdown between the electrodes of the gas-filled surge arrester (the high-voltages and the grounded), the number of free electrons should be accelerated and the critical volume should be as large as possible. In order for the critical volume in the gas surge arrester to be as large as possible, it is necessary to choose such arrester electrodes that they form a homogeneous electric field (then the entire volume of the arrester is the critical volume). To make the number of free electrons be as high as possible, additional ionization should be induced in the homogeneous field of the arrester (in addition to the previously mentioned mechanisms). Ini-

tially, this problem was solved by inserting a ^{241}Am alpha source inside the gas-filled surge arrester. This proved to be very efficient since α source performs a high ionization density, and in addition, has a low energy deexcitation component. In that sense, with not a very widespread application, it would be a great solution. Well-placed sources of α radiation inside the gas-filled surge arrester, *i. e.* well-focused, they solved another disadvantage of the gas-filled surge arresters. Namely, the gas-filled surge arresters have so-called long-term deconditioning as a significant disadvantage. Long-term deconditioning boils down to the fact that after a long standstill (of the order of the day), the first few values of breakdown voltages can be up to 40 % higher than the following ones. Fortunately, prolonged downtime does not happen often, but if it does, it certainly leads to the destruction of the protected electronic circuit. By solving, so said, all the shortcomings of the gas surge arrester with α radioactive source, it led to the almost exclusive production of this type of gas surge arrester. However, the exponential growth of usage of the gas-filled surge arresters, with α radioactive source without regulations for its monitoring and disposal, has called into question the acceptability of this solution for optimizing the characteristics of the gas-filled surge arresters [11-14].

The aim of this paper is to examine the other technological and physical possibilities of accelerating the response of the gas-filled surge arrester and the long-term deconditioning, while avoiding the use of a radioactive source and/or at least creating a safe protocol for their application where it is necessary [15].

THE FUNCTIONING MECHANISM OF THE GAS-FILLED SURGE ARRESTERS

The gas-filled surge arrester is a two-electrode system insulated with a noble gas located in a sealed chamber, fig. 1. The electrode system is, most often, such as to form a homogeneous electric field. The interelectrode distance is very small (of the order of mm, and less). Insulating gas is at a high vacuum (of the order of magnitude in the sub mbar[1] area) [16, 17].

The gas-filled surge arrester operates on the principle of electrical breakdown, *i. e.* one of its electrodes is located at a point that is protected against the overvoltage, and the other is grounded. When the value of the voltage at the protected point is raised above the nominal value of the breakdown voltage of the gas arrester between the electrodes, a gas breakdown occurs, and the protected point is grounded (thus protecting everything behind it from overvoltage). The gas breakdown mechanism itself is a self-sustaining multiplicative mechanism. The gas breakdown is

---
[1] 1 mbar = 100 pascals

132

T. M. Nedić, *et al*.: Efficient Replacement of the Radioactive Sources in the ...
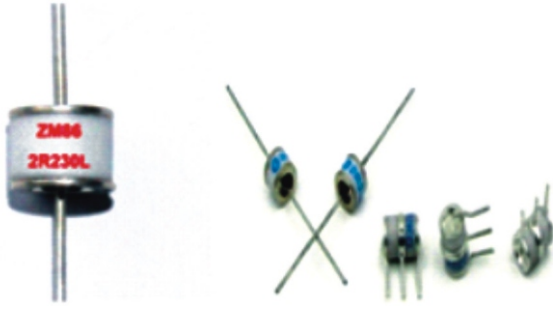Nuclear Technology & Radiation Protection: Year 2020, Vol. 35, No. 2, pp. 130-137

Figure 1. The commercial gas-filled surge arrester [18]

initiated when one free electron at the mean free path length gains enough energy to ionize a neutral molecule (or gas atom). In that case, that free electron becomes initial. The space volume in the electric field where this process takes place is called the critical volume. In order to make such initiations to lead to a breakdown, the process of the gas multiplication should be self-sustaining. If the processes on the electrodes are responsible for the self-maintenance of the multiplicative mechanism, the breakdown occurs by the Tausend mechanism. If the processes in the gas are responsible for the self-maintenance of the multiplicative mechanism, the breakdown occurs through the streamer mechanism. The gas-filled surge arresters works, most often in the area of the Tausend breakdown mechanism [19, 20].

The electrical breakdown can be DC, AC, and impulse. The DC breakdown is achieved by a voltage whose rise time is significantly longer than the time characteristic of the elementary processes of the electric gas discharge [21, 22].

The same situation is in the case of the ac gas breakdown. The impulse breakdown voltage of the gas is realized by an increasing voltage whose rise time is of the order of magnitude of time characteristic of the elementary processes of the gas-electric discharge. The DC and AC breakdown voltage values are, almost completely, the deterministic quantities (*i. e.*, when measuring them, the measurement uncertainty of type A is zero or very close to zero). The impulse breakdown voltage is a stochastic magnitude of significant dissipation (*i. e.* when measuring the impulse breakdown voltage, the measurement uncertainty type A significantly participates in combined measurement uncertainty) [23-25].

Based on the kinetic theory of gases, the value of the breakdown voltage unambiguously depends on the product of pressure and interelectrode distance (so-called pd values). This is true, completely, for the values of DC and AC breakdown voltages since they are deterministic quantities. The dependence of the DC breakdown voltage on the product pd is called the Paschen curve. The Paschen curve is an asymmetric U curve which is limited on the left side by the appearance of the vacuum breakdown. The operating point of the gas surge arresters is usually placed near the mini-

mum of the Pashen curve on the right side. In case of the gas surge arresters, the value of the impulse breakdown of the surge is characterized by the so-called impulse characteristic. The impulse characteristic represents the dependence of a certain quintile probability of the impulse breakdown on time. In practice, two such dependencies were given (for example, for quantiles of 0.1 % and 99 %) and they limit the area in the voltage-time plane in which each value of the impulse breakdown voltage is located (with a predetermined probability) [26, 27].

The gas-filled surge arrester has primarily to protect electronic components from the overvoltages that are a consequence of atmospheric discharges, commutation actions, and irregularities in the voltage shape (deviations from the sinusoid and the appearance of higher harmonics). All these forms of the voltage are most closely reduced to the impulse voltage. This means that in order to increase the efficiency of the GFSA, it should be ensured that its impulse characteristics are as parallel to the time axis as possible and that the distance between the impulse characteristics of the small and large quantiles of the breakdown probability is as small as possible. In addition, the occurrence of the long-term GFSA deconditioning and the stability of its operating point should be minimized [28].

In order to achieve such engineering, the parameters are available on which the electrical breakdown of the gas depends: type of gas, pressure, interelectrode distance, electrode material (output, melting temperature, and thermal conductivity) and topography of electrode surfaces [29, 30].

EXPERIMENT AND PROCESSING OF THE MEASUREMENT RESULTS

The experiments performed in this paper aimed to determine whether there is an alternative to radioactive radiation application in the GFSA. For that purpose, the experiments were conducted with the two-electrode and three-electrode GFSA models. In the two-electrodes GFSA model, the influence of the hollow cathode and the electron material on the impulse characteristics of the GFSA was considered. The influence of the third, floating electrode on the long-term GFSA deconditioning effect was considered in the three-electrode GFSA model. For the purpose of comparison, in parallel and under the same conditions, researches of the influence of α radioactive radiation on the same characteristics were performed.

Figure 2 shows the models of the used chambers. The chambers were designed to be flexible in terms of changing the parameters: the electrode, the interelectrode distance of the gas (or gas mixture), and the gas pressure. The interelectrode distance was ad-

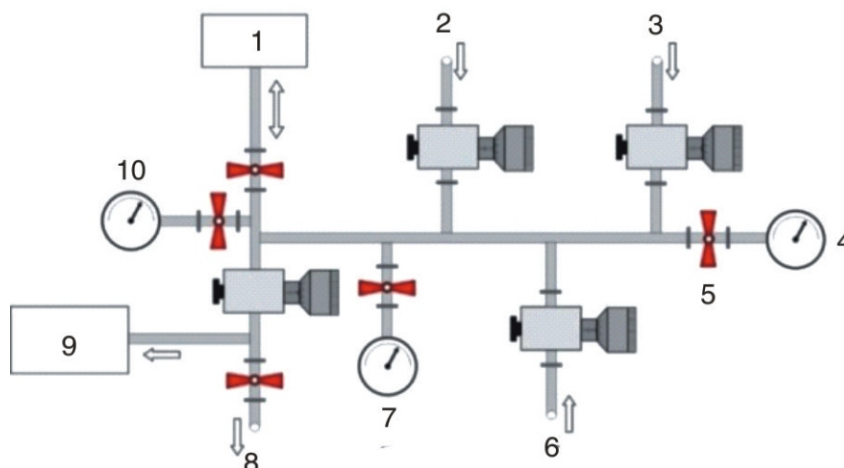**Figure 2. The gas surge arrester gas chamber model**

justed with an electronic micrometer screw. The zero distance between the electrodes was adjusted by measuring the resistance. Helium gas was used as the insulating gas in the model, and a gas mixture of 0.95 He + 0.05 SF_6 was also used. A gas circuit was used to fill the model with He gas and the gas mixture, fig. 3. The ratio of gases in the mixture was adjusted based on the law of the partial pressure additivity. The pressures in the chambers were determined to correspond to the pressure at 0 °C. Before adjusting the working gas pressure in the chambers, they were repeatedly washed with He. The sealing of the chambers was extremely good (could not establish a pressure change on a monthly basis).

To obtain the impulse characteristics, the DC source (the voltage rise rate 8 $V(s)^{-1}$ and the impulse source, fig. 4 were used. The impulse source gave pulses, approximately to the linear rise, at speeds of 1 kVs^{-1}, 5 kVs^{-1}, 10 kVs^{-1}, 50 kVs^{-1}, 100 kVs^{-1}, 200 kVs^{-1}, and 500 kVs^{-1}. The impulse voltage amplitude was always significantly higher than the expected value of the impulse breakdown voltage. The breakdown voltage values were measured with a compensated capacitive voltage divider and a 500 MHz digital oscilloscope. During the measurement, the measuring instruments were placed in a protective cabin (protection greater than 100 dB) and galvanically separated from the capacitive divider.

For the electrode system formation, the cylindrical electrodes with the upper surface of the Rogowski profile were used, fig. 5. The electrodes were made of brass, and for testing the influence of the electron material to the breakdown, the same shape electrodes s were made of: aluminum, electron alloy, and tungsten. The electrodes with a cavity in the cathode were also used to examine the hollow electrode effect (the diameter of the cavity was always significantly larger than the mean free path length of the electron under experimental conditions). In addition to these electrodes, the brass electrodes with a cavity in the cathode that was coated with an electron alloy were also used. In addition, the possibility of placing a ^{241}Am radioactive source so that α radiation was directed at the cathode, was examined. Before each series of measurements, the electrodes were polished to a high gloss.

The measurement procedure consisted of the following steps: 1 – the electrode configuration formation, 2 – filling the chamber with the working gas, 3 – measuring 20 values of the dc breakdown voltage, 4 – measuring 50 values of the impulse breakdown voltage, and 5 – setting new parameters of the GFSA model and repeating measurements. The combined measurement uncertainty of the experimental procedure was less than 8 % [31-34]. The processing of the measurement results was different in the case of examining the influence of the parameters of the GFSA model insulation system on the impulse characteristic and on the long-term deconditioning effect. In the case of examining the impulse characteristics, the processing of the obtained experimental results was performed in the following steps: 1 – application of the Chauvin criterion for rejecting the suspicious measurement results, 2 – determining the affiliation of stochastic values of the impulse breakdown voltages from the statistical distributions of minimum values (*i. e.* exponential, two- and three-parameter Weibull distribution) and Normal distribution, ^{2} test, 3 – determination of the obtained parameters distribution by the moment method, and 4 – drawing the impulse characteristics for 99.9 % and 0.01 % of the probability

Figure 3. The gas circuit scheme;
1 – chamber, 2 – SF6 gas,
3 – noble gas, 4 – vacuum gauge,
5 – two position valve,
6 – air, 7 – manometer,
8 – irradiation,
9 – vacuum pump,
10 – precision vacuum gauge

134

T. M. Nedić, *et al*.: Efficient Replacement of the Radioactive Sources in the ...
Nuclear Technology & Radiation Protection: Year 2020, Vol. 35, No. 2, pp. 130-137
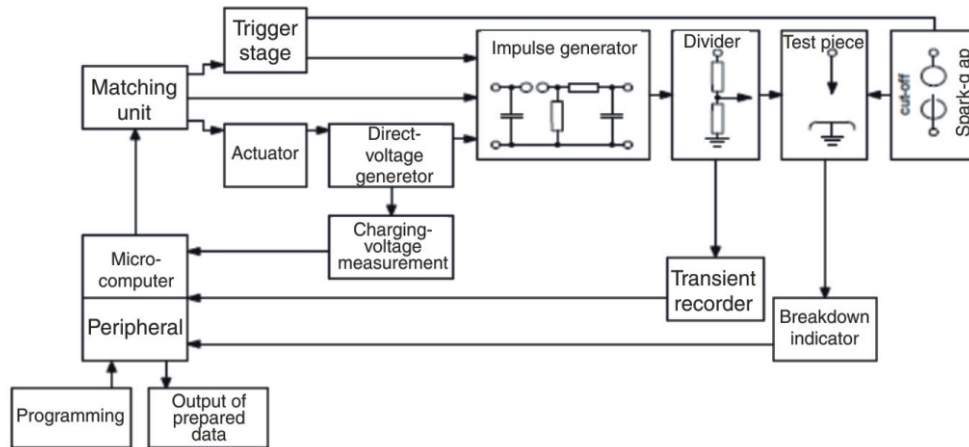
Figure 4. Circuit for generating and measuring impulse voltage

Figure 5. The basic electrodes Rogowski type used in the experiment

quantile of the obtained statistical distribution by applying the law of surface constancy under impulse in voltage-time area. In the case of examining the influence of the GFSA model parameters on long-term decontamination, the first three steps were the same. However, the measurement procedure itself was performed with a break of 1 hour, 12 hours, 24 hours, 5 days, 10 days, 20 days, 30 days, and 45 days. The samples of the random variable impulse breakdown voltage thus obtained, were obtained on chronologically arranged subsamples of five random variable impulse breakdown voltages, normalized to the mean value of the impulse breakdown voltages. By analyzing the statistical sample thus obtained, data on the quantitative indicator of long-term deconditioning of the GFSA model, can be obtained.

RESULTS AND DISCUSSION

Figure 6 shows the impulse characteristics obtained for the application of: the brass electrodes, the brass electrodes with a hollow cathode (the electron al-loy coated cavity), and the brass electrodes with a hollow cathode (the electron alloy coated cavity) and a radioactive source, ^{241}Am.

The results shown in fig. 6 were chosen from lots of results and represent the standard impulse characteristics (the brass electrodes) and their obtained impulse characteristics without the use of radioactivity (the brass electrodes with a hollow cathode where the cavity is coated with an electron alloy) and the impulse characteristics obtained using a radioactive source ^{241}Am. Based on the impulse characteristics shown in fig. 6, it can be concluded that the response acceleration obtained by electrode effects engineering gives good results which, however, lag behind the results given by the application of the same engineering in combination with the radioactive α source.

It turns out that it is difficult to optimize the shape of the impulse characteristic by applying different materials. This is due to the fact that the material for the GFSA electrodes should meet three conditions: the low work output, the high thermal conductivity, and the high melting point value. Such a material does not exist among elemental metals, nor among known alloys. However, the application of the electron alloy coated cavity has been shown to give very good re-
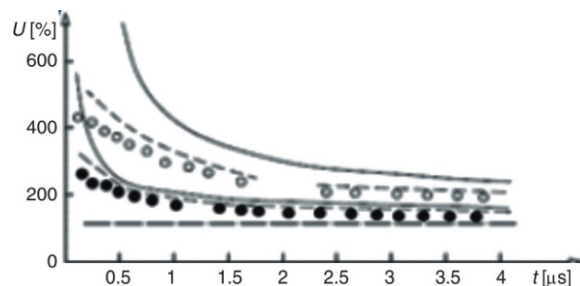

Figure 6. The impulse characteristics obtained by the growth law and the experimental results with an impulse of speed 100 kV(μs)$^{-1}$, *Pd* = 10 mbar mm, − brass electrodes, ○ brass electrodes with cavity coated electron and ● α radioactivity in the chamber

sults. These results are a consequence of the hollow cathode effect which multiplies the number of free electrons and the cold emission effect from the electron alloy which favors this emission with an extremely small value of the output work. In that way, only the good effect of the electron alloy is used, and the bad effects in terms of the value of thermal conductivity and melting point do not come to the fore. Quantitative indicators of the influence of individual parameters of the GFSA insulation system on its response speed, are given in tab. 1. Table 1 shows the mean values of the random variable, obtained for the various impulse voltage velocities, normalized to the mean value of the random variable impulse breakdown voltage, obtained by the impulse rate, increases of $1\,kVs^{-1}$.

According to the data from tab. 1, it can be seen, that by the engineering of the GFSA insulation characteristics, a satisfactory result is achieved at impulse speeds up to $100\,kVs^{-1}$. For higher speeds, the solutions obtained by this engineering do not meet the strict conditions of the overvoltage protection, so, the only possible solution (at today's level of technological possibilities) is to insert an α radioactive source into the chamber. The radiation from this source should be collimated to the cathode surface. With such a solution, results are obtained for the response speed that meets the strictest overvoltage protection conditions.

Figure 7 shows the dependence of the mean value of the first five values of the impulse breakdown voltage, normalized to the mean value of the impulse breakdown voltage (with the constancy of the other parameters of the experiment). Figure 8 shows the mean value of five chronological values of the impulse breakdown voltage, of the normalized mean value, of the impulse breakdown voltage, of their sequence with the time, of deconditioning as a parameter. Table 2 gives an overview of the dependence of the ratio of the first five breakdowns of the impulse voltage, normalized to the mean value on the experimental parameters.

Based on the results obtained experimentally, it can be concluded that deconditioning enters saturation after 10 days and cannot be completely eliminated by the engineering of the electrode system. By far the best results are achieved as a synergistic effect of the best engineering result with the use of a radiation sources collimated to the cathode surface. This is the result of the ability to prevent cathode conditioning (*i. e.*, re-
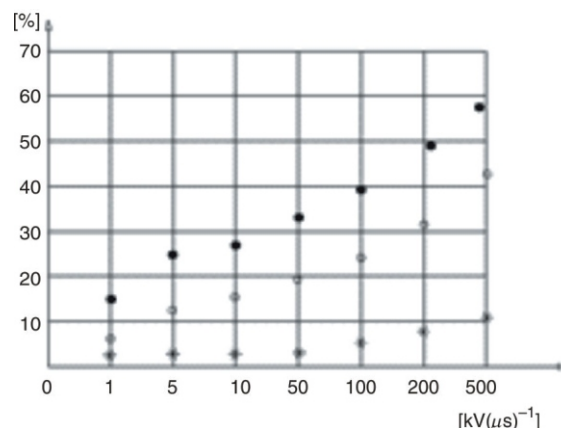

Figure 7. The mean value of the first five breakdowns depending on the impulse rate normalized to the mean value of 50 chronological breakdowns after 10 days of deconditioning, ● brass electrodes, ○ brass electrodes with the electron alloy coated cavity, and * α radioactivity in the chamber
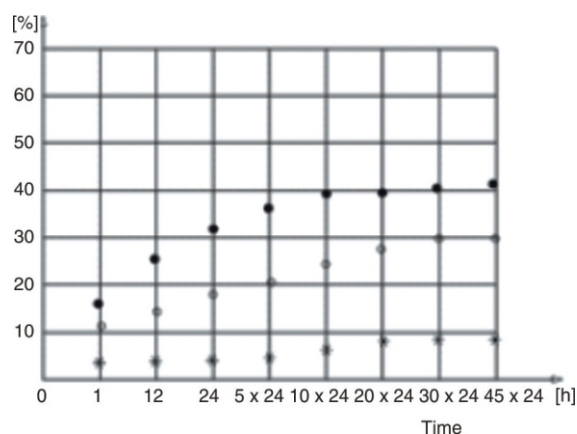

Figure 8. The mean value of the first five values of the impulse breakdown voltages depending on the time of deconditioning, normalized to the mean value of 50 chronological breakdown values, pulse rate 50 kB(µs)$^{-1}$, ● brass electrodes, ○ brass electrodes with the electron alloy coated cavity, and * α radioactivity in the chamber

duction of the electron emission due to gas adsorption, impurity deposition, and cathode corrosion) by maintaining the cathode surface in a dynamic state. This is achieved by the combined effect of a slight oscillation of the electric field on the cathode surface and the ionizing effect of α radiation.

Table 1. The mean values of the random variable obtained for the various impulse voltage velocities, normalized to the mean value of the random variable impulse breakdown voltage, impulse rate 1 kV(µs)$^{-1}$

Electrode type	10 kV(µs)$^{-1}$	50 kV(µs)$^{-1}$	100 kV(µs)$^{-1}$	200 kV(µs)$^{-1}$	500 kV(µs)$^{-1}$
Brass electrode	1, 8	2, 01	2, 85	3, 98	5, 14
Brass + cavity	1, 01	1, 08	1, 1	2, 94	4, 1
Brass hollow electron coated	1	1, 01	1, 03	1, 95	2, 84
Brass + α source	1	1	1, 01	1, 54	2, 14
Brass hollow with electron + α source	1	1	1	1, 1	1, 12

136

T. M. Nedić, *et al*.: Efficient Replacement of the Radioactive Sources in the ...
Nuclear Technology & Radiation Protection: Year 2020, Vol. 35, No. 2, pp. 130-137

Table 2. The dependence of the ratio of the first five breakdowns of the impulse voltage normalized to the mean value on the experimental parameters

Electrode type	1 h	12 h	24 h	5 d	20 d	45 d
Brass electrode	20 %	28 %	35 %	45 %	45 %	45 %
Brass + cavity	20 %	26 %	34 %	45 %	45 %	45 %
Brass hollow coated electron	18 %	24 %	32 %	40 %	40 %	40 %
Brass + α source	0 %	5 %	7 %	10 %	10 %	10 %
Brass hollow with electron + α source	0 %	1 %	3 %	3 %	3 %	3 %

CONCLUSION

The paper presents the results obtained by a parallel study of the effects of the engineering on the GFSA insulation characteristics with and without a radioactive source. Unfortunately, it is shown that radioactive radiation substitution in the GFSA is possible, but only up to some overvoltage impulse rates. For very fast impulses, the characteristics of military applications, and nuclear energy, it is impossible to achieve a satisfactory GFSA response rate and compensation for the long-term GFSA deconditioning. In these cases, the use of the GFSA with a radioactive source is irreplaceable. This means that the GFSA sources with a radioactive source of momentum continue to be produced but only for specific applications. In doing so, they should be specially marked and their user should handle them in accordance with the regulations for handling and disposal of radioactive material. This is necessary because these are relatively small components that contain an α radioactive source and whose entry into the natural environment could lead to its, uncontrolled, contamination.

ACKNOWLEDGEMENT

AUTHORS' CONTRIBUTIONS

The idea of the paper was carried out by T. M. Nedić and A. J. Janićijević and other authors participated in the concept of the instrumental and the measurement uncertainty measurements.

REFRENCES

[1] Standler, R. B., *Protection of Electronic Circuits from Overvoltages*, Dover Publications, New York, 2002
[2] Beyer, M., Boeck, W., *Hochspannungtechnik, Theoretische und Praktische Grundlagen*, Springer-Verlag, Berlin, 1986
[3] Osmokrović, P., *et al*., Investigation of the Optimal Method for Improvement of the Protective Characteristics of Gas-Filled Surge Arresters – With/Without the Built-In Radioactive Sources, *IEEE Transactions on Plasma Science, 30* (2020), 5, pp. 1876-1880
[4] Howard, C., *New Avalanche Diode for Transient Protection, Electronic* Product Design, New York, USA, 1983
[5] Vujišić, M., *et al*., Influence of Working Conditions on Over-Voltage Diode Operation, *Journal of Optoelectronics and Advanced Materials, 9* (2007), 12, pp. 3881-3884
[6] Saranya, A., *et al*., Role of Hexamine in ZnO Morphologies at Different Growth Temperature with Potential Application in Dye Sensitized Solar Cell, *Materials Science in Semiconductor Processing, 92* (2019), Mar., pp. 108-115
[7] Frigura-Iliasa, F. M., *et al*., Case Study About the Energy Absorption Capacity of Metal Oxide Varistors with Thermal Coupling, *Energies, 12* (2019), 3, 536
[8] Stanković, K. D., Perazić, L., Determination of Gas-Filled Surge Arresters Lifetime, *IEEE Transactions on Plasma Science, 47* (2019), 1, pp. 935-943
[9] Osmokrović, P., *et al*., Influence of the Electrode Parameters on Pulse Shape Characteristic of Gas-Filled Surge Arresters at Small Pressure and Inter-Electrode Gap Values, *IEEE Transactions on Plasma Science, 33* (2005), 5, pp. 1729-1735
[10] Metwally, I. A., Heidler, F. H., Reduction of Lightning-Induced Magnetic Fields and Voltages Inside Struck Double-Layer Grid-Like Shields, *IEEE Transactions on Electromagnetic Compatibility, 50* (2008), 4, pp. 905-912
[11] Lončar, B., *et al*., Radioactive Reliability of Gas Filled Surge Arresters, *IEEE Transactions on Nuclear Science, 50* (2003), 5, pp. 1725-1731
[12] Geibig, K. F., *et al*., Use of Fiber-Reinforced Composite Materials in Sparking Gaps, *Zeitschrift fuer Werkstofftechnik/Materials Technology and Testing, 14* (1983), 6, pp. 197-201
[13] Jusić, A., *et al*., Synergy of Radioactive [241]Am and the Effect of Hollow Cathode in Optimizing Gas-Insulated Surge Arresters Characteristics, *Nucl Technol Radiat, 33* (2018), 3, pp. 260-267
[14] Osmokrović, P., *et al*., The Influence of the Electric Field Shape on the Gas Breakdown Under Low Pressure and Small Inter-Electrode Gap Conditions, *IEEE Transactions on Plasma Science, 33* (2005), 5, pp. 1677-1681
[15] Osmokrović, P., *et al*., Mechanism of Electrical Breakdown of Gases for Pressures from 10-9 to 1 bar and Inter-Electrode Gaps from 0.1 to 0.5 mm, *Plasma Sources Science and Technology, 16* (2007), 3, pp. 643-655
[16] Osmokrović, P., Electrical Breakdown of SF6 at Small Values of the Product pd, *IEEE Transactions on Power Delivery, 4* (1989), 4, pp. 2095-2099
[17] Osmokrović, P., *et al*., Determination of Pulse Tolerable Voltage in Gas-Insulated Systems, *Japanese Journal of Applied Physics, 47* (2008), 12, pp. 8928-8934

[18] The Commercial Gas-Filled Surge Arresters, https://www.streamer-electric.com/local/templates/streamer/img/main-protect/9.png

[19] Vereb, L., *et al.*, Effect of Insulation Construction Bending on Stator Winding Failure, *IEEE Transactions on Dielectrics and Electrical Insulation, 14* (2007), 5, pp. 1302-1307

[20] Čaršimamović, A. S., *et al.*, Low Frequency Electric Fieled Radiation Level Around High-Voltage Transmission Lines and Impact of Increased Voltage Values on the Corona Onset Voltage Gradient, *Nucl Technol Radiat, 33* (2018), 2, pp. 201-207

[21] Dolićanin, E, Ć., *et al.*, Monte Carlo Optimization of Redundancy of Nanotechnology Computer Memories in the Conditions of Background Radiation, *Nucl Technol Radiat, 33* (2018), 2, pp. 208-216

[22] Obrenović, M. D., *et al.*, Statistical Review of the Insulation Capacity of the Geiger-Mueller Counter, *Nucl Technol Radiat, 33* (2018), 4, pp. 369-374

[23] Pejović, M. M., Stanković, K., Experimental Investigation of Breakdown Voltage and Electrical Breakdown Time Delay of Commercial Gas Discharge Tubes, *Japanese Journal of Applied Physics, 50* (2011), 8R, 086001

[24] Osmokrović, P., *et al.*, The New Method of Determining Characteristics of Elements for Overvoltage Protection of Low-Voltage System, *IEEE Transactions on Instrumentation and Measurement, 55* (2006), 1, pp. 257-265

[25] Osmokrović, P., *et al.*, The Validity of the General Similarity Law for Electrical Breakdown of Gases, *Plasma Sources Science and Technology, 15* (2006), 4, pp. 703-713

[26] Rajović, Z., *et al.*, Influence of SF6-N2 Gas Mixture Parameters on the Effective Breakdown Temperature of the Free Electron Gas, *IEEE Transactions on Plasma Science, 41* (2013), 12, pp. 3659-3665

[27] Pejović, M. M., *et al.*, Investigation of Post-Discharge Processes in Nitrogen at Low Pressure, *Physics of Plasmas, 19* (2012), 12

[28] Osmokrović, P., *et al.*, Reliability of Three-Electrode Spark Gaps, *Plasma Devices and Operations, 16* (2008), 4, pp. 235-245

[29] Stanković, K., *et al.*, Reliability of Semiconductor and Gas-Filled Diodes for Over Voltage Protection Exposed to Ionizing Radiation, *Nucl Technol Radiat, 24* (2009), 2, pp. 132-137

[30] ***, BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML: Guide to the Expression of Uncertainty in Measurement, Geneva, Switzerland: International Organization for Standardization, 1995

[31] Stanković, K., *et al.*, Free-Electron Gas Spectrum Uniqueness in the Mixture of Noble Gases, *Contributions to Plasma Physics, 56* (2016), 2, pp. 126-133

[32] Dekić, S., *et al.*, Conditions for the Applicability of the Geometrical Similarity Law to Impulse Breakdown in Gases, *IEEE Transactions on Dielectrics and Electrical Insulation, 17* (2010), 4, pp. 1185-1195

[33] Jeftenić, I., *et al.*, Aging of Stator Coil Interconductor Insulation of High Voltage Asynchronous Motor, *IEEE Transactions on Dielectrics and Electrical Insulation, 25* (2018), 1, pp. 352-359

[34] Vereb, L., *et al.*, Effect of Insulation Construction Bending on Stator Winding Failure, *IEEE Transactions on Dielectrics and Electrical Insulation, 14* (2007), 5, pp. 1302-130

**Теодора М. НЕДИЋ, Ацо Ј. ЈАНИЋИЈЕВИЋ,
Ковиљка Ђ. СТАНКОВИЋ, Ненад М. КАРТАЛОВИЋ**

ЕФИКАСНА ЗАМЕНА РАДИОАКТИВНИХ ИЗВОРА ПРИ ИЗРАДИ ГАСНИХ ОДВОДНИКА ПРЕНАПОНА ЗА КООРДИНАЦИЈУ ИЗОЛАЦИЈЕ НА НИСКОНАПОНСКОМ НИВОУ

У раду се разматра могућност класичног инжењеринга брзине одзива и дуговременског декондиционирања гасних одоводника пренапона. Добијени резултати пореде се са истим резултатима добијеним са гасним одводником пренапона уз примену радиоактивног α извора. Рад је експерименталног карактера. Експерименти су вршени на мултинаменском моделу гасног одводника пренапона под добро контролисаним условима. Мерна несигурност експерименталног поступка је била мања од 8 %. Резултати су обрађени софтвером за обраду статистичких података. За цртање импулсних карактеристика коришћен је закон о константности површина испод импулсног напона у волт-секундној равни.

Кључне речи: ѓасни одводник ѝренаѝона, нисконаѝонски ниво, изолациона каракѝерисика