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THE INFLUENCE OF NEUTRON AND GAMMA RADIATION FIELDS ON GAS-FILLED SURGE ARRESTERS

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Abstract: The study examines the effect of neutron and gamma radiation on commercial gas surge arresters. The research is of experimental-theoretical nature. The experimental part of the research was performed un-der well-controlled laboratory conditions. The combined measurement uncertainty was about 5%. The experimental system is specially designed for the observed problem and has certain original solutions. The test procedure was fully automated and had software support in the experiment management and also for data collection and statistical processing. The obtained results show that neutron and gamma ra-diation improves the functional characteristics of gas surge arresters with a memory effect. The obtained results are explained in accordance with the theory of interaction of neutron and gamma fields with ma-terial and with the theory of electric discharge in gases. The results presented in this study are important for the design of surge protection in systems that can be found in the field of neutron and gamma radia-tion because they can achieve a positive synergistic effect of protection in hybrid schemes with other components for surge protection whose characteristics spoil this radiation.

Keywords: gas-filled surge arresters, neutron and gamma radiation, memory effect

INTRODUCTION

Miniaturization of electronic components greatly reduces their resistance to surges. Surge phenomena occur directly as a result of switching processes within the network on which the devices are, or indirectly as a result of the inter-action of the wire structure of the device with electro-magnetic pulses. Possible sources of transient electro-magnetic phenomena are overvoltage pulses on lines, atmospheric discharge, radar pulses and nuclear explo-sion. In case the surge protection of the device is not effi-cient enough, it could cause damage to electronic ele-ments, assemblies and the entire device, leading to its partial or complete destruction. Transient overvoltages can also cause transient disturbances in the functioning of the device [1] - [3].

The effects of destruction are mainly related to semiconductor components, although insulation damage can be caused on other components as well. High-power semiconductor components connected to power lines can be exposed to high transient overvoltages and therefore very endangered. Semiconductor components with low voltage signals and control circuits are indirectly coupled to the power line, but may be destruct due to the relatively small current and voltage range. Due to high frequency compo-nents of transient overvoltage, the destruction of semi-conductor components in the high voltage area can also occur [4] - [10].

From the aspect of consequences, the destruction of electronic components or transient malfunctions are most critical in the case that this electronic component operates in an environment rich in fields of ionizing radiation. This is clear since the danger of ionizing radiation exists in nuclear power plants, nuclear medicine instruments, high-flying aircraft and space systems. For this reason, the aim of this study is to examine the influence of neutron and gamma radiation on the reliability of the gas-filled surge arrester, a component that is indispensable in surge protection at low voltage level [11], [12].

1. GAS-FILLED SURGE ARRESTERS

Gas-filled surge arresters are characterized by high reliability and efficiency, and are used exclusively for surge protection. Gas-filled surge arresters work on the principle of electrical breakdown of gases and can be used for protection against surges of amplitude from several tens to several thousand volts [13].

In terms of energy durability, gas-filled surge arresters are the most durable, and in terms of price, the cheapest elements for surge protection. The advantages of gas-filled surge arresters over other elements for surge protection are the ability to conduct high currents (up to 60 kA) and low self-capacitance (of the order of 1 pF, which makes them suitable for use in high frequencies) [13], [14]. The

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surge arrester consists of two identical electrodes embedded in a ceramic (or glass) housing. The interelectrode distance is of the order of 1 mm. In some cases, a radioactive source is applied to the inner wall of the housing to increase the response rate [14] - [26]. Insulating gas is one of the noble gases or a mixture of noble gases at a pressure of 1 kPa to 100 kPa.

The operation of the gas-filled surge arrester is based on the Townsend gas breakthrough mechanism (Townsend avalanche) [17]-[19]. An important characteristic of the gas surge arrester is the Paschen curve, i.e., dependence of breakdown voltage on the product of pressure and interelectrode distance. The Paschen's curve has the shape of an asymmetric U-curve. The research had been per-formed to adjust the insulation parameters (electrode material, electrode shape, electrode surface treatment, etc.) to fit the Paschen curve to the needs. The tests had also been performed to vary the insulation parameters by increasing the response speed of the gas arrester in order to avoid the use of a radioactive source in the construc-tion of the arrester [20], [21]. The response speed itself is characterized by an impulse characteristic, i.e., voltage-time characteristic. It is shown that the voltage-time curve increases sharply at fast impulse voltages and that is the basic disadvantage of the gas-filled surge arrester, reacts slowly.

2. THE EXPERIMENT

Testing of the influence of ionizing radiation on the characteristics of gas surge arresters was performed on commercial gas surge arresters. A commercial gas arrester with a nominal voltage of 470V filled with Helium gas was tested (pd = 5.75Pamm d= 0.5mm p = 1.15 • 104 Pa mm) [22], [23]. Impulse characteristics were calculated based on the constant area law in the volt second plane below the impulse voltage and constant nominal voltage. Dedi-cated software has been developed for the purpose of calculating impulse characteristics [24], [25].

The high-quality equipment was used for the experiment. In order to eliminate the influence of electromagnetic interference on electronic devices, the test and measuring part of the equipment were separated by a professional measuring cabin for protection against electric fields greater than 100 dB and protection against magnetic fields greater than 40 dB. The connection between the test and measurement part was non-galvanic [26], [27]. The measuring system was fully automated.

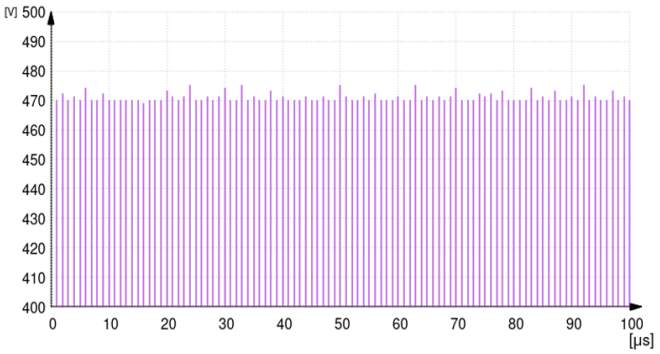
The isotope of Californium 252Cf was used to study the effect of neutron and gamma radiation on the gas circuit. The neutron spectrum of Californium has a maximum at energies of about 0.8 MeV, and the maximum neutron energy is 20 MeV.

Measurement of the influence of neutron and gamma radiation was performed by determining the impulse characteristics and histograms of random variables DC breakdown voltage and impulse breakdown voltage before irradiation, during irradiation and after irradiation. Post-irradiation measurements were performed with time pauses to determine whether there was an induced effect of neutron radiation. To determine one value of DC breakdown voltage, 100 consecutive values of DC breakdown voltage were measured (using a DC voltage source with an increase rate of 8 V/s). To determine one value of the impulse breakdown voltage, 100 consecutive values of the impulse breakdown voltage were measured (using an impulse voltage with an increase rate of 8/20 ms). The break between two consecutive breakthroughs was one minute.

The combined measurement uncertainty of the experimental procedure was about 5% [27], [28].

3. RESULTS AND DISSCUSION

Figure 1 shows the chronological values of the random variable DC breakdown voltage of the gas arrester: a) before placing neutron and gamma radiation in the field; b) during the stay in the field of neutron and gamma radiation (neutron component flux 16.244 • 1011 n/cm^2); c) one thousand seconds after the cessation of the radiation field; d) 100,000 s after cessation of radiation field action.



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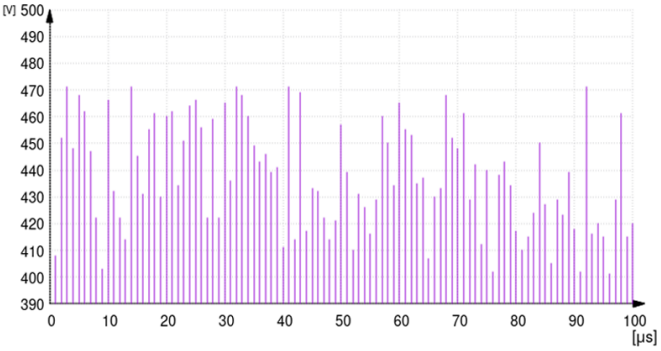

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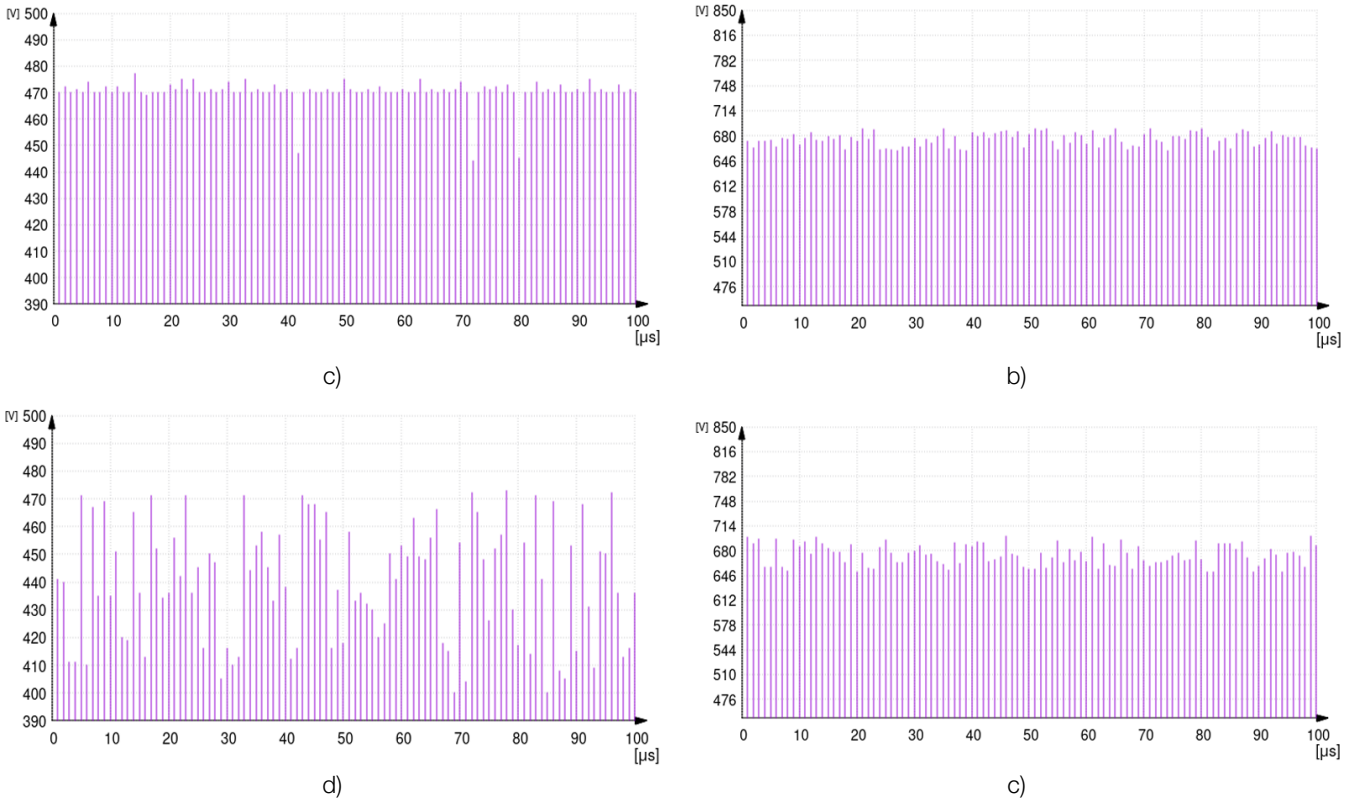
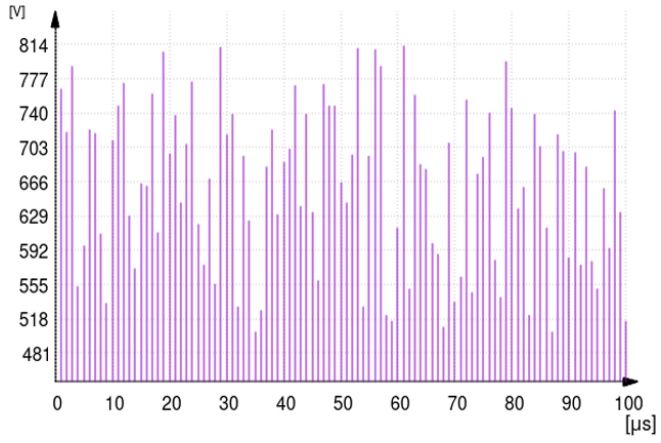


Figure 1: Chronological values of the random variable DC breakdown voltage of the gas arrester: a) before placing neutron and gamma radiation in the field; b) during the stay in the field of neutron and gamma radiation (neutron component flux 16.244 • 1011 n/cm^2); c) one thousand seconds after the cessation of the radiation field; d) 100,000 s after cessation of radiation field action

Figure 2 shows the chronological values of the random variable pulse breakdown voltage of the gas arrester: a) before placing neutron and gamma radiation in the field; b) during the stay in the field of neutron and gamma radiation (neutron component flux 16.244 • 1011 n/cm^2); c) one thousand seconds after the cessation of the radiation field; d) 100,000 s after cessation of radiation field action.



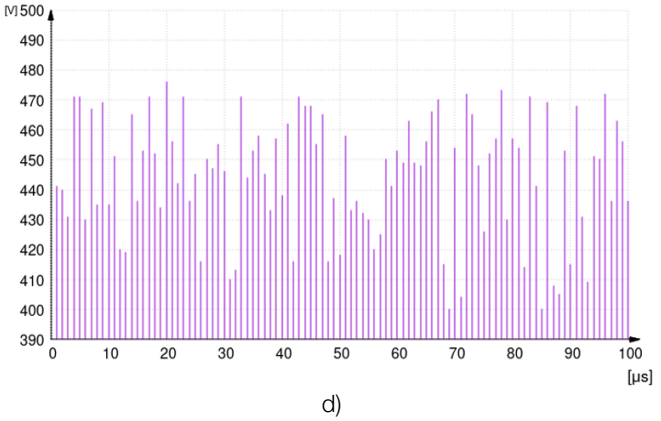


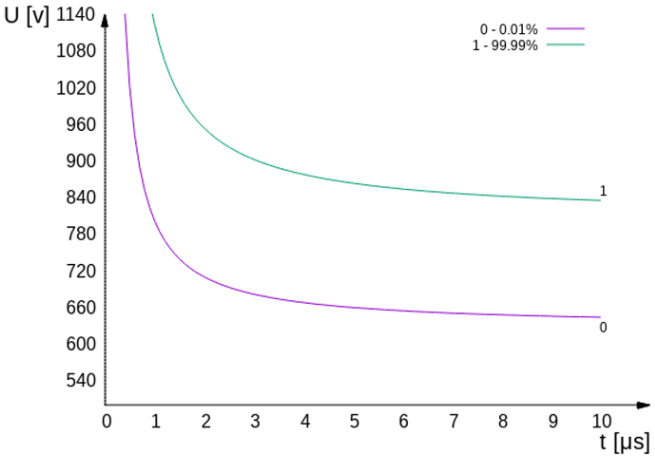
Figure 2: Chronological values of the random variable pulse breakdown voltage of the gas arrester: a) before placing neutron and gamma radiation in the field; b) during the stay in the field of neutron and gamma radiation (neutron component flux 16.244 • 1011 n/cm^2); c) one thousand seconds after the cessation of the radiation field; d) 100,000 s after cessation of radiation field action.

Based on Figures 1 and 2, it can be concluded that neutron and gamma radiation have a different effect on the value of the breakdown voltage of the gas surge arrester. It is obvious from Figure 1a that the value of the DC breakdown voltage is a deterministic quantity (type A measurement uncertainty is zero). By placing the gas surge arrester in the field of neutron and gamma radiation, the value of the DC breakdown voltage became a stochastic quantity (type A measurement uncertainty is greater than zero). This is a consequence of the fluctuation of the number of

free electrons (initial electrons) due to the ionization effects of radiation. Due to the fluctuation of the number of free electrons, the value of the DC breakdown voltage also fluctuates. A thousand seconds after the termination of the effect of neutron and gamma radiation, the fluctuation of the number of free electrons in the interelectrode space of the gas surge arrester continues due to induced radiation from solid materials of the gas surge arrester due to neutron radiation. Also, the induced radioactivity in the material of the gas surge arrester becomes negligibly small and the value of the DC breakdown voltage returns to a constant deterministic value.

The value of the impulse breakdown voltage is a stochastic quantity, Figure 2a. This is a consequence of the fact that the appearance of a free electron at a place where it has the conditions to become an initial electron is a stochastic phenomenon. By placing the gas surge arrester in the field of neutron and gamma radiation, this stochasticity is significantly reduced (or even lost). This is a consequence of the appearance of a large number of free electrons by ionization, which reduces the fluctuation of the appearance of the initial electron. A thousand seconds after switching off the neutron and gamma radiation fields, this phenomenon is still present. It is a consequence of ionization in the interelectrode space due to radioactive radiation of the material of the gas surge arrester activated by electrons. Because short-lived radioactive nucleons were created in this way, 100,000 s after the exclusion of the neutron and gamma radiation fields, the value of the impulse breakdown voltage returns to its stochastic nature, Figure 2d.

Figure 3 shows the impulse characteristics 99.99 % and 0.01% of the gas arrester: a) before placing neutron and gamma radiation in the field; b) during the stay in the field of neutron and gamma radiation (neutron component flux 16.244 • 1011 n/cm^2); c) one thousand seconds after the cessation of the radiation field; d) 100,000 s after cessation of radiation field action.



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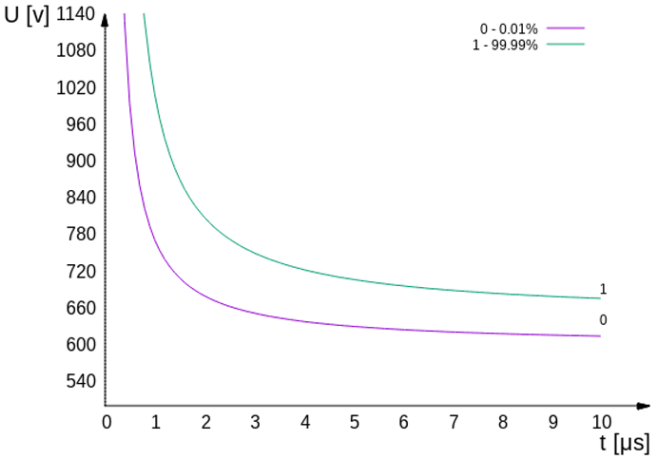

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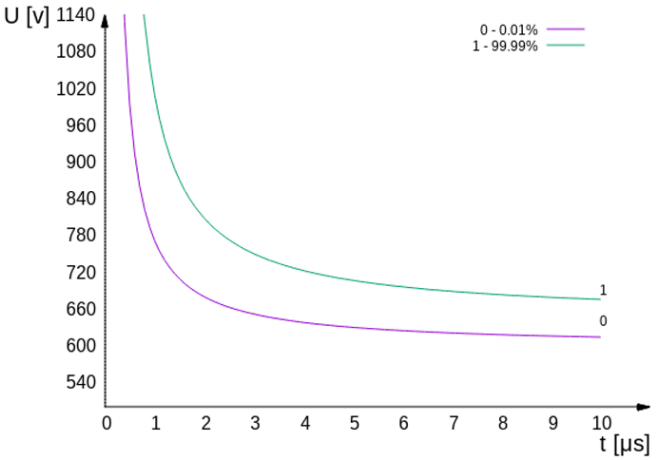

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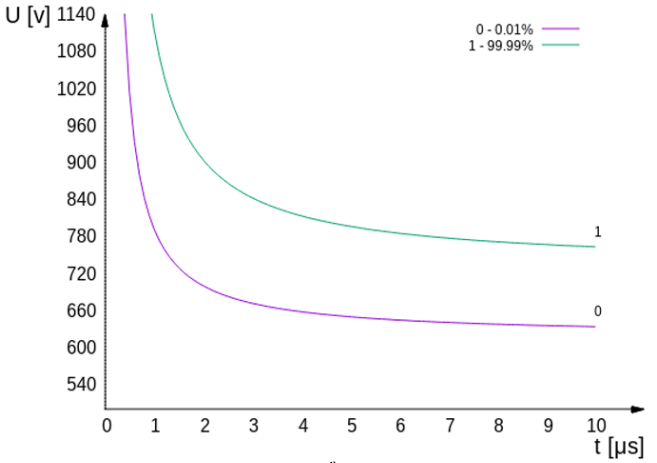

d)

Figure 3: Impulse characteristics 99.99 % and 0.01% of the gas arrester: a) before placing neutron and gamma radiation in the field; b) during the stay in the field of neu-tron and gamma radiation (neutron component flux 16.244 • 1011 n/cm^2); c) one thousand seconds after the cessation of the radiation field; d) 100,000 s after cessa-tion of radiation field action

It is clear from Figure 3 that the action of neutron and gamma radiation lowers and narrows the impulse response. This effect is present when the gas arrester is in the field of radiation and a certain time (a couple of hours) after the radiation stops

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working. After some time, the memory effect is lost. Here it is especially important to note that in Figures 3b and 3c there is a slowdown in the increase of the impulse characteristic in the areas of higher impulse voltage velocities (these are in practice the critical areas of fast induced overvoltages).

The effects observed in Figure 1 - Figure 3 can be explained by the ionization effects of the working gas in the neutron and gamma fields. Since the arrester was isolated with He gas, the neutron component of the applied field moved the nucleus of He (α-particle) by a collision process, which ionized He gas and created ion-electron pairs. The same effect was caused by gamma radiation by the photo-electric effect and Compton scattering. In this way, there is an increase in the number of electrons in the interelectrode space, and each electron found in a homogeneous field can become the initial, i.e., to start the Townsend avalanche process. This is a consequence of the fact that the field is in the interelectrode space (i.e., at each mean length of the electron path, it acquires enough energy to perform ionization). Regarding the memory effect (the established effect of neutron and gamma radiation and after the removal of the radiation field) it is a consequence of the activation of neutron arrester material. This activation has a relatively short half-life. Confirmation of this interpretation are spectrometers (activation analyses) of the gas arrester 1000 s and 100,000 s after the action of radiation, Figure 4.

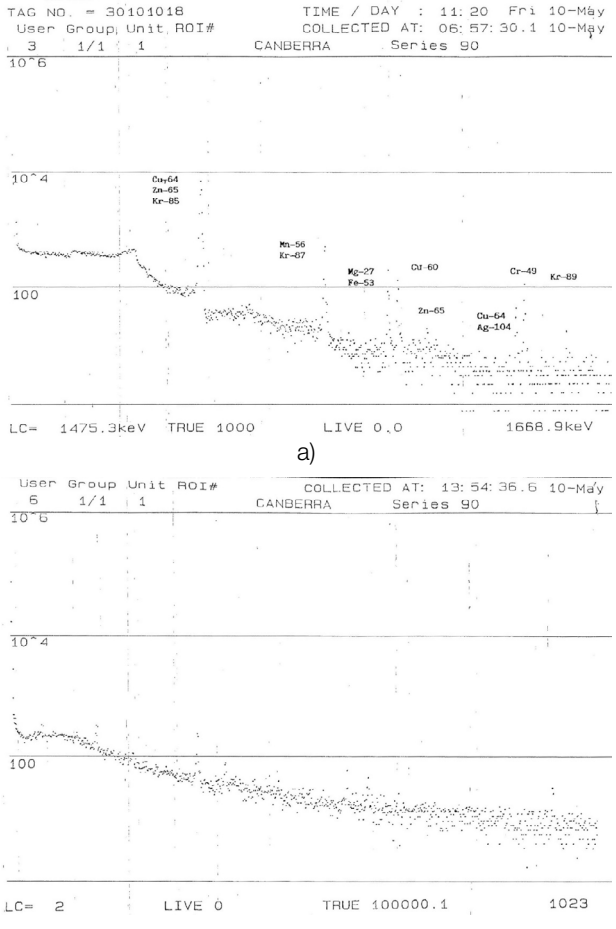

Figure 4: a) Diagram of the activation analysis of gas surge arrester 1000 s after irradiation; b) Diagram of the activation analysis of gas surge arrester 100,000 s after irradiation

4. CONCLUSION

The aim of this work was to examine neutron and gamma radiation for the stability of the characteristics of gas-filled surge arresters. Neutron and gamma radiation were chosen (although neutron radiation does not belong to direct ionizing radiation, it is indirectly ionizing) because these two types of radiation penetrate the body of the gas arrester most easily and act in the interelectrode space. The effect of neutron and gamma radiation is interesting due to the use of gas surge arresters in the control systems of nuclear power plants, since there is a probability of this field of radiation. The obtained results are interesting because they show that the action of neutron and gamma radiation improves the functional characteristics of the gas surge arrester. This improved feature also has a memory effect, i.e., it persists for several hours after the cessation of radiation fields. This result is important for practical applications of overvoltage protection components in hybrid schemes since neutron and gamma radiation reduces the protective properties of arresters and var-istors, which can be compensated by improving the pro-tective properties of gas surge arresters. It should be em-phasized that certain deviations from the nominal voltage can be taken. Severity of these deviations depends on the manufacturer who gives them in the form of permitted tolerance.

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BIOGRAPHY

Alija Jusić was born in 1986 in Travnik, Bosnia and Herzegovina. He graduated from the Faculty of Electrical Engineering, University of Sarajevo in 2010, with a Master's degree in Electrical Engineering. He is currently pursuing his Ph.D. degree at the Faculty of Electrical Engineering, University of Sarajevo, at the Department of Power Engineering. Since 2010 he has been a full-time employee of the Public Enterprise Electric Utility of Bosnia and Herzegovina. He participated in preparation of several studies and projects in the Public Enterprise Electric Utility of Bosnia and Herzegovina in the field of neu-tral point treatment in distribution networks, energy anal-yses and power quality. As an author and co-author, he has published fourteen papers at science conferences.

Uzahir Ramadani was born in Dragas, February 29. 1988. Complete high education in Belgrade and graduated Mechanical Engineering at the University of Belgrade. Completed post-graduate studies and got his M.Sc. at University of Belgrade. Currently is PhD student at the University of Belgrade, Faculty of Mechanical Engineering and working as research collaborator of the University

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Predrag Osmokrović was born in Sarajevo, August 20. 1949. Completed high education in Sarajevo and graduated Electrical Engineering at the University of Belgrade. Completed post-graduate studies and got his M.Sc. and Ph.D. degrees at University of Belgrade. Spent a number of years in Karlsruhe (West Germany) working on various professional projects as a scientific research collaborator of the H.V Institute of the University of Karlsruhe.