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Influence of electrode material on gas-filled surge arresters characteristics in γ and X radiation field

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The aim of this paper is to find the possibility for improvement of gas-filled surge arresters (GFSA) characteristics in γ and X radiation field by appropriate choice of electrode materials. For that purpose electrodes made of different materials were incorporated in the originally developed GFSA model. The obtained results show that both in γ and X radiation fields, copper electrodes are an optimal solution, since they have the highest resistance to radiation effects. It is also shown GFSA are highly resistant to γ radiation, but that X radiation leads to significant degradation of their characteristics.

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1. Introduction

Resistance to the occurrence of over-voltage is significantly reduced through component miniaturization. Therefore, efficient over-voltage protection of electronic devices is of great importance for their proper operation. In the case that it is not efficient enough the effects of over-voltage can cause damage to the electronic component leading to partial or complete destruction [1].

The over-voltage components are divided into linear and non-linear elements. Linear over-voltage protection components include various types of filters made up of capacitors and coils. Non-linear over-voltage protection components include Gas-Filled Surge Arresters (GFSA), Metaloxide Varistors (MOV) and Transient Suppresser Diodes (TSD) [2]. GFSA are made of a ceramic or glass housing, with a symmetric two or three electrode configuration with gas insulation. Noble gases at pressures close to Paschen minimum are most frequently used as insulation gases [3]. The operation of GFSA is based on the principle of electrical breakdown of a gas, which is a consequence of the self-sustained avalanche process that depends on the relative occurrence of electron generation and loss mechanisms [4,5]. The advantages of GFSA compared to the other components for over-voltage protection are [6]: 1) the ability to conduct high currents (up to 5000A), 2) low intrinsic capacity (~1pF), and 3) low costs. The disadvantages of GFSA are: 1) practical irreversibility of characteristics after the electric arc effect, 2) delayed response, and 3) unsuitability with respect to environmental protection (if GFSA have a radioactive filling) [7,8].

2. Experiment

Examination of the GFSA was carried out in a gamma radiation field of ^{60}Co. The average energy of the applied gamma quanta was 1.25 MeV. The absorbed dose rate in air was 96 cGy/h, 960 cGy/h and 1920 cGy/h, respectively. The distance between the radioactive source and the examined over-voltage components was 272 cm, 86 cm and 60 cm, respectively. The following parameters were employed at the Philips MG-320 X-ray generator: high voltage for narrow spectra was 300 kV, average energy 250 keV, electric current 15 mA. The filtration used was in accordance with ISO standards. The energy of X-rays was 45 keV, 115 keV and 250 keV, respectively. The distance between electrodes was 0.5 cm. All testing was carried out at pressures of 4666.27 Pa (35 Torr), and at room temperature of 20 ^{o}C. The electrodes were made either of copper, aluminium, or of electron (aluminium alloy) (Table 1). Such a selection of materials was carried out on the basis of a large range of values of the work function, as well as due to the different values of the melting point and thermal conductivity [9].

Table 1. The electrode material work function, melting points and thermal conductivity.

Material	Copper	Aluminium	Electron
Work function [eV]	4.47	3.70	1.80
Thermal conductivity [J/scmK]	7.1	3.0	1.8
Melting points [K]	1082	641	566

The measuring equipment consists of: 1) gas-vacuum chamber, 2) pressure gage SPEEDIVAC, 3) steel cylinder with Ar gas under pressure, 4) vacuum pump EDWARDS 5, 5) DC high voltage source CANBERRA, 6) AVO meter ISKRA MI 7006, 7) digital multimeter LDM - 852 A, 8) variable resistance MA 2110 and 9) coaxial cables and connectors.

The investigation was based on the following procedure: 1) forming the GFSA model. This includes choosing the appropriate material for the electrodes, placing the electrodes inside the gas-vacuum chamber and adjusting the distance between the electrodes; 2) connecting the formed model (the gas tube) to the gas-vacuum system, using suitable valves, with a vacuum pump on one side and gas supply from a steel gas cylinder on the other, as well as connecting to a pressure gauge; 3) vacuuming the system, which includes establishing a stable pressure using valves leading to the vacuum pump and needle valves for grading the pressure (the pressure needs to be stable. i.e. its value has to be unchanged during the experiment); 4) adjusting the gas chamber on specific dose rate, 5) including the GFSA model into the electric circuit; 6) conditioning the electrode system, i.e. keeping it in discharge state for a while in order to attain stable working conditions, which insures repeatability of measured results, that is the measuring uncertainty; 7) measuring the value of the pre-breakdown current as the applied voltage is gradually increased for a defined dose rate; 8) changing the position of the working point of the GFSA model and going through the measuring procedure again. This includes changing gas-vacuum chamber parameters (electrode material, dose rate). The scheme of test cycle for investigating the GFSA characteristics is shown in Fig. 1.

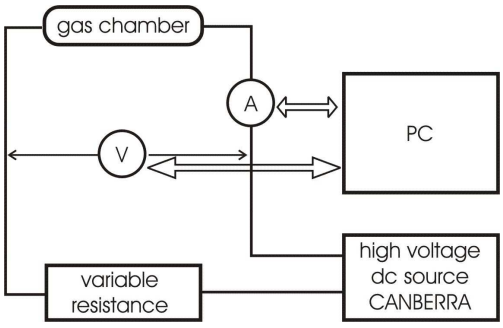

Fig. 1. The scheme of test cycle.

3. Results and discussion

Investigation of the dependence of the pre-breakdown current on the applied voltage, in the absence of radiation and in a gamma radiation field (for electron, aluminum, and copper electrodes) yielded results shown in Figs. 2-4, respectively. In captions shown in these figures current I_1 corresponds to the case when there was no radiation present, current I_2 corresponds to the gamma radiation absorbed dose rate of 0.96 Gy/h, current I_3 to the gamma radiation absorbed dose rate of 9.6 Gy/h, and current I_4 to the gamma radiation absorbed dose rate of 19.2 Gy/h.

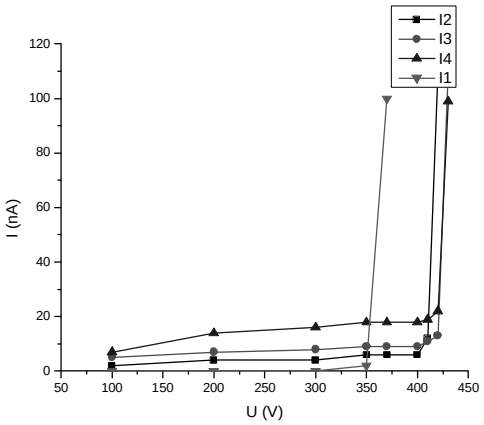

Fig. 2. Pre-breakdown current versus applied voltage in γ radiation field with electron electrodes.

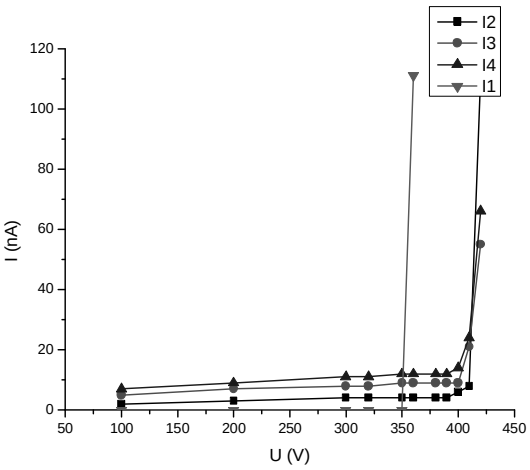

Fig. 3. Pre-breakdown current versus applied voltage in γ radiation field with aluminium electrodes.

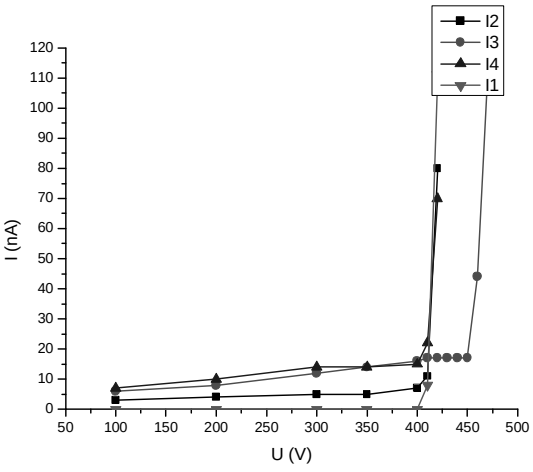

Fig. 4. Pre-breakdown current versus applied voltage in γ radiation field with copper electrodes.

From the obtained graphs it can be concluded that gamma radiation has a strong influence on the pre-breakdown current in GFSA. In the absence of a gamma source pre-breakdown current is constant and independent of the applied voltage up to the value of the breakdown voltage. When ^{60}Co source is present, a steady rise of the pre-breakdown current is noticeable when the applied voltage is increased. For all three electrode materials the rise of the pre-breakdown current is more pronounced the larger the gamma radiation dose rate is. The materials with higher values of work function correspond to larger breakdown voltages [10]. The largest values of breakdown voltage are achieved for copper electrodes (up to 450 V). The smallest impact of ionizing radiation is observed in the material with the highest work function. This fact may be explained by partial screening of the number of radiation produced electron-ion pairs by electrons emitted from the cathode. Since the number of these electrons (cold emission) is larger for an electrode material with a higher work function, the GFSA working point is then also more stable. Also, for all three electrode materials a higher dose rate corresponds to a larger breakdown voltage, i.e. increasing the dose rate also increases the breakdown voltage.

Investigation of the dependence of the pre-breakdown current on the applied voltage in the absence of radiation and in a field of X-rays (for electron, aluminum, and copper electrodes) yielded results shown in Figs. 5-7, respectively. In captions shown in these figures current I_1 corresponds to the case when there was no radiation present, current I_2 corresponds to the X-ray energy of 45 keV, current I_3 to the X-ray energy of 115 keV, and current I_4 to the X-ray energy of 250 keV.

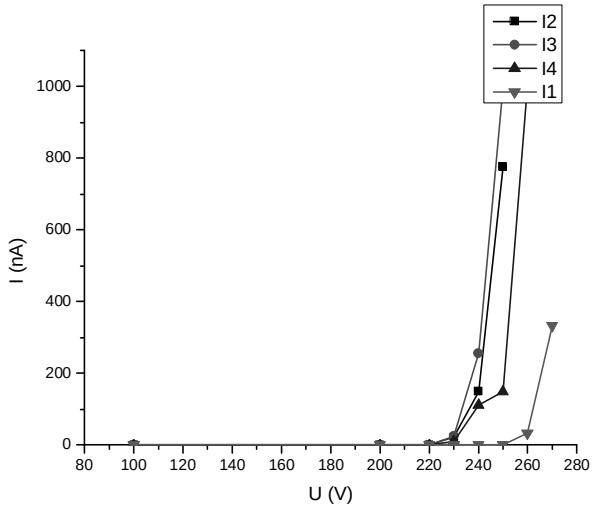

Fig. 5. Pre-breakdown current versus applied voltage in X radiation field with electron electrodes.

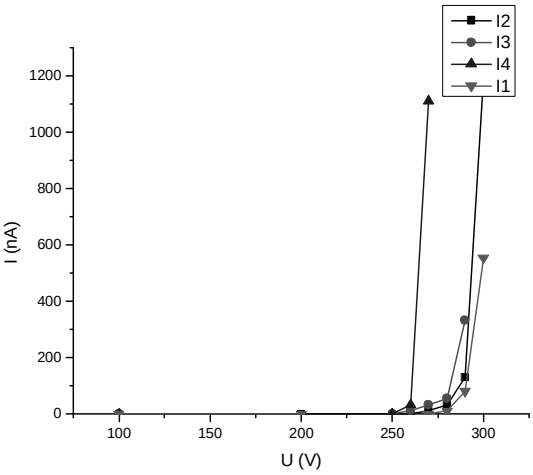

Fig. 6. Pre-breakdown current versus applied voltage in X radiation field with aluminium electrodes.

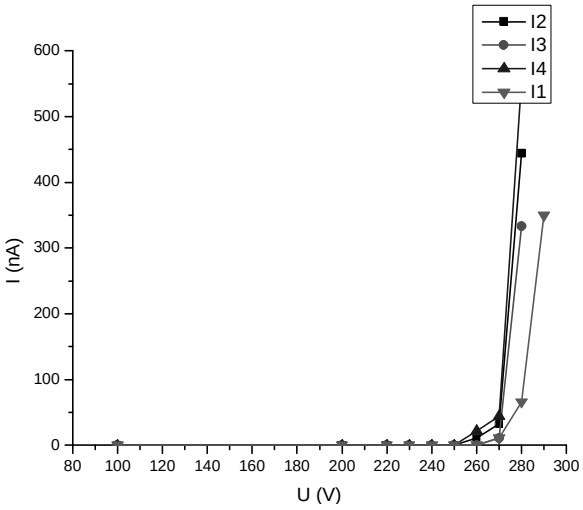

Fig. 7. Pre-breakdown current versus applied voltage in X radiation field with copper electrodes.

The following can be concluded from the obtained results:

1) In the pre-breakdown regime the current is independent of the voltage rise, regardless of the energy of the applied X-rays. Therefore, in the pre-breakdown regime X-rays have practically no effect on the gas-filled surge arresters characteristics.
2) In all cases breakdown occurs at lower values of voltage than when the GFSA is in a gamma radiation field.
3) Copper electrodes are the most resistant to X-ray exposure.

The electrode material with higher values of work function, thermal conductivity and melting point possesses the most stable characteristics (working point) during the exploitation (small changes of electrode topography). The effect of the rapid current increase at the moment of breakdown could be explained by the increase of the

ionization effective cross-section for atoms of the gas, with the increase of the applied radiation energy. The increased number of electron-ion pairs in the area between electrodes leads to the increase of the pre-breakdown current (equal to the total charge of free electrons and ions reaching electrodes per unit of time). In the moment of breakdown, one of the free electrons generated in this way initiate an avalanche process generating a breakdown current, the magnitude of which is independent of the pre-breakdown current. Ohm's law is not valid in this region, since the observed two-electrode system is in saturation. In this case all the electron-ion pairs generated per unit of time reach the electrodes.

Effective cross-section for the ionization of the gas is not a linear function of the applied radiation. During X-ray irradiation resonant increase of the effective cross-section for ionization is apparent for the radiation values corresponding to the limits of the continual atomic spectrum of the gas, in the GFSA. Accordingly, lower values of the X-ray energy correspond to higher values of the pre-breakdown current.

The obtained results, regarding the larger influence of X-ray irradiation (compared to γ radiation) on the pre-breakdown current increase, could be explained by the fact that X-rays have a higher ionization probability during interaction with the atoms of the gas. Namely, the larger wavelength, i.e. the lower energy of X-rays leads to the interaction of X-rays with gas atoms as a whole, resulting in excitation or ionization of the atoms. On the other hand, the smaller wavelength, i.e. the higher energy of γ-rays produces an interaction with a single electron in the atom, resulting in the lower effective cross-section for ionization in case of the applied γ irradiation (Compton effect, photoionization) [11].

4. Conclusion

This paper presents the influence of electrode materials on GFSA's characteristics in γ and X radiation fields. The obtained results show that the electrode materials influence the GFSA's characteristics through the values of work function, melting points and thermal conductivity. Based on the obtained results it can be concluded that in the DC mode the GFSA model with copper electrodes is the most suitable one, since copper electrodes are the most resistant to X- and γ-ray exposure. These results could be explained by the highest values of the work function, the melting point and thermal conductivity of copper, compared to the other two materials used. Since breakdown occurs at lower values of voltage in case of X-ray irradiation than when a gamma radiation field is applied, it can be concluded that GFSA are more resistant to gamma than to X-ray exposure.

Acknowledgement

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