# Electrical Characterization of Commercial Gas-Filled Surge-Arresters With Build-in Radioactive Source aimed at reducing delay response

Milić Pejović

*Abstract*— **The paper presents experimental results of mean value of electrical breakdown time delay as a function of relaxation time and applied voltage for gas-filled surge arresters (GFSAs) of the Company SIEMENS. Components with a DC-spark over-voltage 230 V with a 20% tolerance were used. Based on the obtained data, the values of delay response of these components were estimated. Analysis showed that there is an increase in delay response for relaxation time interval from 1 µs to 1 ms and then retains an approximately constant value. It has also been shown that delay response decreases with increasing voltage at GFSA and that this change is more significant for voltage close to DC-spark over-voltage. In addition, paper present the analysis of processes in insulating gas responsible for delay response of these components.**

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***Index Terms*—Delay response, Electrical breakdown, Electrical breakdown time delay.**

## I. Introduction

GFSAs are nonlinear components and are most commonly used for protection from over-voltage transient in telecommunication (where over-voltage transient may arise from different source including lighting) as well as in high voltage engineering (where switching over-voltage transient is a consequence of energy redirection with power system) [1,2]. GFSAs are connected in parallel connection with electronic components wherein one electrode is grounded. Operating principle of GFSA is based on electrical breakdown in the insulating gas, i.e., when the gas changes from a state of high electrical resistance (order MΩ) to a state a good conductivity (order kΩ) when self-sustaining discharge occur [3]. The voltage for which a breakdown occurs is called the breakdown voltage and can be static or dynamic [4].

One of the unwanted effect which occurs when using GFSAs in over-voltage protection is delay response and it is a consequence of electrical breakdown delay in insulating gas even for the voltages higher than the breakdown voltage. The time that elapses from the voltage connection to the breakdown is called electrical breakdown time delay $t_d$ and represents the sum of statistical time delay $t_s$ (the time that elapses from the application of voltage higher than static breakdown voltage to the GFSA to appearance of electron in inter electrode gap that will initiate the breakdown) and formative time $t_f$ (the time that elapses from the appearance of this initial electron to the formation of an avalanche resulting in breakdown) [5]. It has been shown that the delay response of GFSAa can be monitored very efficiently based on the experimental data of electrical breakdown time delay [3,4]. In this paper, the delay response analysis was performed on the basis of experimental data of mean value of electrical breakdown time delay in the function of relaxation time in insulating gas τ and applied voltage $U_W$ on GFSAs. τ represents the time interval between two successive voltage pulse application on the GFSA electrodes, i.e., the time when there is no voltage on the GFSA [2].

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## II. Experimental details

The experimental samples used in this paper are commercial GFSAs made by SIEMENS 230 98 O where cross section is shown in Fig. 1. The components contain a low-activity radioactive source locate inside the housing that provides a constant number of electrons per unit time (electron yield) in inter-electrode space. The electrodes were profiled to provide in inter-electrode space $d$ a homogeneous electric field. The insulating gas type and pressure were unknown, but GFSAs are must often filled with noble gases or their mixtures at low pressure. DC-spark over-voltage of these components reported by manufacturer is 230 V with ±20% tolerance and this values was obtained for voltage increase rate of 100 V/s and is adopted as a deterministic quantity. The impulse spark over-voltage, which is statistical quantity, reported by manufacturer, is < 750 V and this value was obtained for voltage increase rate of 1 kV/µs.

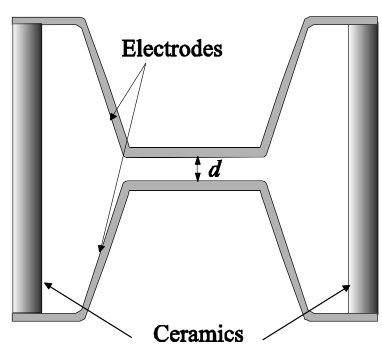


Fig. 1 GSFA cross section

$t_d$ was performed by a system for automatic measurement and data acquisition which block diagram is shown in Fig. 2. Among to a high DC voltage source, the system contain an analog and digital subsystem. The analog

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subsystem provides fast high voltage switching on GFSA and forming a suitable impulse for START and STOP. Voltage rise time during the connection the voltage of the GFSA is about 20 ns (for example impulse voltage rise time causing by atmospheric discharge is of the other of milliseconds [6]). Digital subsystem detects signals generated by the analog subsystem and detects the time between their appearances. This detection is performed using MICROCHIP PIS18F2550 microcontroller. Subsystem also controls the important parameters on which $t_d$ depends. These are the relaxation time and duration of self-sustaining discharge after the breakdown. The system allows to measurement of electrical breakdown time delay for an interval relaxation time from 1 μs to several hours. The $t_d$ data are stored in memory.

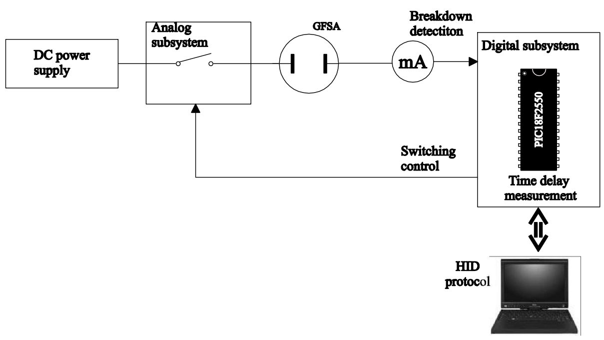


Fig. 2. Block diagram of the system for the electrical breakdown time delay measurement

## III. Results and Discussion

In order obtain the final value $t_d$ it is necessary that the applied voltage at GFSA is greater than the breakdown voltage. If $t_d$ measured at the same parameters, due to the stochastic character of this quantity, different values are obtained which are subjected to a certain distribution. In this paper the distribution 1000 $t_d$ data is consider for applied voltage $U_W$ which is 2% greater than DC-spark over-voltage and relaxation time τ=30 ms. In Fig. 3 shows the histograms of the normalized relative frequency of these data (rectangles) and the Weibull density distribution function (solid line) with the fitting of this data was performed). The Weibull density distribution function is given by the following expression [7]:

$$f(U_b) = \frac{\beta}{\eta}\left(\frac{U_b-\delta}{\eta}\right)^{\beta-1} exp\left(-\frac{U_b-\delta}{\eta}\right)^{\beta}, \qquad (1)$$

where β is the slope parameter (Weibull slope), η is the scaling parameter and δ is the location parameter. It can be observed that the experimental results are very well fitted by this distribution.

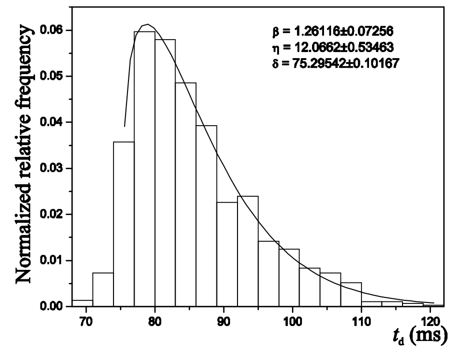


Fig. 3. Histogram of normalized relative frequency and Weibull density distribution function of 1000 $t_d$ data. The data was obtained for applied voltage $U_W$ which 2% higher than DC-spark over-voltage.

During breakdown and subsequent discharge in insulating gas certain concentrations of positive ions and electrically neutral particles are formed which recombination/de-excitation time has a final value after voltages turned off. When the voltage is reconnected, while the positive ions are present in the gas, they gain sufficient kinetic energy to release secondary electron from the cathode that will initiate breakdown. Also some electrically neutral particles have enough energy to collide with the cathode during diffusion and release secondary electrons. The presence of these particles in the insulating gas can be very efficiently monitored by the method of the time delay which is based on the analysis of $\bar{t}_d = f(\tau)$, where $\bar{t}_d$ is mean value of electric breakdown time delay [8,9]. This dependence is known as the memory curve [10]. The use of the value $\bar{t}_d$ in this method is due to the fact that $t_d$ is a quantity of statistical character. Monitoring the presence of these particles for different $\tau$ value is important in order to determine the time their complete recombination/de-excitation occurs in the insulating gas. Their presence in insulating gas significantly reduced the reliability of GFSAs in over-voltage protection.

The memory curve obtained for applied voltage $U_W$ which 2% higher than DC-spark over-voltage is shown in Fig. 4. In this figure $\bar{t}_d$ represents the mean value of 100 data $t_d$ for each value of $\tau$. The same figure show the standard deviation $\sigma$ of these data as a function of $\tau$. It can be noticed that in the interval $\tau$ from 1 $\mu$s to 1 ms the value of $\bar{t}_d$ increases for about an order of magnitude, while for large values of $\tau$, $\bar{t}_d \approx const$. In the whole considered interval $\tau$, the standard deviation changes slightly and is an order of magnitude smaller than $\bar{t}_d$. The increase in $\bar{t}_d$ to $\tau$=1 ms is primarily due to the presence of positive ions since the time of their recombination after switching off the voltage at GFSA is 1 ms [10]. Influence of electrically neutral particles on time delay, whose deexcitation time is 1 ms, can be neglected with respect to positive ions.

For $\tau$>1 ms, the concentration of positive ions is very small, so that the dominant role in initiating the breakdown is played by electrons formed by the interaction of ionizing radiation which originates from a low activity radioactive source located in GFSA housing. The electron

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yield (the number of electrons in the inter electrode space per time unit), which originates from the ionizing radiation emitted by the GFSA housing, exist in the case when positive ions are present, but it is significantly smaller than the electron yield formed by positive ions. The electron yield caused by this radiation is approximately constant, which is manifested by an approximately constant value of $\bar{t}_d$. Based on these data it can be concluded that the reliability of these components in surge protection when the time between two pules is greater than 1 ms.

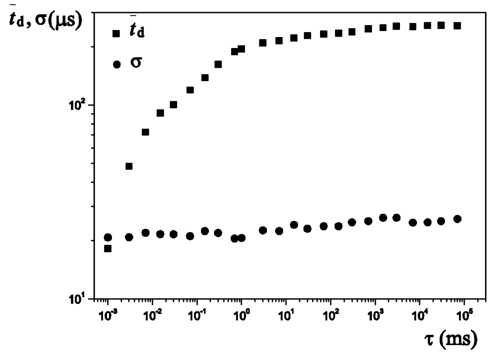


Fig. 4. Mean value of electrical breakdown time delay $\bar{t}_d$ as a function of relaxation time $\tau$ (memory curve) and standard deviation $\sigma$ for applied voltage $U_W$ which 2% higher than DC-spark over-voltage.

From Fig. 4 it can be seen that $\bar{t}_d >> \sigma$. It is known that the mean value of statistical time delay $\bar{t}_s = \sigma$ [11] and $t_d = t_s + t_f$ [5]. From this analysis it can be concluded that $\bar{t}_d \approx t_f$, i.e., that delay response depends exclusively on formative time in insulating gas.

The influence of the applied voltage on memory curve of GFSAs is shown in Fig 5. Namely, the memory curves were recorded for the values of $U_W$ which were 2% and 25% higher than the DC-spark over-voltage. It can be noticed that the shape of the memory curves is very similar and that the curve obtained for $U_W$ 2% higher than DC-spark over-voltage is shifted towards higher values of $\bar{t}_d$ in relation to the memory curve for $U_W$ 25% higher than DC-spark over-voltage. This is in accordance with our earlier conclusion [9] that the breakdown probability for the same electron yield (the same value of $\tau$) in inter-electrode space decreases with decreasing applied voltage which is manifested by an increase in the value of $\bar{t}_d$.

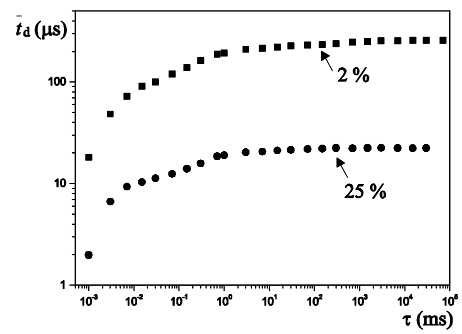


Fig. 5. Mean value of electrical breakdown time delay $\bar{t}_d$ as a function of relaxation time $\tau$ (memory curves) for applied voltage $U_W$ values which 2% and 5% higher than DC-spark over-voltage.

In order to analyze the influence of applied voltage on delay response of GFSAs, mean value of electrical breakdown time delay $\bar{t}_d$ were performed as a function of applied voltage $U_W$. These dependencies for values of relaxation time $\tau = 30$ $\mu$s and $\tau = 30$ ms are shown in Fig. 6. In these figures $\bar{t}_d$ represents the mean value of 100 $t_d$ data for each value of $U_W$. As can be seen from these figures, the values of $\bar{t}_d$ decreases with increasing in value of $U_W$ and this change is greater for values of $U_W$ that are closer to DC-spark over-voltage. This behavior is due to the fact that with increasing voltage, increases the probability of electrical breakdown in insulating gas of these components, which is manifested by a decrease in the value of $\bar{t}_d$. Since the delay response in GFSAs is due to the delay of the electrical breakdown, it can also be concluded that the delay response of these components decreases with increasing applied voltage. From this figure it can also be observed that the values of $\bar{t}_d$ are smaller for $\tau = 30$ $\mu$m than for $\tau = 30$ ms. This behavior is due to different concentration of positive ions in the insulating gas after the voltage is turned off. Namely, due to the recombination process, the concentration of positive ions in insulating gas of GFSAs is significant for $\tau = 30$ $\mu$m while for $\tau = 30$ ms it is practically equal zero. When positive ions are present in insulating gas the probability that they will hit the cathode and release secondary electrons when the voltage is reconnected to GFSA, which is manifested by a decrease in the value of $\bar{t}_d$ in relation to the case when they are not present.

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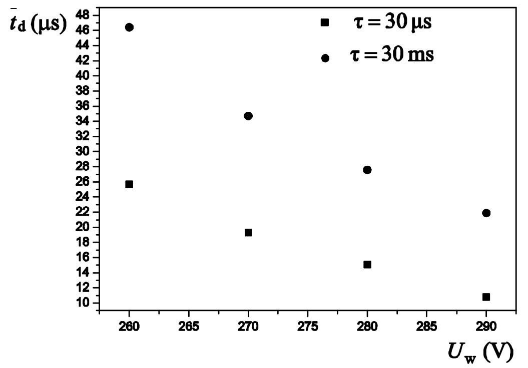


Fig. 6. Mean value of electrical breakdown time delay $\bar{t}_d$ as a function of applied voltage $U_W$. The data for $t_d$ was obtained for two values of relaxation time $\tau$.

## IV. Conclusion

For the reliable function of GFSAs in protection from over-voltage transient it is necessary among parameters, to perform a good assessment of delay response. Delay response is due to inertia of the insulating gas on the electrical breakdown even the over-voltage transient is significant greater than DC-spark over-voltage. Delay response is a value of statistical character and its value can be estimated on the basis of experimental data mean value of electrical breakdown time delay which was the subject if this paper. It has been shown that the delay response depends on the relaxation time when positive ions formed by the previous breakdown in the insulating gas are present. For relaxation time greater than 1 ms delay response has a constant value determined by the electron yield originating from a radioactive source built into the housing of these components The applied voltage also significantly affected the value of delay response so that its decreases with increasing voltage. Such behavior of delay response is a consequence of increasing the probability of breakdown in insulating gas with increasing voltage on GFSAs.


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