Studying the Voltage Increase Rates Using Discrete Dynamic Method

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ABSTRACT: *In this work we have given the data to study the voltage increase rates using discrete dynamic method. This is used for studying the gas-filled surge arresters. The data that we have drawn is projecting the consistency which is shown in a perfect graph. In the intersection of the line fit we saw the breakdown of the voltage data which is presented in the datasheet available. We also noticed that the response time of the GFSA by the siemens is not depending on any parameters and the electrical breakdown values show a relaxation time. The response time shows increase with the relaxation time and it is the consequence of the positive ions concentration. During the breakdown we found the formation of neutral active particles where the response time decrease with the increase of applied voltage. We noticed that the value change depends on the relaxation time in the case of GFSA and it is not applied to the other GFSA.*

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1. Introduction

The gas-filled surge arresters (GFSA) are non-linear elements used in overvoltage protection. They are known in literature as surge voltage protectors (SVP) or gas discharge tubes (GDT). The main advantages of GFSA, in comparison to other protection components (suppressers diodes and metal oxide varistors), are: the ability to conduct high currents (>5 kA), low intrinsic capacity (<1 pF), high insulating resistance ($> 1G\,\Omega$) and low resistance in conducting regime ($\sim 0.1\,\Omega$) [1-4]. These components are used in overvoltage protection in the range of 70-1200 V. GFSA are mostly used in protective circuits in telecommunications (where overvoltage may arise from different sources including lightning), as well as in high voltage engineering (where switching overvoltage may arise as a consequence of energy redirection within power systems). The main problems in GFSA application are response delay [5], cut off delay when voltage is disconnected and the existence of flow-up current in impulse regime, which is a consequence of GFSA activation by impulse voltage and the ±20% deviation of GFSA activation voltage from nominal values reported in datasheet.

GFSA operation principle is based on electrical breakdown in insulating gases. The voltage at which electrical breakdown occurs is called the electrical breakdown voltage and it is defined as the voltage when discharge in the gas transits from non self-sustaining to self-sustaining mode [6], which is characterized by rapid transition of gas from a poor electrical conductor with a resistance of about 10^{14} Ωm^{-1} to a relatively good conductor [7].

The electrical breakdown in insulating gases can be static or dynamic depending on the type of applied voltage. Static direct current (DC) breakdown occurs when the rate of change of the applied voltage is lower than the rate of change of elementary processes related to electrical breakdown. If these two rates are comparable, the breakdown is dynamic. The static breakdown voltage U_s is a deterministic quantity, whereas the dynamic voltage U_b is a stochastic quantity with a certain distribution [8]. The U_s can not be precisely determined, but only estimated [9].

One thing common for all gas-filled devices, including the GFSA, is the delay of electrical breakdown, which is present even when applied voltage is higher than breakdown voltage. The time which passes between the moment of application of voltage higher than breakdown voltage and the moment when GFSA current starts to flow is called the time delay of electrical breakdown t_d. Response delay of GFSA is a consequence of electrical breakdown time delay, which consists of the statistical time delay t_s and formative time t_f, i.e. $t_d = t_s + t_f$ [7]. t_s is the time which passes from the moment of voltage application on GFSA until the appearance of an electron which leads to breakdown. During this period a small current flows through the tube (10^{-19}-10^{-8} A) but its fluctuations are of the same order as the current itself. The formative time t_f is the time taken from the end of the statistical time to the onset of breakdown, characterized by the collapse of the applied voltage and a self-maintained glow [7]. t_d is dependent on various parameters, but one of the most significant ones is the relaxation time τ, i.e. the time interval between two successive measurements when there is no voltage on the GFSA [10]. Based on functional dependence $\bar{t_d} = f(\tau)$ (memory curve), the presence of active particles responsible for the initiation of subsequent breakdown can be monitored, i.e. the memory effect in gas, which is responsible for time delay of GFSA, can be tracked.

2. Experiment

The measurements of time delay of electrical breakdown were conducted with commercial GFSA made by SIEMENS and CITEL. These components have two flat electrodes which are sealed in ceramic housing. The cross section of these components is presented in Figure 1. The manufacturers haven't disclosed the data of insulating gas type and pressure, although noble gases are most frequently used as an insulating medium. SIEMENS made GFSA have a small radioactive source built in the casing which supplies a constant electron yield (the number of generated electrons in the inter-electrode space per time unit) in order to decrease the response time. Static breakdown voltage (DC spark-over voltage) of these components reported by manufacturers is 230 V with ±20% tolerance and this was obtained for voltage increase rates of 100 V/s. On the other hand, the dynamic breakdown voltage (impulse spark-over voltage) is less than 750 V and this value was obtained for voltage increase rate of 1 kV/µs.

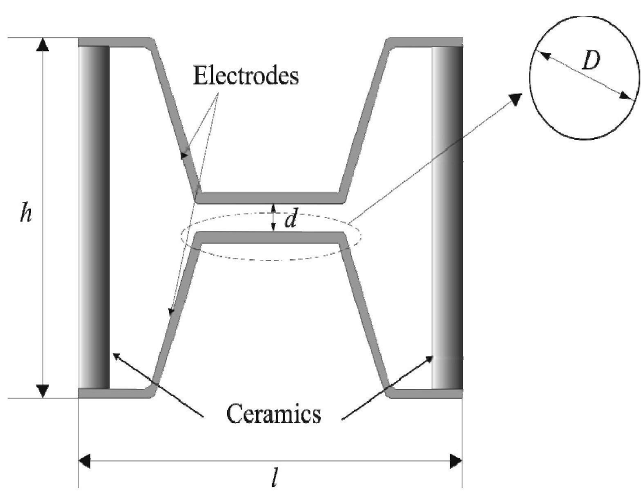

Figure 1. GFSA cross section

The breakdown voltage was measured using the discretized dynamic method, i.e. method of DC voltage increase in step U_p for defined duration of the step tp until breakdown. Voltage source for this system is a serial connection of two Keithley models 248 and 2400. The control of these two voltage sources is performed by personal computer PC via IEEE standard interface bus. PC sends the starting voltage value U_p, which is considerably lower than expected breakdown voltage value, and this voltage is applied to the tube over Keithley model 248. Starting voltage level is increased for the value U_p every predefined time interval tp.. The duration of time step tp is controlled by counter timer model ED2300-CT, which is a part of acquisition card ED2001. In order to provide the accurate breakdown detection, the current flow through device under test is monitored with A/D module of ED2001. Namely, Keithley model 248 has the output which gives the voltage value in the range from 0 to 10 V, which corresponds to the current in the range 0 to 5.25 mA. After breakdown it is necessary to maintain stable glow discharge in the tube. This is achieved by application of constant value Uc for a predefined time interval. After discharge GFSA is disconnected from power supply for the duration of the afterglow period, which is also controlled by ED2300-CT counter/timer module (see [11] for more details).

Measurements of electrical breakdown time delay td were performed with the system which consists of DC power supply, analog and digital subsystem. Analog subsystem should provide accurate and fast voltage switching on the GFSA. For this purpose we have used IRG4PH40KD bipolar transistor with isolated gate. The switching is controlled by command signals from digital subsystem over TC429 MOSFET driver circuit. Such system configuration provides satisfactory results regarding the accuracy, reliability and performance for time delay measurements. Roughly, the digital subsystem main function is to give measurement start signal, which controls the switching transistors and applies the voltage on the tube. The voltage pulse on the tube is shaped by the analog subsystem in the form suitable for detection by digital subsystem. Upon its detection time delay measurement is finished. The main part of digital subsystem is the microcontroller. The signals for the beginning and the end of time delay are detected on digital impulse pins, while the time interval between them is measured using standard timer interrupt routines with the use of 16-bit timer module. In order to perform accurate measurement CCP (capture/compare/PWM) module of the microcontroller is incorporated in the whole procedure (see [12] for more details).

3. Results and Discussion

The dependencies of the mean values of breakdown voltage $\overline{U_b}$ on the voltage increase rate $k = U_p / t_p$ for SIEMENS and CITEL GFSA are displayed in Figure 2. $\overline{U_b}$ was established from a series of 100 measurements of U_b data for each value of k. U_p values were varied from 0.1 to 1 V, while t_p was 0.1 s, which corresponded to voltage increase rates from 1 to 10 V/s. It can be seen that U_b increases for less than 1 V as k increases and that experimental results are fitted well by a straight line. The values of static breakdown voltage obtained at the intersection of the fitted lines and $\overline{U_b}$ axis for SIEMENS and CITEL GFSA are 250 and 245 V, respectively. These values are in good agreement with nominal values of $230\ \text{V} \pm 20\%$ given by manufacturers.

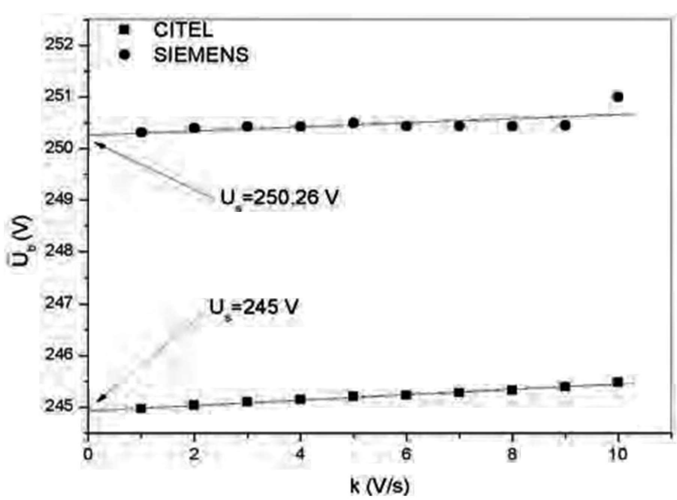

Figure 2. Mean value of breakdown voltage $\overline{U_b}$ as a function of voltage increase rate k for SIEMENS and CITEL GFSA

The dependencies of the mean value of time delay of electrical breakdown $\bar{t}_d$ on the relaxation time τ (memory curve) for SIEMENS and CITEL GFSA are shown in Figure 3. $\overline{t_d}$ is the mean value of a 100 td data obtained for each value of τ. t_d data has been obtained when voltage impulses were 300 V. As can be seen from Figure 3, for SIEMENS made GFSA $\bar{t}_d$ has approximately constant value of about 60 µs for all values of relaxation time. This shows that processes which occur in gas in SIEMENS made GFSA during discharge have no influence on the following breakdown since breakdown initiation is conditioned by electron yield caused by radioactive source. Based on the behavior of the memory curve of the SIEMENS made GFSA it can be concluded that response time of these components is entirely determined by the time needed for avalanche formation, which is in this case, 60 µs .

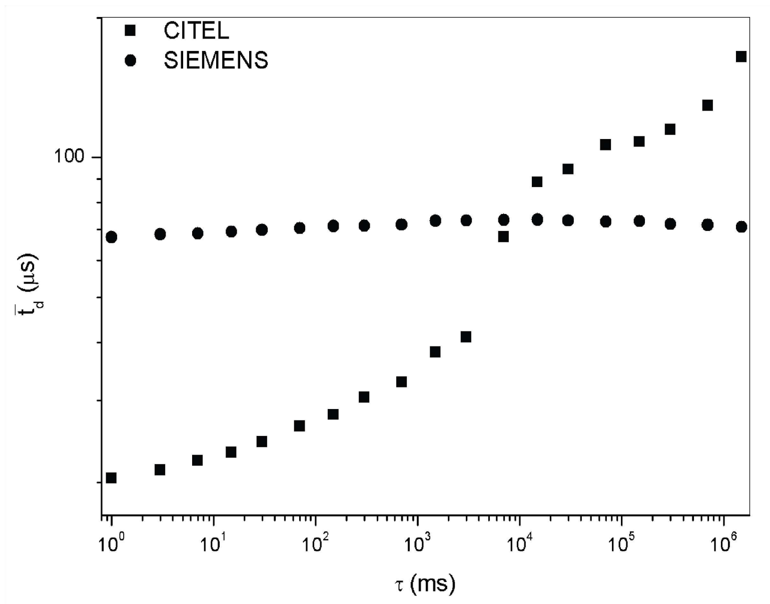

Figure 3. Mean value of electrical breakdown time delay $\bar{t}_d$ as a function of relaxation time τ for SIEMENS and CITEL GFSA

The shape of the memory curve of CITEL made GFSA is more complex than SIEMENS's which is a consequence of the change of electron yield with the increase in τ. Namely, the electron yield in CITEL GFSA originates from electrons released from electrodes by ions and neutral active particles formed during and after breakdown. Recombination/deexcitation time of these particles differs and insulator gas "remembers" that breakdown has occurred in it. This shows that response time of CITEL made GFSA depends on the type of particles which have a dominant influence on electron yield in the inter-electrode gap. Since in the region $1ms < \tau < 1000$ ms $\bar{t}_d$ increases from 20 to 40 µs it can be concluded that electron yield originates from positive ions formed during and after breakdown (the mechanisms of positive ions formation and their contribution to electron yield is described in details in [13]). For $\tau > 1000$ *ms* electron yield originates from neutral active particles formed during breakdown and the mechanisms of their creation are also described in [13]. The probability of secondary electron release from the cathode by neutral active particles impact is much lower than probability of release by ions, which is manifested by the increase in $\bar{t}_d$ (increase of response time of GFSA). The concentration of neutral active particles decreases with the increase of τ due to their de-excitation on the housing walls and electrodes, which leads to decrease of the electron yield and increase in $\bar{t}_d$. As can be seen in Figure 3, the memory effect of CITEL made GFSA is present even at $\tau > 10^5$ ms (memory curve has not reached saturation) which leads to conclusion that this components are less reliable than SIEMENS GFSA in overvoltage protection.

$\bar{t}_d$ dependencies on the applied voltage impulse for SIEMENS and CITEL GFSA are displayed in Figures. 4 and 5, respectively. These dependencies have been obtained for relaxation times of 3, 300 and 3000 ms. It can be seen from Figure 4 that the increase of voltage impulse from 240 to 250 V leads to the decrease in $\bar{t}_d$ for one order of the magnitude (response time is also decreased for an order of the magnitude), while $\bar{t}_d$ has a much slower decrease rate for larger values of applied voltage impulse. With SIEMENS GFSA $\bar{t}_d$ is practically independent from τ. This confirms our conclusion that electron yield originating from the radioactive source has a main role in breakdown initiation, while memory effect can be neglected.

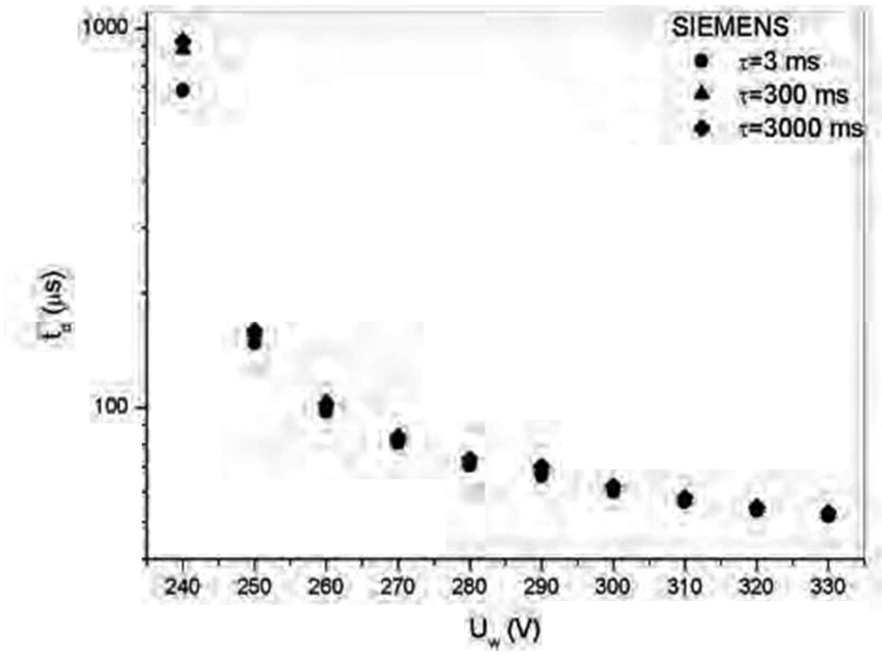

Figure 4. Mean value of electrical breakdown time delay $\bar{t}_d$ as a function of applied voltage U_w for SIEMENS GFSA

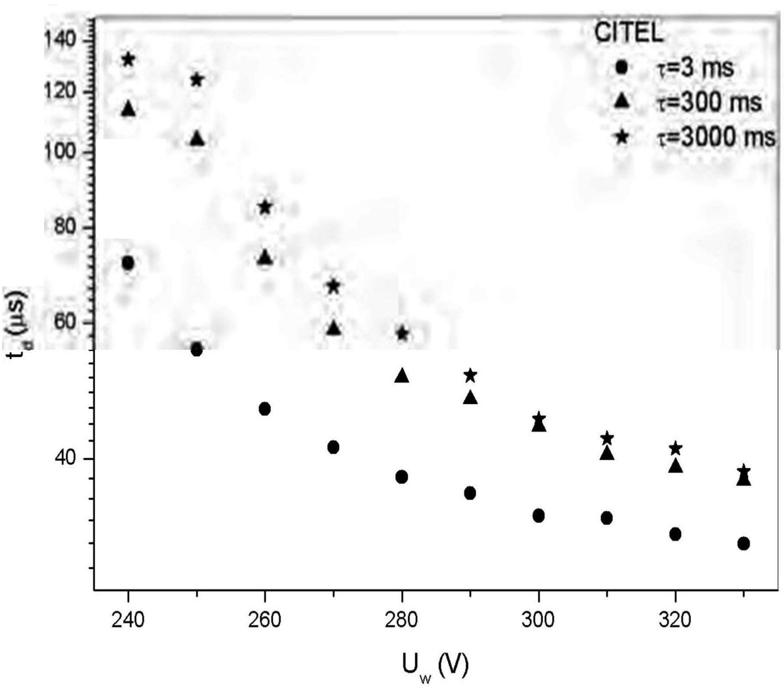

Figure 5. Mean value of electrical breakdown time delay $\bar{t}_d$ as a function of applied voltage U_w for CITEL GFSA

$\bar{t}_d$ values of CITEL GFSA decrease with the increase of voltage impulse also (Figure 5). However, the curves shift towards higher values of td with the increase in τ. The increase of t_d with the increase in t is in accordance with our conclusion that electron yield originates from particles formed during breakdown which decrease in concentration during after glow period thus reducing the electron yield and increasing $\bar{t}_d$.

4. Conclusion

On the basis of the above written consideration, the following can be concluded. The static breakdown voltage, as a deterministic quantity, can very precisely be estimated by fitting the dependence of mean value of the electrical breakdown voltage on the voltage increase rate. The values of static breakdown voltage obtained in this manner are in good agreement with nominal values reported by manufacturers and within their tolerance range of $\pm 20\%$. The response time of GFSA can be estimated based on experimental data of time delay of electrical breakdown. The estimated value of SIEMENS GFSA response time is 60 µs and this value is independent of relaxation time. This is due to the fact that the dominant contribution in breakdown initiation has a constant yield originating from radioactive source placed into the components housing. The response time of CITEL made GFSA increases with relaxation time, which is a consequence of the decreasing concentration of particles which contribute to electron yield in the inter-electrode space. Response time of SIEMENS GFSA decreases with increase of applied voltage and is practically independent of relaxation time.

Finally, it should be pointed out that although SIEMENS GFSA have somewhat better characteristics regarding the response time, their main drawback is the negative effect of the radioactive source on the environment.

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