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Measuring Picosecond Flashover in Closing Coaxial Spark Gap Switch

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Flashover voltage and picosecond risetime of breakdown in pressurized SF_6 gas is studied on a coaxial line. Gas pressure is varied from 1 to 19 bar. The homogeneous field gap has an opening from *ca.* 0.2 to 0.9 mm, and flashover voltages reach 120 kV. Measurements are performed using a D-dot probe with 16 to 20 GHz real-time oscilloscopes and a 50 GHz sampling oscilloscope. Measured risetimes are down to *ca.* 50 ps, and the dependence of voltage collapse on gas density and electric field between the electrodes is reported. Integrity of data is analyzed and experimental results are compared with present theory found in literature and previous results measured with alternative real-time systems.

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1. Introduction

Ever-growing advances in measurement technology have improved the accuracy of measuring fast transients enabling real-time sampling of picosecond pulses. Here, previous real-time (single-shot) data from digital signal analysers of lower bandwidth are compared with greater resolution series sampling data. Using alternative systems and measuring technique aims at distinguishing the phenomenon pertaining to the immensely fast voltage collapse from the characteristics of the test setup.

2. Measurement setup

The spark gap is of coaxial structure with identical hemispherical stainless steel electrodes facing each other (Fig. 1). The impedance of the coaxial line is maintained at *ca.* 30 Ω along the entire coaxial structure via a biconical design. The inter-electrode distance can be adjusted and the electrodes are situated in a gas-tight chamber where the insulating gas can be pressurized accordingly. A high voltage impulse with steepness ranging from 400 to 1200 kV/μs is fed to one electrode while the other electrode is connected to the ground via resistance approximately equal to the characteristic impedance of the line. The two D-dot probes (standard straight bulkhead SMA jack) are located on the coaxial line *ca.* 7 cm away from the gap on both directions and inserted flush to the inner wall of the outer conductor. One probe measures the signal propagating towards the resistive load and the other the signal propagating back towards the impulse generator. Impulses were fed at 2 Hz and 500 samples were collected to compile a pulse with a time resolution of 2 ps.

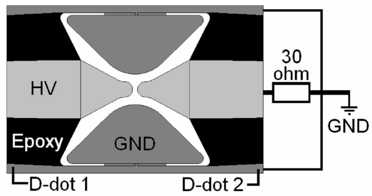

Fig. 1. Spark gap construction.

A derivative of voltage ($\mathrm{d}V/\mathrm{d}t$) is measured and in order to calculate voltage collapse the acquired pulse is integrated. Bandwidth was improved from earlier setups [1] by implementing a Tektronix TDS8200 series sampling oscilloscope with a 80E01 sampling module having bandwidths exceeding 50 GHz. Due to the statistical nature of breakdown, disturbances which further increase data scatter and zero-level fluctuations were minimized by employing rigorous electromagnetic shielding of measurement equipment and proper grounding technique in efforts to preserve data integrity.

3. Results

Three sub-millimeter gap spacings were used and applied pressure increased from 1 to 19 bar. Breakdown voltages ranged from 10 kV to 120 kV and followed a somewhat linear relationship with pressure as described by theory. Figure 2 shows the newly acquired data (50 GHz) along with prior results measured with alternative setups. Significant deviations from Paschen's law at lower values of pd were observed which correspond to E/p values exceeding approximately 15 kV/(mm bar). Here,

E is electric field strength in kV/mm, p is pressure in bar and d is gap distance in mm.

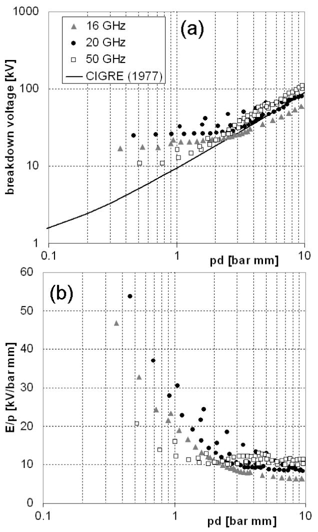

Fig. 2. Top — measured breakdown voltages plotted along the Paschen's curve [2]. Bottom — E/p plotted against pd values.

For each gap spacing the test switch was opened and cleaned to avoid contaminating the SF_6 insulation gas. Considerable scatter was observed in breakdown voltages and measured pulse shapes for the first 1000 triggers. As the series sampling oscilloscope collects a number of samples from which it builds a pulse, this scatter significantly hindered measurements. It was necessary to trigger the test switch at least 1000 times until subsequent pulses stabilized and scatter was decreased to an acceptable level. Malik and Qureshi [3] refer to this as the "conditioning effect" where weak points of the gap are destroyed by breakdown sparks.

Two distinct dV/dt pulse shapes were observed which allows the measured processes to be grouped into three categories — region I, transition region, and region II — which are evaluated in Table. Calibration of the D-dot probes [4] was not consistent for the entire measurement range. Hence, presented dV/dt values are arbitrary. However, these values do not effect the calculation of risetimes which were conducted from normalized 10% to 90% coordinates.

TABLE

dV/dt pulse regions.

Region	Pressure range [bar]	E/p [kV/(mm bar)]	Risetime [ps]
I	1–3	> 30	50
Transition	4–9	10–30	N/A
II	> 10	~ 10	200–350

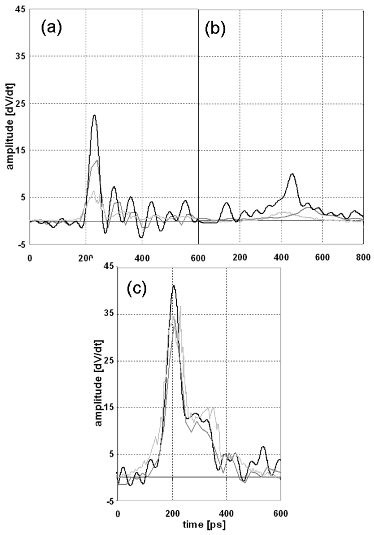

Fig. 3. Comparison of dV/dt pulse shapes where light grey is from 50 GHz series sampling, black is 20 GHz Tektronix DSA72004 using interpolation and dark grey is 16 GHz Tektronix without interpolation. Gap distance $d \sim 0.50$ mm and pressure is (a) $p = 1$ bar, (b) $p \sim 5$ bar, (c) $p = 19$ bar.

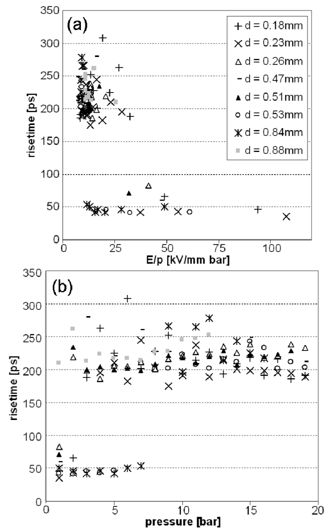

Fig. 4. Risetime of measured voltage collapse correlated with (a) E/p and (b) pressure.

Region I, where E/p exceeds 30 kV/(mm bar), is characterized by a clean dV/dt pulse with a distinct rising face and peak which returns to zero level, as shown in Fig. 3a, thus giving a linear voltage collapse from which risetimes are easily calculated. When pressure is increased, which in turn decreases E/p values, a transition region begins where the measured dV/dt pulse becomes almost unrecognizable and differing with each trigger and consequently risetime calculations are misleading (Fig. 3b). Deviations from Paschen's law described earlier fall into region I and continue into this transition region. Once pressure is increased so that E/p is approximately 10 kV/μs, a repetitive pulse is once again observed (Fig. 3c).

However, this pulse after peaking does not directly return to zero level but rather plateaus, signifying that the gradient of the voltage collapse changes and thus increases risetimes as calculated in Fig. 4.

4. Conclusions

This paper presents short SF_6 gap risetime measurements performed with a 50 GHz series sampling oscilloscope and confirms results acquired with lower bandwidth systems. The changes in the observed pulse shapes suggest an alteration in the breakdown phenomenon within different pressure ranges corresponding to certain E/p values with relatively constant risetime. Furthermore, deviation from Paschen's law is also restrained to E/p values observed in region I and the transition region. Since gap distance affects field strength, variations in d appear to somewhat influence the onset of each region.

Acknowledgments

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