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Particle-Initiated Corona and Breakdown Under dc/ac Mixed Voltages

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Abstract

The influence of conducting particles on the corona onset voltage and the breakdown voltage in a uniform field gap under ac voltage superimposed with negative dc biasing voltage is investigated. The effect of particle length, gap spacing and the dc biasing voltage on the corona onset and the breakdown voltages is also presented and discussed. The breakdown voltage of different gap spacing and dc biasing voltage is compared with calculated values. The comparison shows good agreement between experimental and calculated values.

Introduction

The development and design improvement of gas-insulated substations (GIS) and transmission lines have made possible a rapid increase in their use during the last few years. Equipment of 550 kV maximum system voltage are in service, and 1200 kV development programs are in progress [1-3]. It is fact that conducting particles in GIS could reduce the dielectric strength drastically. ac voltage equipment is stressed by dc voltages. This stress occurs after interruption of capacitive currents, when a dc voltage is left on the load side. This phenomenon is known in the case of capacitive switching with circuit breakers, but is also known during disconnector switching, where a trapped charge is left on the load side. Depending on the discharge time constant, this charge may exist for hours or even for days. The ac system voltage will superimposed on the dc prestress. The strength under this composite stress may be important factor for GIS design.

This paper discusses the corona onset voltage and the breakdown voltage of air and SF_6 under such composite dc/ac stress. The effect of the most important factors such as value of dc biasing voltage, particle parameters, gap spacing and gas pressure on the corona onset and breakdown voltages will be investigated. Comparison between calculated and measured values will be presented and discussed.

Method of Analysis

The uniform field gap is subjected to dc/ac mixed voltages, where the upper plate is subjected to an ac voltage while the lower plate with a fixed particle is subjected to dc voltage. The negative dc biasing voltage is fixed at a constant value where it is small compared to an ac voltage. The applied ac voltage is increased gradually till breakdown occurs. When the applied ac voltage increased, the corona discharge first starts on the negative polarity (i.e. the polarity of the fixed particle is negative relative to the opposite electrode), and then starts on the positive polarity at a higher voltage level [4].

Criterion of corona onset and breakdown voltages

In order to study the corona onset and the breakdown voltages for a fixed particle contaminating a parallel plane gap under dc/ac mixed voltages, the electric field around the particle must be calculated. The charge simulation technique is used to solve this field problem.

Positive corona

Assume an electron exists at the border of the ionization zone ($\alpha = \eta$) surrounding the stressed particle tip, where α (m^{-1}), and η (m^{-1}) [5] are the ionization and attachment coefficients, respectively. This electron generates a primary avalanche by electron collision with gas molecules . The size of the primary avalanche N_{+1} is calculated . Due to photoionization process, photons produced from the avalanche head ionize the gas molecules in the ionization zone . Due to this process photoelectrons are produced, and as a result, successor avalanches are produced in the ionization zone, Fig 1. Then the size of the successor avalanches N_{+2} forming the second generation is calculated . At the corona onset voltage N_{+2} just exceed N_{+1} and the discharge process becomes self-sustained [6,7].

$$N_{+2} \geq N_{+1} \quad (1)$$

Negative corona

When the electric field strength in the vicinity of the particle tip reaches the threshold value for ionization of gas molecules by electron collision, a primary avalanche starts to develop along the direction away from the particle tip, Fig. 2. With growth of the avalanche, more electrons are developed at its head, more photons are emitted in all directions and more positive ions are left in the avalanche wake . The growth of the primary avalanche is terminated at the ionization zone boundary ($\alpha = \eta$) where the electrons get attached to the gas molecules .

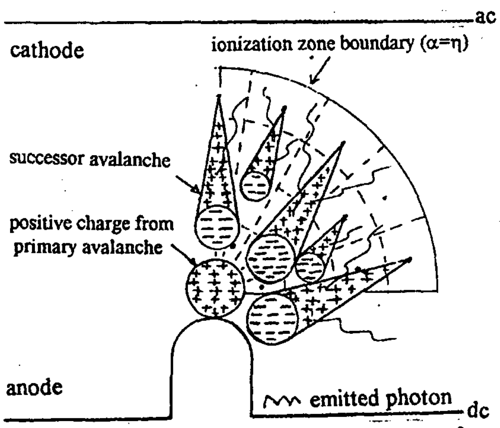

Fig.1 Growth of successor avalanches starting from the centers of sectors and ending at the positive space charge sphere or the protrusion tip.

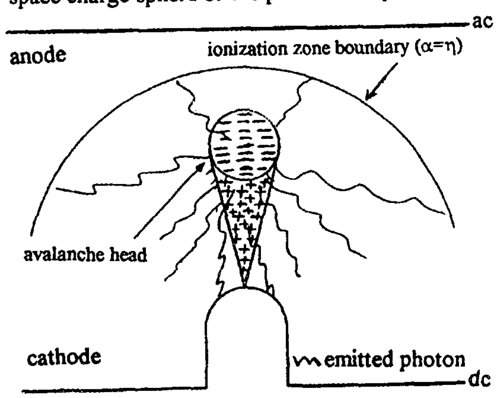

Fig.2 Growth of the primary avalanche and Emission of photons in negative corona .

In negative corona, the successor avalanches are initiated from the cathode surface . For the successor avalanche to be started, the emitted photons from the primary avalanche which reach the cathode should act for the emission of photoelectron N_{eph} . For a self-sustained discharge [6]:

$$N_{eph} \geq 1 \quad (2)$$

The onset voltages (V_{o+}, and V_{o-}) for positive and negative corona, respectively, do not appear explicitly in the relations (1) or (2) . However, the critical peak value of the applied ac voltage which satisfies the relation (1) or (2) is the onset value .

Breakdown criterion

In non-uniform field gap, corona discharges will occur when the conditions for a streamer formation in the gas are fulfilled. Streamer formation is both pressure and field dependent, and therefore depends on the contaminating particle, its position in the gap between electrodes if it is free, and on the instantaneous value of the ambient field. The condition for streamer formation is given by;

$$\int_0^{x_c} [\alpha(x) - \eta(x)]dx \geq K \quad (3)$$

Where, x_c is the critical distance of the ionization zone starts from the particle's tip to the ionization boundary. There is some controversy over the value of K; the discharge constant. In this work the value of K is taken as 18.42 [8,9].

Results and Discussions

The experimental investigations were performed with fixed copper particles having a diameter (2r) of 0.75 mm and lengths (L) ranged from 1 mm to 5 mm, in uniform field gaps. The calculations were performed with fixed particles having diameters of 0.2 mm, 0.75 mm and 1.0 mm and lengths ranged from 1 mm to 5 mm, in uniform field gaps.

Fig.3 shows the comparison between the experimental and the theoretical results for fixed particle contaminating parallel plane gap under ac voltage with different gap spacing (G). Good agreement between experimental and theoretical studies is

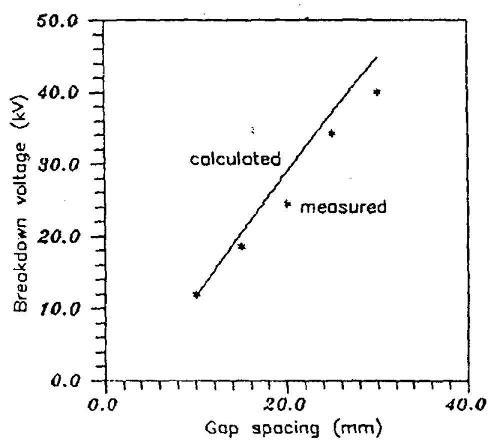

Fig.3 BDV in different gap spacing under ac voltage

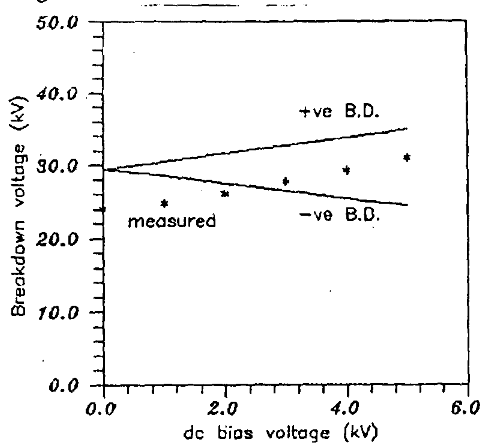

Fig.4 Effect of dc biasing voltage on BDV with fixed particle contamination

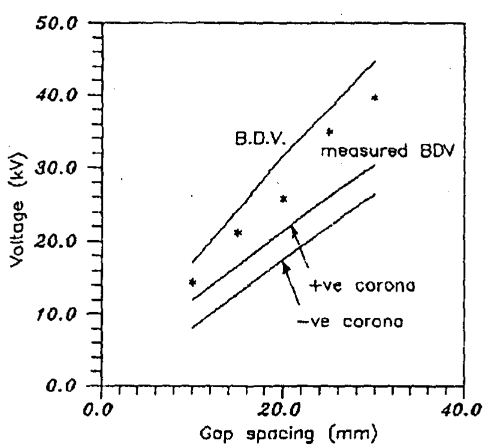

Fig.5 Effect of gap spacing on corona onset and BDV With 2 kV dc biasing voltage.

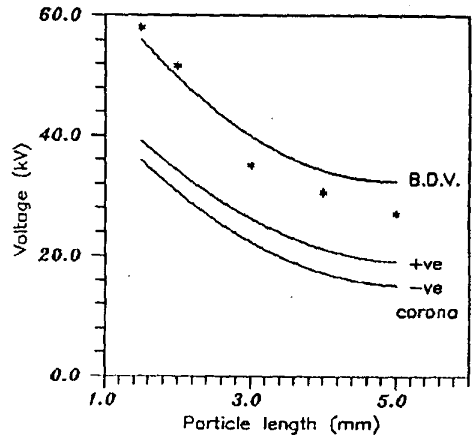

Fig.6 The BDV versus particle length under dc/ac Voltage

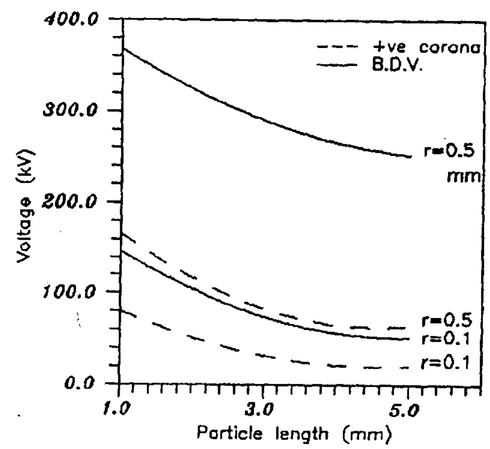

Fig.7 Effect of particle dimensions on corona onset and BDV with 5 kV dc biasing voltage for SF_6

achieved and the maximum deviation between them is about 10%.

The effect of biasing dc voltage on the corona onset and breakdown voltages for gap spacing 20 mm and particle dimensions L=3 mm and diameter 0.75 mm is shown in Fig.4. It shows that the calculated positive breakdown voltage has the same trend with the experimental results. Thus the breakdown takes place on the negative half cycle of the ac applied voltage. A good agreement between the. calculated and the experimental results is obtained if the biasing dc voltage increases from 0 to 5 kV

Fig.5 shows the effect of gap spacing on the corona onset and breakdown voltages for dc biasing voltage 2 kV with particle length and diameter 3 mm and 0.75 mm, respectively. There is a good agreement between calculated and experimental results for breakdown voltages; for G=25 mm the deviation is less than 10%. As the gap spacing increases, the field intensification on the tip of the particle is decreased and the breakdown voltage is increased.

The effect of particle length on the breakdown and corona onset voltages under dc/ac with 2 kV dc biasing voltages and gap spacing 25 mm is shown in Fig.6. It appears that, as the particle length increases from 2 mm to 5 mm the breakdown voltage decreases from 51.6 kV to 27.1 kV and the corona onset voltage is decreased from 33 kV to 18.7 kV. If the particle length increases, the field intensification is also increase and thus the corona onset and the breakdown voltages are decreased.

Fig.7 shows the effect of particle dimensions on the corona onset and breakdown voltages for SF_6 gas under 5 kV dc biasing voltage; for gas pressure 200 kpa and G=25 mm. As the particle diameter increases the field intensification is decreased and thus the corona onset and the breakdown voltages are increased.

Conclusions

1. Positive corona is less stable and can induce breakdown more readily than the negative corona.
2. For ac/dc mixed voltages in a uniform field gaps with fixed particle contamination, the breakdown takes place on the negative half cycle of the ac applied voltage.
3. As the dc biasing voltage increases the positive breakdown voltage increases and vice versa with the negative breakdown voltage.
4. A good agreement between the measured breakdown voltage and the calculated positive breakdown voltage is achieved as the dc biasing voltage increases.

References

[1] T. Nojima et al., "Installation of 275kV-3.3km Gas-Insulated Transmission Line For Underground Large Capacity Transmission in Japan", CIGRE, Paper 21/23/33-01, 1998.

[2] A. Eriksson et al., "Experience With Gas Insulated Substations in The USA", IEEE Trans, on Power Delivery, Vol.10 No.1, pp. 210-218, 1995.

[3] R. M. Radwan, R. Morsi and M. A. Abd-Allah, "Motion of Free Conducting Particles in SF_6 Insulated Systems Under dc/Switching Voltages", IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 1, No.1, Feb. 1994.

[4]Y. Inuishi, "Electrical Discharges of SF_6 Gas in Non-uniform Fields", Electra, No. 84, pp. 45-52.

[5] M. Abdel-Salam and E. K. Stanek" On the Calculation of Breakdown Voltages For Uniform Electric Fields in Compressed Air and SF_6 " . IEEE Trans. IA, vol. 22, pp.27-33, 1988 .

[6] M. Abdel-Salam and P. Weiss " Discharges in air from point electrodes in the presence of dielectric plates, theoretical Analysis " IEEE Trans. on E I. Vol. 27. No 2, 1992 .

[7] M. El-Bahy "Onset Voltage of Positive Corona in Rod Gaps in Air- Theory Versus Experiment ", 6th International MEPCON' 98, Egypt, 1998.

[8] N.H. Malik, A.H. Qureshi, "Breakdown Gradients in SF_6-N_2, SF_6-Air and SF_6-CO_2 mixtures", IEEE Trans. On Electrical Insulation, Vol. EI-15, No. 5, pp. 413-418, 1980.

[9] T.W. Dakin et al., "Breakdown of Gases in Uniform Fields Paschen Curves For Nitrogen, air and Sulpher-hexaflouride", Electra CIGRE, Paper No. 32, pp. 64-70, 1974.