

# CALCULATION of CORONA INCEPTION VOLTAGES in N<sub>2</sub>+SF<sub>6</sub> MIXTURES via GENETIC ALGORITHM

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## ABSTRACT

**In this paper, AC corona inception voltages of mixtures of N<sub>2</sub>+SF<sub>6</sub> in non-uniform field were studied. The electrode gap spacing and the relative gas pressure were varied within the range of 5-25 mm and of 100-500 kPa respectively. The results were first measured experimentally and then estimated by means of Genetic Algorithm. The comparison of measured and computed values show that there is a good agreement between two values. The corona inception voltages of the mixtures can be found correctly by the Genetic Algorithm. Therefore, Genetic Algorithm can be considered an alternative tool to estimate the inception voltages.**

## I. INTRODUCTION

It is well known that SF<sub>6</sub> has excellent dielectric characteristics and is the most commonly used insulating gas at present. However, its disadvantages such as green house effect, high sensitivity to conductor surface roughness and high cost limit its applications. Using a mixture of SF<sub>6</sub> with an inexpensive simple gas like CO<sub>2</sub>, N<sub>2</sub> and air can minimise the above problems. These gases are used as electrical insulation purposes for high voltage equipment.

Several investigations have been reported in the literature on the breakdown and corona inception behaviour of SF<sub>6</sub>, N<sub>2</sub> and N<sub>2</sub>+SF<sub>6</sub> mixtures [1-2]. However, there is still insufficient information regarding the alternating breakdown and corona inception voltages of such mixtures with small amount of SF<sub>6</sub> in nonuniform field gaps. Pure N<sub>2</sub> insulation though would result in unrealistic designs for the required levels. But even by adding of some SF<sub>6</sub>, an insulating capability is achieved which is realistic in relation to practical use. The present paper describes a study of corona inception voltages of various N<sub>2</sub>+SF<sub>6</sub> mixtures in rod-plane gap under alternating voltages. These results were first measured experimentally and then estimated by means of Genetic Algorithm.

Earlier researchers have shown that for the calculation of corona inception voltage based on the streamer criterion. It is well known that the simple streamer breakdown criterion [3-4 ]

$$\int_0^{x_c} (\alpha-\eta) dx = K \quad (1)$$

can be used to determine the lowest possible voltage which can cause breakdown or corona inception in SF<sub>6</sub>.  $\alpha$  and  $\eta$  are ionization and attachment coefficients respectively. These coefficients are functions of the electric field and the gas pressure. Here  $x_c$  is the critical avalanche length which is the distance between the highly stressed electrode and the point in the electrode gap where  $\alpha=\eta$ . Equation (1) has also been used in several reports [5-6] to predict the discharge voltages of uniform and quasi-uniform field gaps insulated with SF<sub>6</sub>-N<sub>2</sub> mixtures. However, based on equation (1), Nitta et al. [7] have described a rather simple method to determine the discharge voltages of long gaps insulated with compressed SF<sub>6</sub>. In this method, a detailed knowledge of field distribution in the gap is not essential, and only the ratio between the average and the maximum field strengths is required. In the breakdown criterion, we are interested only in the value of  $\bar{\alpha}=\alpha-\eta$  in a narrow interval around the limiting value of the parameter E/p, i.e. (E/p)<sub>lim</sub> which is defined by  $\bar{\alpha}(E/p)=0$ . In this range we may consider the variation of  $\bar{\alpha}/p$  with E/p to be linear [7]. The effective ionization coefficient  $\bar{\alpha}$  can therefore be expressed as,

$$\bar{\alpha}/p = \beta[(E/p)-(E/p)_{lim}] \quad (2)$$

The value of  $\beta$  is 27 kV<sup>-1</sup> and of (E/p)<sub>lim</sub> is 877.5 V(cm.kPa)<sup>-1</sup> for SF<sub>6</sub>. The streamer breakdown criterion of equation (1) then becomes

$$\beta \int_0^x E(x) dx - \beta \cdot p \cdot x_c \cdot (E/p)_{lim} = K \quad (3)$$

In a uniform field gap,  $E(x)$  is constant and  $x_c$  is equal to the gap length  $a$ . The breakdown voltage  $V_d$  in such cases as obtained from equation (3) is given by

$$V_d = E \cdot d = K/\beta + (E/p)_{lim} \cdot p \cdot a \quad (4)$$

For uniform or nearly uniform field gaps, the streamer formation directly grows to a breakdown. However, in non-uniform field gaps it is not always so. For extremely non-uniform field gaps, at low pressures, the streamers develop into a steady corona discharge. Because of the stabilization effect of this corona, the breakdown voltage is substantially higher than the corona inception level. In such cases, the criterion for streamer formation corresponds to the corona inception. Since in non-uniform field gaps  $x_c$  is generally a small fraction of the total gap length  $a$ , the field in the vicinity of the highly stressed electrode along its axis of symmetry can be approximated by [8]

$$E(x) = \frac{E_{max}}{(1 + x/R)^2} \quad (5)$$

where  $E_{max}$  is the field at the tip of the electrode and

$$\frac{1}{R} = \frac{1}{2} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \quad (6)$$

Here  $R_1$  and  $R_2$  are the radii of curvature in the two directions orthogonal to each other. From  $E(x_c)/p = (E/p)_{lim}$ ,  $x_c$  can be determined as

$$x_c = R \left( \sqrt{\frac{E_{max}}{(E/p)_{lim} \cdot p} - 1} \right) \quad (7)$$

Following Nitta and Malik et al. [7-8], the discharge inception voltage in non-uniform field gaps can be calculated from equations (3), (5) and (7) expressed as:

$$V_d = (E/p)_{lim} \cdot u \cdot p \cdot a \left( 1 + \frac{C}{\sqrt{pR}} \right) \quad (8)$$

u, utilization factor  $= E_{av}/E_{max}$

$$C = \sqrt{\frac{4 \cdot K}{\beta \cdot (E/p)_{lim}}} \quad (9)$$

From uniform field breakdown data, a value of  $K=10.5$  has been suggested for  $SF_6$  [8]. The value of the constant  $C$  is therefore  $1.33 \text{ (kPa.cm)}^{0.5}$  for pure  $SF_6$ . Equations (4) and (8) give the minimum discharge voltage in uniform and non-uniform field gaps for electrodes with smooth

surfaces. Equation (1) can be used to formulate a breakdown criterion for  $SF_6-N_2$  mixtures if the effective ionization coefficient is known for the mixtures. However, since to our knowledge such measurements have not been reported in the literature, Therefore, the assumptions made in deriving equations (4) and (8) are valid for  $SF_6-N_2$  mixtures and the discharge voltage in  $SF_6-N_2$  mixtures can be expressed as

$$V_d = \frac{K_m}{\beta_m} + (E/p)_{lim} \cdot p \cdot a \quad (10)$$

in uniform field gaps and

$$V_d = \left( \frac{E}{p} \right)_{lim} \cdot u \cdot p \cdot a \left( 1 + C_m / \sqrt{pR} \right) \quad (11)$$

in non-uniform field gaps,

$$C_m = f_3(z) = \sqrt{\frac{4 \cdot K_m}{\beta_m \cdot (E/p)_{lim}}} \quad (12)$$

Since  $K(SF_6)=10.5$  and  $5 < K(N_2) < 8$ , it is plausible to assumed  $K_m \leq K(SF_6)$ . In our calculations we have assumed  $K_m < K(SF_6)$  in equation (12) and the resulting values of  $(E/p)_{lim}$  and  $C_m$  are given in Table 2. In this study, constants of  $(E/p)_{lim}$  and  $C_m$  are determined by using genetic algorithms and then corona inception voltages are found by using this constant. These results are compared with experimental results.

## II. GENETIC ALGORITHMS

Genetic algorithms (GAs) are adaptive search procedure, based on the Darwinian nature of evaluation. The genetically process in living organism life can be modelled by computer. Generic algorithms are increasingly commonly used in a variety of searches, optimizations of complex engineering problems, and machine learning applications [9]. For the optimization problems, the major advantages of GAs may be outlined as follows [10].

- They search from a population and not from a single parameter set.
- They are capable of searching for solutions from disjointed feasible domains.
- They can operate on irregular functions and those that are no differentiable.
- They don't require the computations of gradients.

The basic GAs may be outlined as follows [11]. Genetic algorithms begin with a population of randomly generated candidate solutions. Solutions are represented by chromosomes. This random solution is called population. Mutation, crossover and reproduction process are applied to a population to produce new members. It's evaluated

the fitness of each chromosome in the initial population. Two parent chromosomes from a population according to their fitness are chosen under selection to create new child (offspring) for the next generation. The parents are crossover depending on crossover probability to form a new child (offspring). After the mutation of the new offspring, depending on a mutation probability, it is placed in a new population. The new generated population is used with the same set of trials, selected and reproduced. This process is repeated until the end condition is satisfied.

In this study, the genetic algorithm with real-value coding is applied to a high voltage measurement system to compute  $(E/p)_{lim}$  and  $C_m$  constants. In the work here, the fitness is defined as follows

$$Fitness = \frac{1}{\sum (V^m - V^p)} \quad (13)$$

Here,  $V^m$  and  $V^p$  represent the measured and predicted values. As the difference values in the measured and predicted decreases, fitness value increases. For the high-fitness values, difference between measured values and predicted values can be minimized. It is necessary to compute the growth of a single critical electron avalanche. The present paper at first describes a study of corona inception voltages of mixtures of  $N_2+SF_6$  experimentally and then estimates the corona inception voltages. These results may be compared with previous investigations. The parameter GAs is chosen as follows; the size of the population is kept as 150, probability of crossover as 0.7, probability of mutation as 0.01, tournament probability as 0.7, scale for mutation as 0.01.

### III. EXPERIMENTAL SET-UP

Experiments were carried out using a rod-plane electrode system with a rod tip radius of 1 mm and plane disc diameter of 75 mm (Fig. 1).

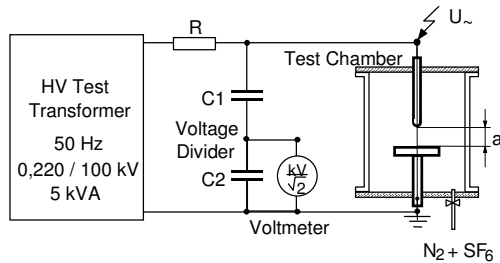


Fig.1 Test Circuit

In all experiments, the electrode gap spacing and the relative gas pressure were varied within the range of 5-25 mm and of 100-500 kPa respectively. Electrodes were mounted in a pressure vessel of 120 mm diameter and 600 mm length. In rod plane arrangement, the rod was connected to the high voltage supply while the plane was earthed. The inception voltage was determined by

observation with a sensitive oscillograph. The voltage drop, across a 100  $\Omega$  resistor inserted in the earth lead, caused by corona current, was measured with an oscillograph. The mean value of corona inception voltages and standard deviation were calculated by means of ten voltage applications. In the experiments, the  $SF_6+N_2$  gas mixtures with 4, 10, 20, 100 %  $SF_6$  content were used.  $u$ , the utilization factor of the electrode system was computed from Stenbigler theory [12].

Table1.  $u$ , field utilization factor for various electrode systems

a(cm)	u
2,5	0.054
2,0	0.066
1,5	0.085
1,0	0.120
0,5	0.210

### IV. APPLICATION and TEST RESULTS

Experimental and theoretical investigations of the corona inception voltages are reported for rod-plane gaps using AC voltages in the pressure range of 100-500 kPa. The different ratio of  $SF_6-N_2$  mixture is used in this calculation. It is shown that corona inception voltages of  $SF_6+N_2$  gas mixtures can be affected electrode gap configuration, gas pressure, gas mixture ratio. Also the measured corona inception voltages are in reasonable agreement with the streamer corona inception voltages given by equation (11). The constants of  $(E/p)_{lim}$  and  $C_m$  in Eq.11 are determined by using genetic algorithms. The corona inception levels for non-uniform field gaps filled  $SF_6-N_2$  mixtures can be estimated with a reasonable degree of accuracy using the streamer breakdown criterion. Variation of corona inception voltages versus to electrode gap spacing for different pressure range is shown in Fig.2-5.

Table 2. Variations of  $(E/p)_{lim}$  and  $C_m$  with different  $SF_6$  content  $SF_6-N_2$  Mixture

$z = \frac{p(SF_6)}{p} \%$	$\left(\frac{E}{p}\right)_{lim} V(cm.kPa)^{-1}$	$C_m (kPa.cm)^{0.5}$
100	873.4481	1.7197
20	611.3772	2.70
10	534.0088	3.0898
4	456.7999	4.4369

Where  $(E/p)_{lim}$  and  $C_m$  vary with the gas mixture ratio and the values of these constant are calculated by Genetic Algorithm for  $SF_6-N_2$  mixtures.  $u=E_{av}/E_{max}$  is the field utilization factor while  $p,a$  and  $R$  are gas pressure (kPa), electrode gap spacing and radius of rod electrode (cm).

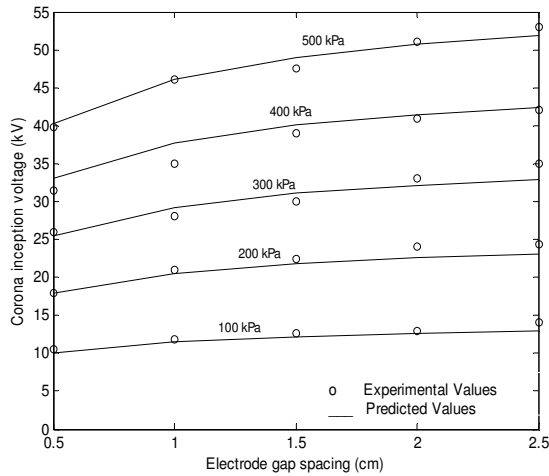


Fig.2 Variation of corona inception voltages versus to electrode gap spacing for 100% SF<sub>6</sub>

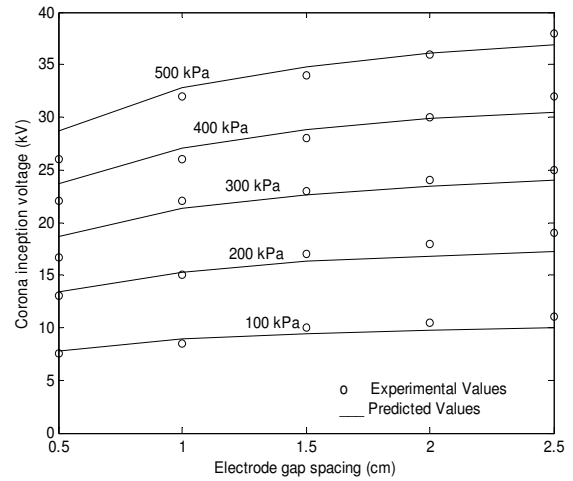


Fig.4 Variation of corona inception voltages versus to electrode gap spacing for 10% SF<sub>6</sub>+90% N<sub>2</sub>

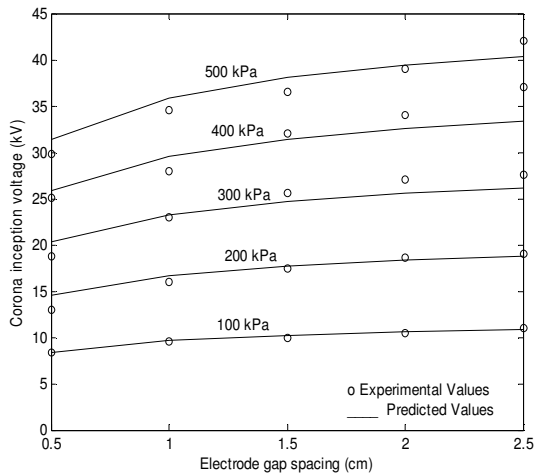


Fig.3 Variation of corona inception voltages versus to electrode gap spacing for 20% SF<sub>6</sub>+80% N<sub>2</sub>

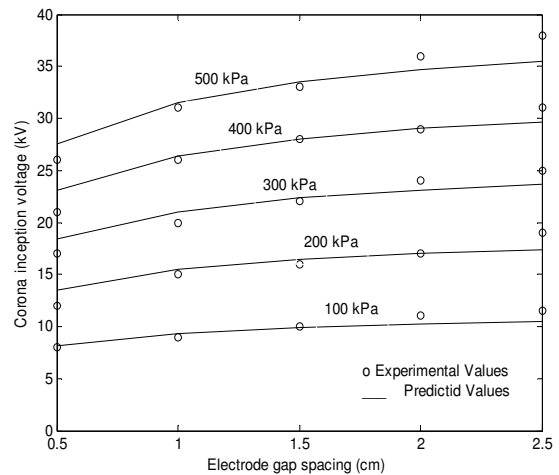


Fig.5 Variation of corona inception voltages versus to electrode gap spacing for 4% SF<sub>6</sub>+ 96% N<sub>2</sub>

## V. CONCLUSION

In this paper the calculation of the corona inception voltages SF<sub>6</sub>+N<sub>2</sub> mixtures was reported. The described method is based on GAs. Experimental measurements and estimated values of corona inception voltages using rod-plane gap indicate that there is a reasonably good degree of agreement between the measured and the estimated values for different electrode gap spacing and pressures. Hence, GAs proposed to estimate the corona inception voltages in the different experimental cases has shown a very good performance with an accuracy of 5.5 % approximately. The behaviour of The GAs gives an idea of how well the GAs is converging. Therefore this approach can be accepted as a simple alternative tool to solve the difficulties in most experimental studies.

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