Impulse Characteristics of Different Gas Mixtures

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***Abstract*—This study is concerned with experimental investigation of breakdown characteristics of various gas mixtures under different pressures. Pure N_2, %50 SF_6+%50 N_2, %1 SF_6+%99 N_2 and %1 SF_6+%CO_2 gas mixtures are used as insulators. Gas pressures are varied between 1 and 10 bar. Weibull statistical analysis are used for evaluation of experimental data and breakdown characteristics are plotted by using least squares regression. As a result of this analytical assessment, the pressures required for safer protection levels are obtained as 1 bar for %50 SF_6+%50 N_2, 10 bar for %1 SF_6+%99 N_2, 5 bar for %1 SF_6+%99 CO_2 gas mixtures and 10 bar for N_2.**

***Index Terms*—gas insulation, weibull probability, sulphur-hexafluoride, time to breakdown**

I. Introduction

SF_6 is the main insulating medium in almost all insulated high voltage equipment. However, because of some undesirable characteristics of good insulating gas, United National Conventions decided to reduce the quantity of greenhouse gases in insulated systems. One of the possible solutions is to use gas mixtures containing a lower content of SF_6. In this regards, SF_6-N_2, SF_6-CO_2 gas mixtures containing different percentages of SF_6, have been found to be a good dielectric medium and widely accepted as the best replacement of SF_6. Weibull probability distribution, which is commonly used today in data analysis in relation with lifetime and failure ratios, mostly includes a logarithmic model with parameters. For the life-time assessment of new insulation, rapid breakdown tests and endurance tests at elevated electrical stress levels of different values are performed [1]-[3]. In this way, the life-curve is obtained and by extrapolation it can be noted whether the insulation is able to operate reliably for a required period of time [4]-[7]. The aim of this study is to establish the basic relationship between the statistics of time delays and the breakdown voltage probability distribution. Therefore, the present study evaluates the safest case of gas mixtures as pressure for our experimental set by using Weibull probability distribution [8]-[10].

II. Experimental Set Up

The lightning impulse voltages used in this study are produced by a 1 MV, 50 kJ, Marx type impulse generator (Fig. 1). The voltages are measured by means of a capacitive divider and a HIAS 743 digital oscilloscope with 12-byte real vertical resolution at 120 Mega sample/sec. Electrode systems have non uniform field. All data have sample frequency of 1 Giga sample/sec. Experimental set-up is shown in Fig. 2.

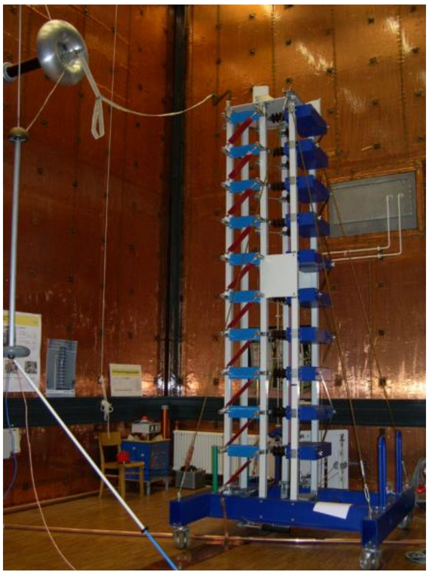

Figure 1. 1 MV Marx impulse generator [11].

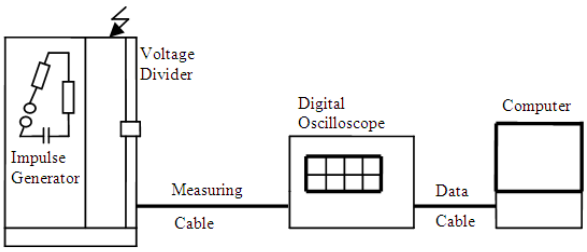

Figure 2. Experimental setup.

Signals are carried out using rod-plane electrode with a rod diameter of 1 mm and electrode gap spacing is 5 cm. Rod electrode is connected to high voltage while plane electrode is earthed. Electrodes are mounted in a pressure vessel of 120 mm diameter and 600 mm length. All measurements of the experimental study are given in IEC standard. The signal data with shielding is taken from oscilloscope which placed in screen cabinet [11].

III. Results and Discussions

By using measured peak-points and break-times, breakdown characteristics are obtained. For this purpose, least squares regression analysis and exponential model

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was used to fit curve to the data. In order to obtain breakdown probability, well known Weibull analysis is used. The Weibull function used for this purpose is given in Eqn. (1) [12].

$$P(V) = 1 - 0,5^{\{[(V - V50)^{3,4}/3.\sigma].\ln 2\}} \quad (1)$$

In this equation, P(V) is breakdown probability, V is applied voltage, V_{50} is the voltage corresponding to 50% probability to develop for breakdown and σ is standard deviation. Application of this equation to all data from lower to higher voltage values gives us a value of 1 (100% possibility) after a value corresponding to the breakdown voltage. This means that, higher voltages applied than the obtained one are results in breakdown. According to this, the highest breakdown voltage for a gas or gas mixture occurs in a pressure can be said a reliable gas or gas mixture as an insulator at that pressure. Under this knowledge, the results obtained for different gas mixtures and different pressures are given as following.

A. Case 1. %50 SF_6+%50 N_2 Gas Mixture

The breakdown characteristics of %50 SF_6+%50 N_2 gas mixture with positive polarity obtained for different pressure values changed from 2 to 9 bar are given in Fig. 3-Fig. 6. In this following figures, the measurement points are not plotted on graph to avoid complexity. The exponential equations for the curves given in the figure are in the form of

$$V = a.e^{b.t} \quad (2)$$

The coefficients a and b in (2) are obtained from least squares regression.

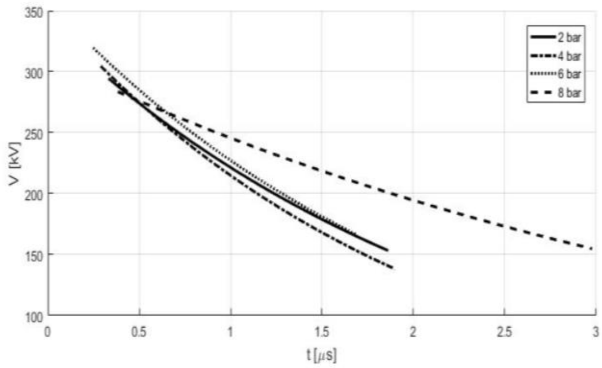

Figure 3. Time to breakdown characteristics of %50 SF_6 + %50 N_2 gas mixture.

Weibull probability distributions for all pressure values and gas mixtures are determined. As an example, graphs are given in Fig. 4-Fig. 6 for %50 SF_6 + %50 N_2 mixture at the pressure of 2, 4 and 6 bar. As seen these figures, the higher voltage, the higher probability of breakdown at insulation. There is a dispersion in measurement result at low voltage like 170 kV. This case is physical phenomena related to breakdown. It is clearly understood that the interval of estimated is smaller and it can be obtained higher probability [13].

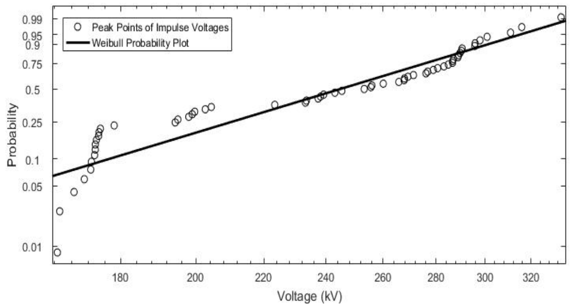

Figure 4. Weibull probability distribution of %50 SF_6+%50 N_2 gas mixture for the pressure of 2 bar.

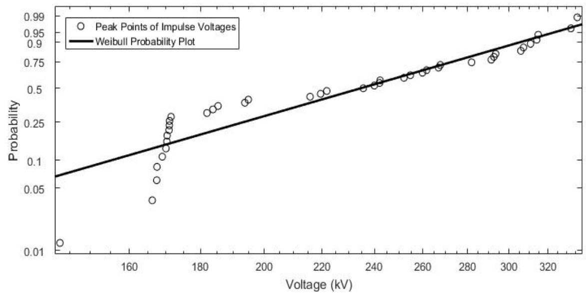

Figure 5. Weibull probability distribution of %50 SF_6+%50 N_2 gas mixture for the pressure of 4 bar.

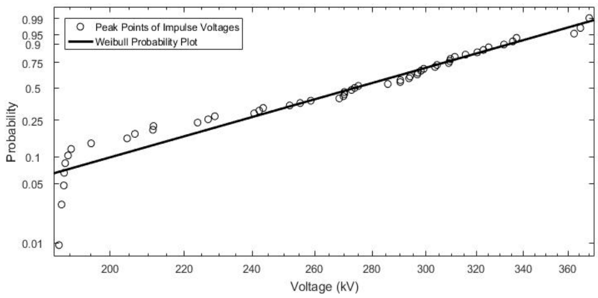

Figure 6. Weibull probability distribution of %50 SF_6+%50 N_2 gas mixture for the pressure of 6 bar.

For all pressure values, standard deviations and voltage values giving 50% breakdown possibility are calculated and given in Table I.

TABLE I. POSITIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %50 SF_6 + %50 N_2 GAS MIXTURES

Pressure (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
1	47,25	206
2	49,66	245
4	57,04	235
5	56,87	224
6	**52,00**	**274**
7	39,13	207
8	44,06	248
9	26,71	222

Positive polarised voltage values giving 100% breakdown possibility determined from (1) are given in Table II.

From this table, 6 bar is shown as the most reliable pressure for %50 SF_6 + %50 N_2 gas mixtures.

Similar evaluations are carried out for other gas mixtures. For this study, only obtained results are given in the following. At the following, different cases of gas insulations are shown from Table III to Table XIV for positive and negative polarities.

TABLE II. POSITIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %50 SF_6 + %50 N_2 GAS MIXTURES

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
1	216	8
2	256	3
4	246	4
5	235	5
6	**285**	**1**
7	217	7
8	259	2
9	231	6

B. Case 2. %1 SF_6 + %99 N_2 Gas Mixture

As shown in Table III-Table VI, maximum breakdown voltage at 10 bar for %1 SF_6+%99 N_2.

TABLE III. POSITIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %1 SF_6 + %99 N_2 GAS MIXTURES

Pressure (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
10	**44,95**	**168**
8	47,52	152
6	48,04	139
4	55,72	157
2	54,51	154

TABLE IV. NEGATIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %1 SF_6 + %99 N_2 GAS MIXTURES

Pressure (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
10	**48,76**	**329**
8	49,47	327
6	41,91	305
4	35,24	250
2	28,07	179

TABLE V. POSITIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %1 SF_6 + %99 N_2 GAS MIXTURES

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
10	**179**	**1**
8	163	4
6	150	5
4	168	2
2	165	3

TABLE VI. NEGATIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %1 SF_6 + %99 N_2 GAS MIXTURES

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
10	**340**	**1**
8	338	2
6	315	3
4	260	4
2	188	5

C. Case 3. %1 SF_6 + %99 CO_2 Gas Mixture

As shown in Table VII-Table X, maximum breakdown voltage at 5 bar for %1 SF_6+%99 CO_2. If this two gas mixture are compared %1 SF_6+%99 CO_2 gas mixture has advantages for the reason of leakage problem.

TABLE VII. POSITIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %1 SF_6 + %99 CO_2 GAS MIXTURES

Pressure (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
9	34,60	162
7	43,04	223
5	**36,79**	**239**
3	31,87	211
1	50,93	208

TABLE VIII. NEGATIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %1 SF_6 + %99 CO_2 GAS MIXTURES

Pressure (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
9	69,40	321
7	39,74	312
5	**41,42**	**326**
3	41,44	246
1	58,97	211

TABLE IX. POSITIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %1 SF_6 + %99 CO_2 GAS MIXTURES

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
9	172	5
7	233	2
5	**249**	**1**
3	221	3
1	219	4

TABLE X. NEGATIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %1 SF_6 + %99 CO_2 GAS MIXTURES

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
9	333	2
7	322	3
5	**336**	**1**
3	256	4
1	222	5

D. Case 4. %100 N_2 Gas

As shown in Table XI-Table XIV, maximum breakdown voltage at 10 bar for %100 N_2. The breakdown voltage of pure N_2 at 10 bar is the same that of %1 SF_6+%99 CO_2. As seen tables, the breakdown voltage of negative polarities is higher than that of positive polarities.

TABLE XI. POSITIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %100 N_2 GAS

Pressures (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
10	**42,09**	**201**
8	48,26	177
6	55,83	158

TABLE XII. NEGATIVE POLARISED VOLTAGE VALUES GIVING 50% BREAKDOWN POSSIBILITY FOR %100 N_2 GAS

Pressures (Bar)	Standard deviations	%50 breakdown possibility giving voltage (kV)
10	**62,73**	**245**
8	39,42	218
6	51,53	194

TABLE XIII. POSITIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %100 N_2 GAS

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
10	**211**	**1**
8	188	2
6	169	3

TABLE XIV. NEGATIVE POLARISED VOLTAGE VALUES GIVING 100% BREAKDOWN POSSIBILITY AND THEIR RELIABILITY SEQUENCE FOR %100 N_2 GAS

Pressure (Bar)	%100 breakdown possibility giving the lowest voltages (kV)	Reliability sequence
10	**257**	**1**
8	228	2
6	205	3

IV. CONCLUSIONS

In this paper, Weibull probability distribution test method is recommended to estimate the impulse breakdown voltages accurately for non-self-restoring electrical insulation. Besides, to know the break time of insulations is very important at protection techniques. It gives an information about breakdown and non-breakdown of insulation at the certain working voltage. This paper recommends the use of the parameters of probability distribution, like the scale and shape parameters. As seen from figures the slope of the straight line depend on the measurement parameters like pressure, electrode system and insulation type. This study can be considered as a small part of the comprehensive study. To achieve more accurate and general results, the experiments should be repeated with some other gas mixtures. According to the results of this study, following conclusions can be drawn:

For high voltage protection devices

- With %50 SF_6 + %50 N_2 gas mixture insulator, 6 Bar is obtained as maximum reliable pressure.
- With %1 SF_6 + %99 N_2 gas mixture, 10 bar is obtained as maximum reliable pressure.
- With %1 SF_6 + %99 CO_2 gas mixture, 5 bar is obtained as maximum reliable pressure.
- With %100 N_2 gas, 10 bar is obtained as maximum reliable pressure.

For easy production, the pressure of gas or gas mixture contained by high voltage protection devices should be closer to the atmospheric pressure. In this respect, %1 SF_6 + %99 CO_2 gas mixture is said to be the most preferable insulator.

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