# BREAKDOWN CHARACTERISTICS OF $CO_2$ AND $N_2$ CONTAINING 0.125% OF $SF_6$ IN NON-UNIFORM FIELDS

**E. Önal** onal@elk.itu.edu.tr

**Ö. Kalenderli** ozcan@elk.itu.edu.tr

**K. Mardikyan** kevork@elk.itu.edu.tr

Istanbul Technical University, Electrical- Electronics Faculty
80626 Maslak – Istanbul – Turkey

## ABSTRACT

AC breakdown strengths of $CO_2$, $N_2$, $SF_6$ and mixtures of $SF_6$+$CO_2$ and $SF_6$+$N_2$ containing 0.125% of $SF_6$ in non-uniform fields were experimentally studied. The electrode gap spacing was 5 and 25 mm, the relative gas pressure was varied within the range of 100-500 kPa. The experimental results show that in non-uniform field gaps the AC breakdown strength of $N_2$ and $CO_2$ in the practical range of pressure (100 to 400 kPa) may be increased by adding a small amount of $SF_6$. As an example at about pressures of 300 kPa and 25 mm rod-plane gap spacing breakdown voltage of $SF_6$+$CO_2$ mixture were obtained 15% and 54% higher than that of pure $SF_6$ and $CO_2$ respectively but the breakdown voltages of $SF_6$+$N_2$ mixtures obtained lower than those of pure $SF_6$ at all defined pressures. At above 350 kPa the breakdown voltages of mixtures drop below than those of pure $N_2$ and $CO_2$.

## INTRODUCTION

$SF_6$ is the most commonly used as an insulating gas in electric power apparatus such as switchgears, due to its superior insulation strength. However, it is known that breakdown strength of $SF_6$ under non-uniform electric field like metallic particle condition is extremely susceptible leading to be lower breakdown voltage. Furthermore, from the view point of environmental protection, as $SF_6$ has strong greenhouse effect, the use of $SF_6$ will be strongly controlled. Thus, it is needed to develop the alternative dielectric gas or gas mixtures having better insulating characteristics and no greenhouse effect. For these reasons, insulation characteristics of various kind of gas or gas mixture have been extensively studied [1]. Earlier measurements have shown that under positive direct voltage at 500 kPa, the breakdown voltage of $SF_6$+$N_2$ mixtures having less than 30% $SF_6$ is below that of pure $N_2$. When the rod electrode is negative, the breakdown voltage of a mixture containing 0.1% $SF_6$ is about half that of pure $SF_6$. Further increase in $SF_6$ content causes a slower increase in the breakdown strength of the mixtures [2]. At pressures below 200 kPa as the content of $SF_6$ is reduced below 5% the breakdown strength increases rapidly and reaches a maximum value for a mixture composed of about 99.8% of $N_2$ and 0.2% of $SF_6$. At high pressures, $SF_6$+$CO_2$ mixtures had breakdown voltages higher than the corresponding values for $SF_6$+$N_2$ mixtures for direct and impulse voltages. As mentioned earlier, in the low pressure range, for $SF_6$+$CO_2$ mixtures the breakdown voltages of negative and positive direct voltages have similar values. However, at higher pressures, negative breakdown voltages are significantly higher than the positive ones. Most of the $SF_6$+$CO_2$ mixtures investigated exhibited breakdown voltages which were similar to or even slightly higher than those observed for pure $SF_6$ for impulse voltages. Under negative impulse conditions, $SF_6$+$CO_2$ mixtures with less than 1% of $SF_6$ content have breakdown levels slightly lower than the corresponding values in pure $CO_2$ at gas pressures in excess of 300 kPa [3-4]. The main purpose of this work is therefore to investigate the effect of field non-uniformity and amount of $SF_6$ on breakdown voltages of compressed $N_2$, $CO_2$ and $SF_6$ mixtures under alternating voltage.

## EXPERIMENTAL SET-UP

In the experiments rod-plane and rod-plane with protrusion were used to simulate and study the effect of field non-uniformities in practical systems which usually have a relatively lower utilization factor. The relative gas pressure were varied within the range of 100-500 kPa and the electrode gaps that were 5 and 25 mm long. Experiments were carried out using a rod plane electrode with a rod tip radius of 1 mm and plane disc diameter of 75 mm. In order to simulate a distortion of the highly inhomogeneous field between rod-plane electrode a metallic spherical protrusion with 1 mm radius was fixed to the center of the plane electrode. 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 test vessel was first evacuated for at least two hours and then filled with the desired gas up to a relative pressure of 500 kPa. For the 50 Hz. AC tests with voltages up to 100 kV rms a high voltage transformer was employed. AC breakdown voltage was measured by means of a capacitive divider. The mean value of breakdown voltage and standard deviation were calculated by means of ten voltage applications. The main purpose of this work is therefore to investigate the effect of field nonuniformity and amount of $SF_6$ on breakdown voltages of compressed $N_2$, $CO_2$ and $SF_6$ mixtures with these gases with and without presence of electrode surface roughness

## TEST RESULTS

The breakdown voltages of $CO_2$, $N_2$, $SF_6$ and the mixtures of $SF_6$+$CO_2$ and $SF_6$+$N_2$ with 0.125% of $SF_6$ were measured up to a pressure of 500 kPa for rod-plane and rod-plane with protrusion electrode.

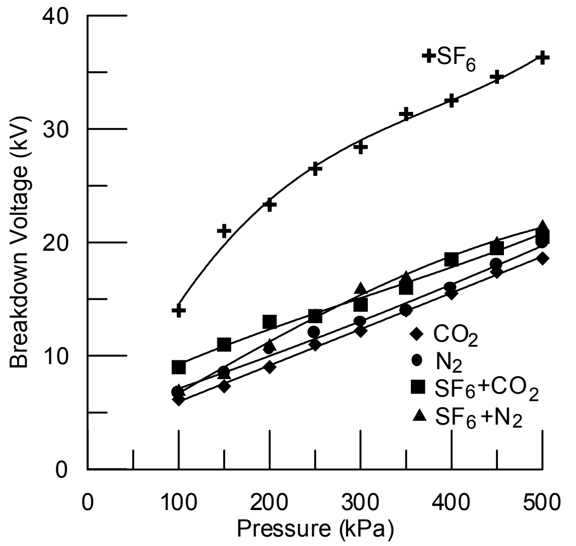


Figure 1. Variation of breakdown voltage with pressure in $CO_2$, $N_2$, $SF_6$, 0.125%$SF_6$+$CO_2$ and 0.125%$SF_6$+$N_2$ for 5 mm rod-plane gap spacing.

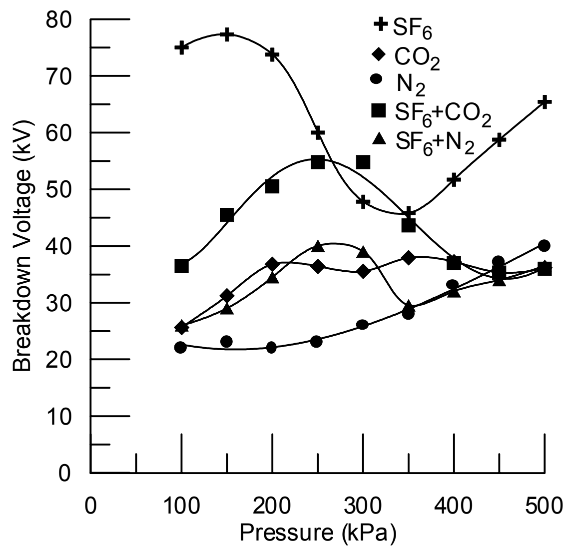


Figure 2. Variation of breakdown voltage with pressure in $CO_2$, $N_2$, $SF_6$, 0.125%$SF_6$+$CO_2$ and 0.125%$SF_6$+$N_2$ for 25 mm rod-plane gap spacing

Figures 1-4 show the AC breakdown voltages as a function of gas pressure in $CO_2$, $N_2$, $SF_6$ and $SF_6$ mixtures for 5 and 25 mm gap spacing.

Figures show the effect of gap length on the breakdown voltage pressure characteristics for alternating voltages. As the gap length is reduced the breakdown voltage peak is lowered and for a 5 mm gap no pronounced peak is observed. This effect was present at 25 mm gap. Under alternating voltages, the addition of few percent of $SF_6$ to $N_2$ and $CO_2$ causes a large increase in the breakdown of mixture voltage.

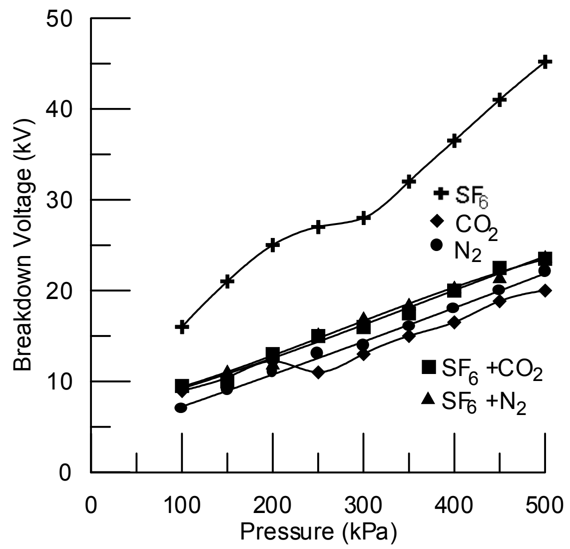


Figure 3. Variation of breakdown voltage with pressure in $CO_2$, $N_2$, $SF_6$, 0.125%$SF_6$+$CO_2$ and 0.125%$SF_6$+$N_2$ for 5 mm rod-plane with protrusion gap spacing.

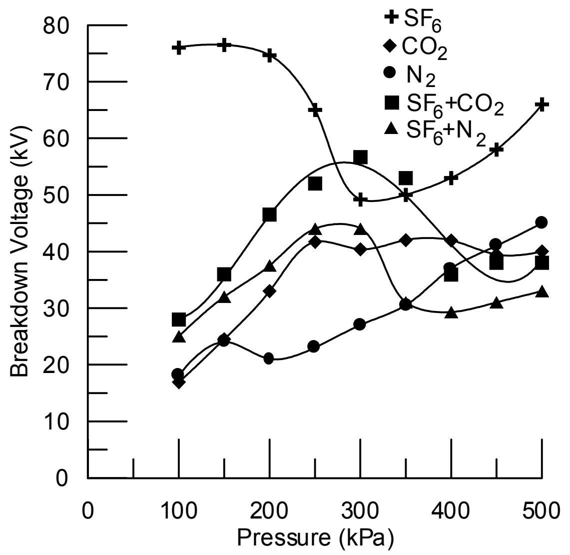


Figure 4. Variation of breakdown voltage with pressure in $CO_2$, $N_2$, $SF_6$, 0.125%$SF_6$+$CO_2$ and 0.125%$SF_6$+$N_2$ for 25 mm rod-plane with protrusion gap spacing

As seen in Fig. 1 and 3 for 5 mm gap spacing the breakdown voltage of pure $SF_6$ is higher than that of other gases. At 5 mm gap spacing, the rod-plane with protrusion electrode system is similar to uniform field so the breakdown voltages for rod-plane with protrusion gap spacing are higher than that of rod-plane gap spacing at all defined pressures. The breakdown voltages of rod-plane gap are higher than other electrode system up to the pressure at that the breakdown voltage is maximum. After that pressure, the breakdown voltages of rod-plane with protrusion electrode system are higher. This effect increases with pressure probably because of increasing space charge density and reduced diffusion at higher pressure. the result is that at high pressure, the breakdown streamers are more curved. Previous investigations in $SF_6$ with small single electrode surface protrusions showed that at pressures up to 200-500 kPa, the breakdown strength may be influenced by generating initial electrons. At higher pressures this time lag effect decreases. From observations it has been found out that $SF_6$ and its mixtures, the spark channels were affected by the total gas pressure and electrode geometry. These experiments have shown that in the pressure range pressure $p < p_m$ at which the breakdown voltage is maximum, there is a uniform corona discharge at rod tip with a few millimeters length. The spark followed the shortest distance between electrodes. By increasing the pressure to $p_m$ the streamer discharge are developed into different directions from the rod tip. This means that space charge increases the radial field strength and introduces a spark in that direction. In the region around $p_m$, the spark discharge does not follows the shortest path between electrodes, but advances along a curved path to the cathode and the designation curved spark [5]. Furthermore the movement of space charge due to ion drift and diffusion process will also be affected by the total pressure, field configuration and waveform of the applied voltage. As it has been seen from our experiments, for 25 mm gap spacing the breakdown voltages of rod-plane with protrusion are higher than those of other electrode system for high pressures (200-500 kPa). Because of curved path, the electrode gap spacing is higher than that of rod-plane electrode system. At above 350 kPa the breakdown voltages of mixtures drop below than those of pure $N_2$ and $CO_2$. Earlier experiments show that, at mixtures with less than 1% $SF_6$, similar observations have been reported for direct voltage, lightning and switching impulses Earlier authors reported that for $SF_6$+$N_2$ mixtures, the corona onset levels of $SF_6$+$N_2$ mixtures are higher than those of nitrogen but since at such high pressures the corona stabilization is more effective in nitrogen than in $SF_6$, the breakdown voltages of mixtures containing low $SF_6$ content drop below that of nitrogen [6-8]. The breakdown voltages of $SF_6$+$CO_2$ mixtures were obtained higher than those of pure $SF_6$ at the pressure range of 250-350 kPa for 25 mm gap spacing but the breakdown voltages of $SF_6$+$N_2$ mixtures obtained lower than those of pure $SF_6$ at all defined pressures.

# CONCLUSION

The results show that in non-uniform field which is inevitable and predominant in a practical system, $SF_6$+$N_2$, $SF_6$+$CO_2$ gas mixtures are at least as good as $SF_6$ in terms of their AC breakdown characteristics. The experimental results show that in non-uniform field the AC breakdown strength of $N_2$ and $CO_2$ in the practical range of pressure (100 to 400 kPa) may be increased by adding a small amount of $SF_6$. There are indications that these mixtures are technically and economically attractive alternatives.

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