# Impulse flashover voltages in air at low pressure

O. Kalenderli[1], E. Onal[1], A. Merev[2] and K. Mardikyan[1]
[1]Istanbul Technical University, Department of Electrical Engineering, Istanbul, Turkey
[2]TUBITAK, National Metrology Institute (UME), Kocaeli, Turkey

**Abstract:** In this study, impulse flashover experiment results on insulator specimens with different profiles in a uniform electric field in air at low pressure are presented. Under positive and negative impulse voltages, two types insulators are placed between two parallel plane electrodes. Breakdown in air alone is studied as a reference for comparison. Because the space charges are accumulated in the insulator, a higher electric field is required for breakdown air rather than along insulator surface. It is shown that a strong relation between the discharge propagation and breakdown exists; the insulator profile exerts similar influence on the breakdown field as on the propagation field. The positive impulse breakdown voltages decrease due to presence of negative charges deposited on the insulator surface.

## 1. Introduction

Comparing insulators for impulse voltages as high breakdown strength, high dielectric constant, very low costs and easy maintenance are very important. In general, the breakdown voltages are strongly affected by the shape of insulator between the electrodes. Application of multiple insulators or an insulator with favorable shape lead to a significant increase in breakdown voltages.

Since dielectric barriers are useful for increasing breakdown voltage of gas-gap, the barriers are frequently applied to medium voltage air insulated switchgear and $SF_6$ insulated systems operating at moderately low pressure. Therefore, the barrier effect has been widely studied in air and the other insulating gases such as $SF_6$ [1-4]. These studies show that the insulation barriers have beneficial effects in both partial discharge characteristics and flashover voltages. The electrical strength performance of solid insulation depends on parameters characterising the dielectric and geometric properties of the insulator.

In mountain region, outdoor insulators used on transmission lines are subjected to low pressure.This environmental factor can reduce the electrical performance of insulators and sometimes in flashover. A number of power outages are considered to be related to insulator flashover due to low air pressure. In order to study the influence of high altitude on the electrical performance of insulators, a large of studies have been carried out over the past 30 years under various condition such as clean and polluted insulators under low pressure [5-7].

The impulse discharge in air at low pressure has a simple discharge channel and its reproducibility. Discharge propagation length was decreased by a small addition of $SF_6$ gas. In air and $SF_6$, electrical field near the tip of a streamer is maintained around ionisation electrical field. In nitrogen, electrical field near the tip of a streamer decreases gradually with the propagation of the streamer. The propagation time of a discharge in nitrogen is a few times as long as that in air and $SF_6$ [8-9].

Insulators used in high voltage technique, transmission lines, transformers and high voltage connection equipment provide insulation between conductors as well as insulation between earth and conductors. In addition of providing electrical insulation, insulators are an important element in electrical installations because they also allow mechanical connections to be made. Structural properties of insulators, environmental conditions such as temperature, humidity, pressure and dirt, operating conditions such as voltage level influences the reliability of them. It is, therefore, very important to investigate the effects of these conditions on insulators, to develop new designs and to determine their behaviour. There are many researches currently being conducted on this matter [1-4].

Reference [3] is about the surface discharge phenomena of different property insulators at various pressure values and positive and negative impulse voltage. Insulators depending on the service altitude and environmental conditions can be at different pressures. The humidity effect on the breakdown voltage decreases with the increase of the altitude over the sea level. The influence of the atmospheric conditions (temperature and humidity) in positive polarity is greater than that of negative polarity. Several researches are currently being conducted on the behaviour of insulators at different pressures [1]. Inserting an insulator into a electrode system usually causes a large decrease in the breakdown voltage, while it seems to have less effect on the performance of a high pressure gas gap. Generally with pulsed voltages the surface flashover voltage decreases with increasing pulse duration. If the breakdown voltage under normal atmospheric conditions is known, breakdown voltages at various pressure values around this condition can be determined using by a correction factor. However, if the pressure value is much different than the normal atmospheric pressure, determining the value of the breakdown voltage at this condition may be determined experimentally.

In this study, a series of impulse flashover tests on the insulators were carried out under air pressure varying between 100 mbar and 1000mbar, simulating high altitude conditions.

Two different type cast resin support insulators were tested to determine the impulse flashover voltages in air at low pressure between plane electrodes. One of these insulators is cylindrical and other is conical (or shuttle form) type. This paper presents determination of the impulse flashover voltages with and without high voltage insulators. Experiments were performed for positive and negative polarities for each case. Experimental tests of impulse flashover characteristics of cast resin support insulators under low pressure in dry air were carried out to investigate the factors affecting the flashover voltages.

## 2. Application and Test Results

All experiments were carried out using a disc type plane-plane electrode system with diameter of 75 mm (Fig.1).

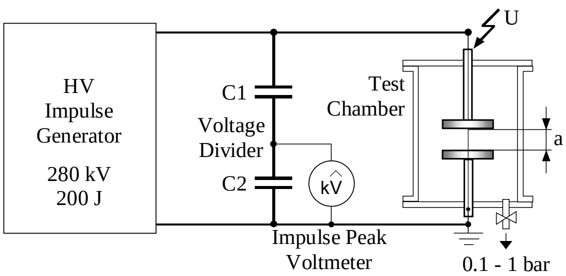


**Figure 1**. Experimental setup.

The lightning impulse voltage with a rise time of 1.2 µs and a tail time of 50 µs was produced by a 280 kV, 200 J Marx generator. The voltages were measured by means of a capacitive divider and recorded by a digital oscilloscope. The impulse breakdown voltages were determined by the "up and down method". Experiments were performed for negative and positive polarities. The shuttle and cylindrical indoor type epoxy cast resin insulators were used in these experiments (Fig 2).

The insulators each having a length of 40 mm were placed between two plane electrodes. One of the plane

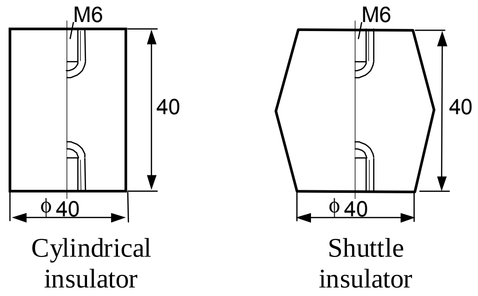


**Figure 2**. Test insulators.

electrode was connected to a impulse voltage generator while the other one was connected to ground. This arrangement was mounted in a plexiglas pressure vessel of $10^{-3}$ bar (Fig 3).

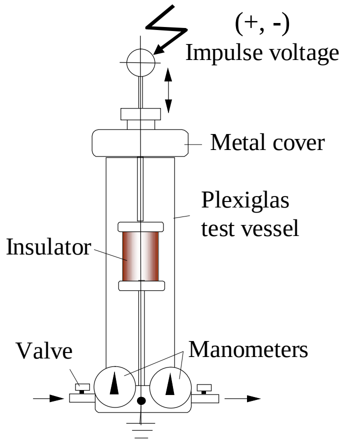


**Figure 3**. Test vessel.

The pressure of the vessel was adjusted using a vacuum pump and the pressure was measured from a manometer mounted on bottom of the vessel. Pressure in the test vessel was varied by 100 mbar step between 100 mbar and 1000 mbar. At each pressure step, positive and negative 50% impulse flashover voltages were determined. Measured breakdown voltages as a function of pressure are illustrated in Figures 4 - 9.

As shown in Figure 8 - 9 there is a minor difference in flashover voltages of electrode profiles. But the simplest shape has lower holdoff voltages than do more complex shape. It is clear from Figures 4 and 6 that the surface charging is proportional to the applied voltage and is generally positive. Pressure values which are lower than 800 mbar the breakdown voltages without insulator increases by a factor of 15-45% compared to that of with insulator. Negative charging has been observed in experiments which could resolve the charge distribution over small areas. Since there is no insulator between two electrodes, the growth from avalanches to streamer is free. The infinity of the breakdown channel

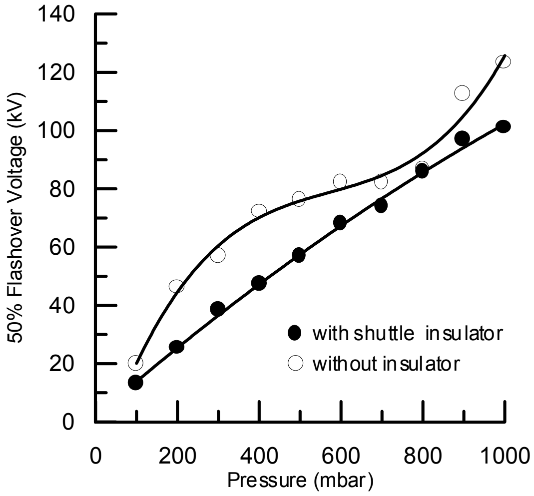


**Figure 4**. 50% positive flashover voltage versus pressure for the shuttle insulator.

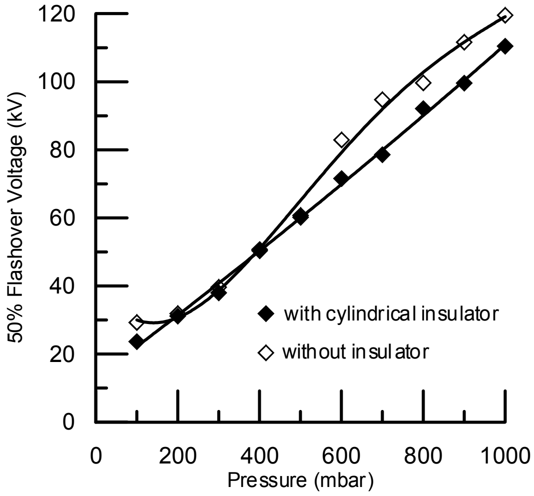


**Figure 7**. 50% negative flashover voltage versus pressure for the cylindrical insulator.

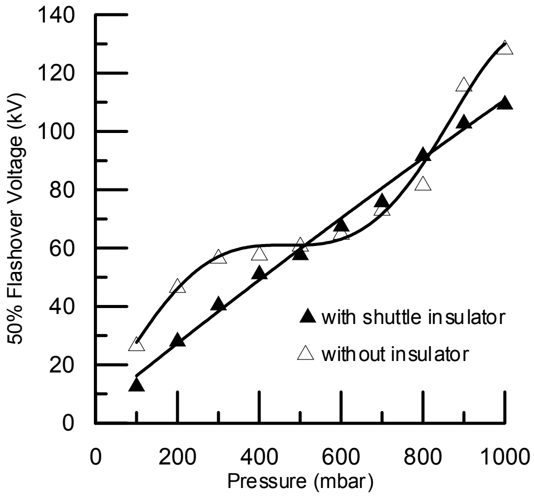


**Figure 5**. 50% negative flashover voltage versus pressure for the shuttle insulator.

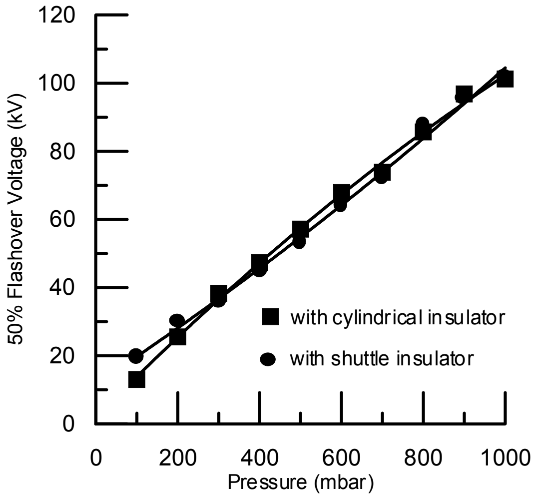


**Figure 8**. 50% positive flashover voltage versus pressure for two types insulator.

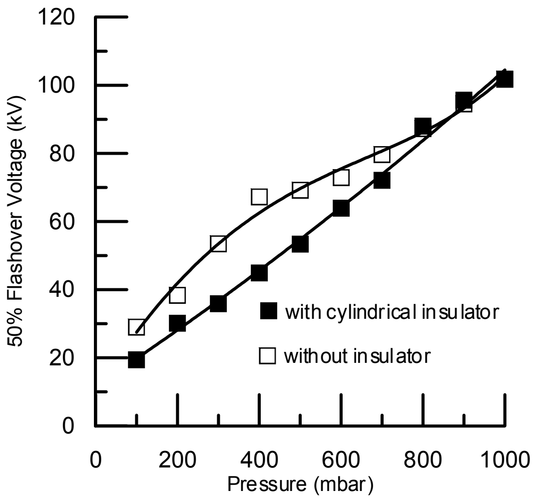


**Figure 6**. 50% positive flashover voltage versus pressure for the cylindrical insulator.

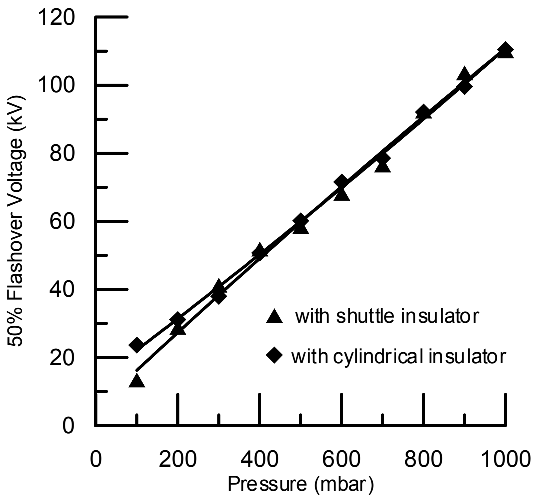


**Figure 9**. 50% negative flashover voltage versus pressure for two types insulator.

whether it follows the insulator surface or is repelled from it was investigated. It was observed that for negative lightning impulses, the breakdown channel followed the insulator surface in most cases while for the positive lightning impulses, the breakdown channel was repelled from it. Differences were found in waveforms of breakdown voltages when the breakdown channel following or being repelled from the insulator surface.

From the figures, one can see that there is no clear evidence of any polarity effect. The appearance of such in figure is deceiving and arises breakdown voltage in the negative tests than in the positive ones.

## 3. Conclusion

The experiment was conducted on plane-plane gap with the applications of positive and negative lightning impulses in the absence and in the presence of two different type insulators. This has not been clearly observed in the breakdown voltage of electrode profiles used in the experimental setup.

Studies have shown that the breakdown strength is strongly infuenced by voltage waveform.This difference is very obvious in positive voltages. The reason for this difference is probably that the amount of the trapped positive charge is larger than that of negative trapped charges. From these experiments, it is useful for preventing the flashover to apply the guiding principle on based electric line force.

Experiments with more complex profiles need to be performed, are combined with a surface charge measurement technique. We must investigate the quantitative guiding method for design of high voltage gear in future.

## 4. References

[1] J. Garcia, F. Herrera, H. Ortiz, "Study of breakdown voltage of the air altitudes, applying lightning impulses (1.2/50µs) under conditions of controlled humidity and temperature". Proceedings 11th International Symposium on High Voltage Engineering, London, UK, paper no. 3.59.S7, 1999.

[2] L. Ming, M. Leijon, T. Bengtsson, "Factors influencing barrier effects in air gaps". Proceedings 9th International Symposium on High Voltage Engineering, Graz, paper no. 2168, 1995.

[3] H. Craig Miller, "Surface flashover of insulators". IEEE Transactions on Electrical Insulation, Vol. 24, No. 5, pp. 765-768, 1989.

[4] R. A. Anderson, W. K. Tucker, "Vacuum surface flashover from bipolar stress". J. Appl. Phys. Vol. 58, pp. 3346-3349, 1985.

[5] H. M. Ryan, *High Voltage Engineering and Testing,* 2nd edition, IEE Publication, London, 2001.

[6] E. Kuffel, W. S. Zaengl and J. Kuffel, *High Voltage Engineering Fundamentals,* 2nd edition, Butterworth-Heineman Publication, Oxford, 2000.

[7] Y. Li, M. Farzaneh and J. Zhang, "Critical Flashover Voltage of Short HV Insulator Covered with Ice at Low Atmospheric Pressure". Powercon'98 International Conference on Power Technology, Beijing, China, vol. 1, pp. 520-523, 1998.

[8] Boeck W. et al. Insulating Behavior of $SF_6$ with and without Solid Insulation in case of Fast Transients. CIGRE 15.17, 1986.

[9] W. Pfeiffer, V. Zimmer, P.Zipfl; Predischarge development and dielectric strength of $N_2$, $SF_6$ and $SF_6/N_2$ mixtures stressed by very fast transient voltages, Conference On Gas Discharges and their Applications, Swansea, 1992.

**Author address:** Ozcan Kalenderli
Istanbul Technical University, Department of Electrical Eng., 80626 Maslak - Istanbul, Turkey
E-mail: ozcan@elk.itu.edu.tr