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ELECTRICAL ENGINEERING

Impact of Sand/Dust Pollution on the Engineering Design Criteria of High Voltage Air Insulated Networks

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Abstract. Outdoor air insulated, high voltage transmission and distribution networks are frequently exposed to atmospheric pollution in the form of sand and dust storms which can affect the breakdown and prebreakdown characteristics and insulation performance of air gaps. This paper summarizes the findingks of an extensive study carried out to determine the effect of sand/dust contamination on the high voltage impulse breakdown characteristics of different types of air gaps. Analysis of the results of this study highlight the influence of airborne and surface adhering sand/dust contamination on the engineering design criteria to specify clearances of overhead lines and station equipment, design and performance of protective rod gaps and the accuracy of high voltage measurements using sphere gaps.

Introduction

High voltage power networks are commonly subjected to transient over voltages. These over voltages which may be caused by lightning strokes or switching actions, determine the safe clearances required for proper insulation level. Therefore, electrical breakdown characteristics of air gaps under different types of applied voltages have great engineering significance, for these act as the dimensioning parameter in the design of air insulated high voltage network or its individual components.

In the past several decades, extensive amount of research work has been done to understand the electrical breakdown and pre-breakdown of 'clean' air gaps and there is resonable understanding about most of the phenomena involved. These efforts have lead to the formulation of internationally accepted empirical relations for the general design of safe air clearances of high voltage power networks [1,2]. However, airborne particles resulting from sand and dust storms could be of major concern for air clearances since such particles may influence the insulation behavior of open air gaps. A survey of literature reveals that only a limited amount of work has been carried out to explain the influence of such pollu8tion on the breakdown characteristics of air insulation. Most of these studies concern AC and DC stresses and are confined to air gaps of a few tens of millimeter. However, they agree in general that the presence of atmospheric particles can deteriorate the air insulation performance to as low as 40% of the clean air values [3-9]. To the best of our knowledge, no systematic study has ever been carried out which addresses the effects of sand and dust pollution in large air gaps under fast high voltage surges.

Keeping these factors in mind a research project was initiated at the High Voltage Laboratory of Kind Saud University. As environmental chamber was designed and erected to simulate the natural sand and dust storms that are frequent in the Arabian Gulf region. Different shapes of electrodes forming asymmetrical and symmetrical air gaps were employed for the study of breakdown characteristics. In our most recent work, we used standard lightning (LI) and switching impulses (SI) of both polarities and the effect of pollution on insulation behavior of different gap configurations have been presented elsewhere [10-14]. The objective of this paper is to highlight the engineering implications of sand/dust pollution and summarize the behavior of polluted air gaps which are associated with transmission line clearances, overvoltage protection equipment and high voltage measurements. The results presented are applicable to systems that posess a basic impulse level (BIL) of 1000 kV and surge impulse level (SIL) of ~ 850 kV. The engineering significance of air pollution on the design and performance of high voltage air insulated networks is also highlighted. These results are applicable to areas where atmospheric humidity remains below 11 g/m^3, and the sand/dust particles remain suspended in air for long spells.

Design of the Environmental Chamber

The reduction in insulation level will depend not only on the shape, material and size of particles which are commonly found in sand and dust storms, but also on the voltage magnitude and waveform. Usually air-borne sand particles are large ($\geq$ 200 μm diameter) and heavy, and jdo not rise more than a few meters above the ground, and pose no problem for 8-20 m high overhead transmission lines. Airborne dust particles, on the other hand, are usually smaller than 100 μm in diameter and can be found 100 m above ground level and hence dust sotrms could be of major concern both for transmission line clearances as well as for open air protective gaps [10]. A rational experimental simulation of such varying parameters can only be conducted in a closed chamber which should meet the following requirements:

a) Suitable size and material of the chamber to withstand the maximum lev4eel of anticipated stresses,
b) suitable bushing/feed-through system to connect the external high voltage source to the air gaps under test inside the chamber,
c) suitable means to supply clean air inside chamber at a known discharge rate and a filtering network to avoid recirculation of the pollutants, and,
d) flexible means for precise control of pollution feed rate.

Keeping these criteria in mind, an environmental chamber was designed for this study. It was built inside the High Voltage Laboratory which is 18 m x 20 m x 13 m in size. It is supplied with conditioned air at the ambient air pressure, a temperature of 23 ~ 25°C and absolute humidity varying in the range of 4 ~ 10 g/m^3. The salient features of the environmental chamber are as follows.

Size and material of the environmental chamber

The size of the chamber is dictated by the maximum available voltage. Generally the necessary clearances between the electrode or equipment and walls/ceiling are determined on the basis of most severe conditions, i.e. positive polarity switching impulse with the critical time to crest and highly divergent field configuration. The maximum available voltage was ±1.0 MV. Therefore, based on the switching surge breakdown data of reference [15] the value of required clearance is 2.8 m. This implies a minimum width of 5.6 m and a minimum height of 5.6 m. The chamber length, however, can be based on the length of the required HV feed-through and the size of electrodes. The construction material for the chamber structure was preferred to be of good insulating characteristics instead of metallic sheets because it was found more economical and lead to easier construction.

Design of a HV bushing

The following two options were considered for feeding the high voltage output of generator into the chamber, (i) vertical arrangement, which requires feeding the HV from the chamber top, and (ii) horizontal arrangement, which requires entry of a cylindrical HV feed-through parallel to the ground, from one of the side walls of the chamber. After economical and technical considerations, the horizontal arrangement was adopted. Consequently, the HV feed-through is inserted into the chamber through a double wall built from perspex sheets which have excellent insulating properties. Other walls of the chamber were made of wood. The final internal dimensions selected for the environmental test chamber were: width = 4 m; length = 5.6 m and height from the chamber floor = 6 m.

Metallic HV feed through is cylindrical in shape with both ends closed with metallic hemispheres. Based on a maximum field of 22 MV/m at applied voltage of 1000 kV and using the charge simulation technique, its dimensions were determined to be: length = 1.7 m and radius = 3000 mm. The combination of HV feedthrough and compound perspex vwalls, therefore, constitutes a noval high voltage bushing. It has been successfully and extensively tested up to ± 1000 kV. Figure 1 shows a schematic view of the chamber.

Pollution generation system

It consists mainly of a positive displacement screw feeder powered by a variable speed motor to provide the desired rate of dust particles. In designing the system, provisions were made to control the particulate concentration so that its feed rate remained constant and uniform over the period of a test run. Moreover, feeding and stopping could be achieved instantaneously and the system was easy to operate remotely for safety considerations.

An exhaust system was necessary to draw air outside the chamber to avoid a back pressure. The exhaust air must be clean and free of dust particles before being delivered to the laboratory space. Recirculation must be avoided. A baghouse consisting of a set of four acrylic bag filters was designed to handle the maximum inflow rate and particulate concentration. For such a purpose two rotary exhaust fans, each of a capacity of 6 m^3/s were installed.

The test dust

Dust particles were collected from the dry surface layer of open desert area around the city of Riyadh. Only particles in the range of $\leq$ 1150 μm diameter were selected by sieving. This range of particles is selected because most of the particles found in natural sand/dust storms are usually below this value as the larger particles are much heavier and can not remain in suspension in air for prolonged time periods. The particle concentration values, varying from ~ 1.0 mg/m^3 to ~ 1.0 g/m^3 were selected such that a wide range of sand/dust storm conditions are simulated. The chemical analysis of these particles has been reported in [10].

Test electrodes

For rod-plane gaps, hemispherically terminated cylindrical brass rods of 10 and 38 mm radii were used whereas the plane electrode used was 3 m x 3 m square and was fabricated by using galvanized steel sheets on a wooden frame. Hemispherically terminated as well as square cut, 30 mm diameter cylindrical electrodes were used for rod-rod gaps. In sphere-plane gap studies, sphere had a diameter (D) of 250 mm. Similarly two sets of spheres having D = 125 mm and D = 250 mm were used for sphere-sphere configuration. The electrodes were arrange axially parallel to ground plane and located at a distance of ~ 4.7 m from the ground level (3 m from the chamber floor).

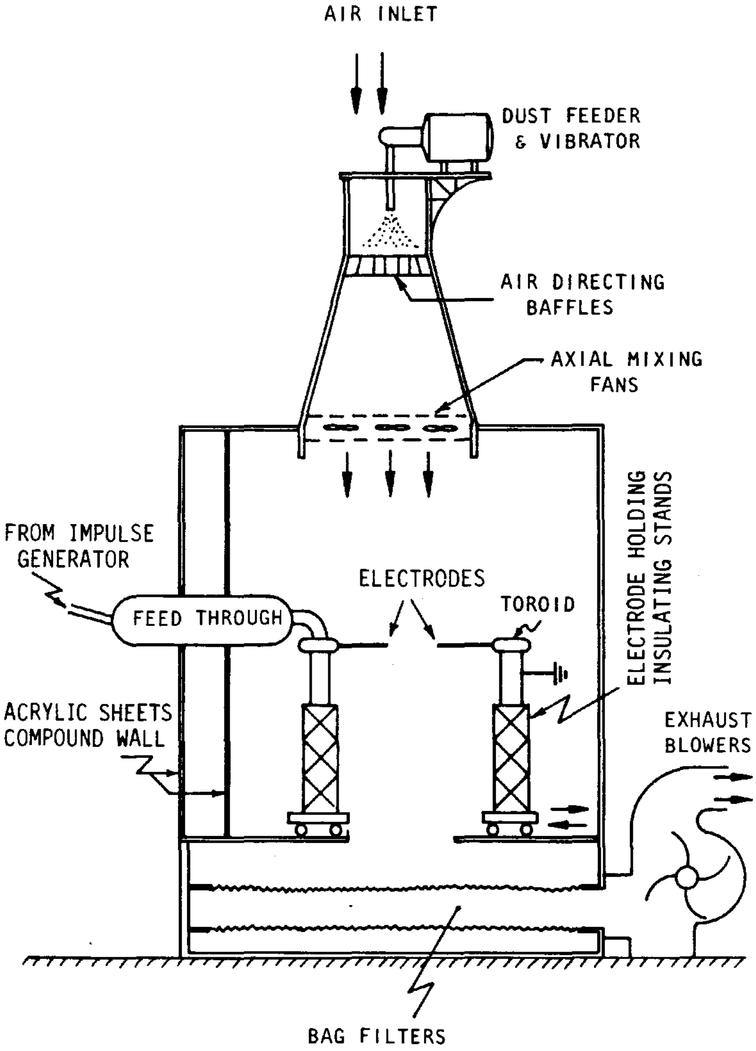

Fig. 1. Schematic view of the environmental chamber.

Experimental Setup and Procedures

The gaps were stressed with standard lightning impulses (1.2/50 μs) or standard switching impulses (250/2500 μs) using "Haefley" 10-stage ±1000 kV, 40 kJ Marx generator. Voltage output was measured using a damped RC-divider with the measurement accuracy of ±0.5%. Time lag studies were made either using a dual beam 35 MHz bandwidth oscilloscope or a "Haefely type 66" time to breakdown meter. The breakdown probability functions were measured and V_{50} values determined using statistical method [16]. The measured values were corrected to standard values of temperature, humidity and pressure according to IEC 60-2. The breakdown probability distrigbution curve for a fixed gap was determined by applying 20 impulses at a fixed voltage level. The voltage was then changed by 1 ~ 2% and the test repeated so that the shape of the curve was determined from voltage settings that ranged generally from 5 ~ 30. In order to investigate the influence of surface adhering particles, a dust storm was created in the chamber for 30 minutes and left overnight for the particles to settle on the electrode. Thus during such measurements, the electrodes were covered with a "dust film" while the gap was clean.

Results and Discussion

Air clearances of overhead power lines

From insulation point of view, the air clearances of overhead power lines are determined by the minimum impulse voltage withstand levels of asymmetrical nonuniform field gaps. In the laboratory such gaps are simulated by rod (or point) to plane geometry. In real situation, point or rod electrode represents any sharp protrusion on the conductor surface or the conductor itself whereas the plane electrode represents either the ground plane or the grounded tower structure. Therefore, the breakdown data for the rod-plane gaps are the design basis for the determination of overhead line clearances. Rod-plane gaps having large electrode gap 'd' to electrode tip radius 'r' ratios, d/r, simulate practical overhead lines more closely. However, gaps with smaller d/r ratios are also important since such gaps not only simulate the station equipment, but also provide useful informations about electrical breakdown mechanisms. In the present study, breakdown behavior of rod-plane gaps was investigated using positive andnegative lightning and switching impulse voltages up to 1000 kV and 850 kV, respectively. With these voltages, the following gap length (d) ranges were investigated thoroughly:

Positive (lightning and switching) impulses	50 mm ≤ d ≤ 20000 mm
Negative lightning impulse	50 mm ≤ d ≤ 1200 mm
Negative swtiching impulse	50 mm ≤ d ≤ 400 mm

Extensive breakdown voltage measurements were carried out for clean and contaminated gaps and the results were analyzed. It was found that for positive lightning and switching impulses, the V_{50} values (in kV) of clean rod-plane gaps can be related to d (in mm) by equations (1) and (2), respectively.

$$V_{50} = 0.547\,d + 600\,(0{,}1d)^{0.85} \qquad 100 \le d \le 2000 \text{ mm} \tag{1}$$

$$V_{50} = 11.63\,(0.1d)^{0.81} \qquad 300 \le d \le 18000 \text{ mm} \tag{2}$$

These equations are derived from the measured data and are applicable with an error of less than 1% for both rod radii (r = 10 mm and r = 38 mm) and agree reasonably well with results reported in the literature [1]. For both of these impulses, sand and dust particles in the gap and/or on the electrodes in various concentrations and size were introduced and it was observed that due to the presence of such particles, the breakdown voltages of rod-plane gaps under positive impu8lses are slightly reduced. The highest measured reduction was about 3%. However, for most of the cases, the reduction was 2% or less. Figure 2 shows typical breakdown probability distributions for one meter long, clean and dust contaminated air gap under positive lightning impulses. Since the highest reductions measured are within the range of experimental error of ± 3% allowed by IEC-60, one can ignore the influence of sand/dust pollution on V_{50} for positive lightning and switching impulses. Hence, equations (1) and (2) can be used for clean and contaminated air gaps without introducing any further correction factor to account for the presence of sand/dust particles.

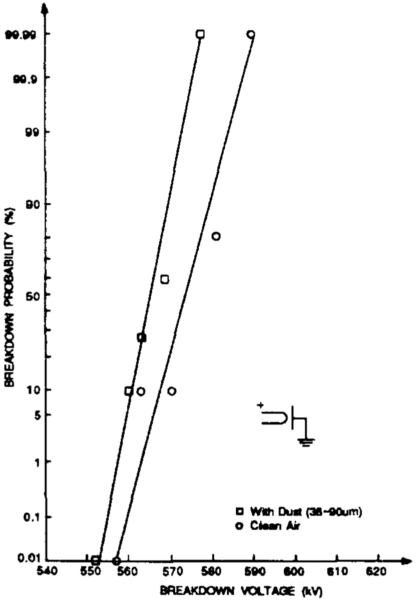

Fig. 2. Breakdown probability of clean and dust contaminated 1 m long air gap under positive lightning impulse, rod radius = 38 mm.

Since air brakdown under impulse voltages is a statistical phenomena, the breakdown voltages exhibit some scatter. This scatter in breakdown voltages can best be described quantitatively by standard deviation (σ). In the literature, the values of σ for clean air gaps have been reported as 2% for positive lightning impulses and 5-6% for positive switching impulses [1]. From present measurements, it is found that for positive lightning and switching impulses σ is respectively $< 2\%$ and $\leq 5\%$ under both clean and sand/dust contaminated conditions and such contaminats do not increase σ significantly.

For a given gap, the breakdown voltages under negative lightning or switching impulses are usually significantly higher than the corresponding positive polarity values. Moreover, for negative polarity impulses, V_{50} depends upon d as well as r, and it can not be related to d by some simple equation. The atmospheric pollution has a major effect on the breakdown voltages of rod-plane gaps under negative impulses. This effect depends on d, r and the impulse voltage waveform, and can best be summarized by Figs. 3 and 4

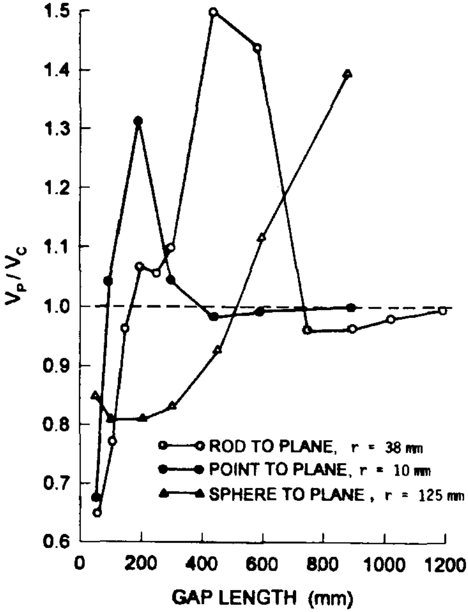

Fig. 3. The value of polluted gap V50 (Vp) to clean gap V50 (Vc) ratio as a function of gap length under negative lightning impulse for asymmetrical electrodes. Sphere radius = 125 mm.

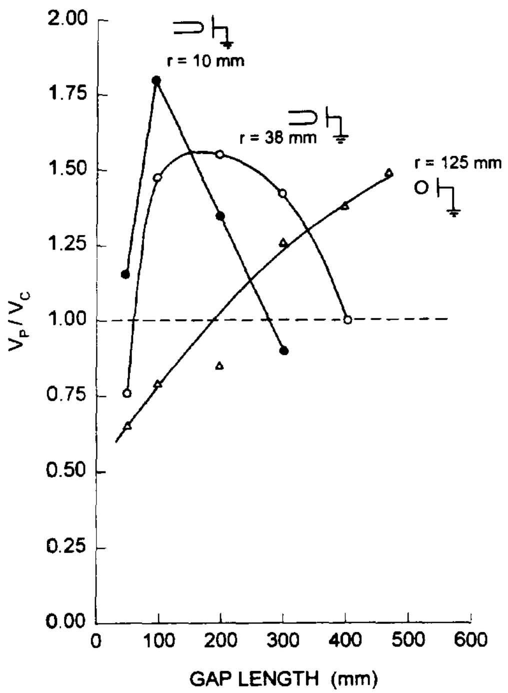

Fig. 4. Ratio of (VF/Vc) as a function of gap length under negative swwitching impulses.

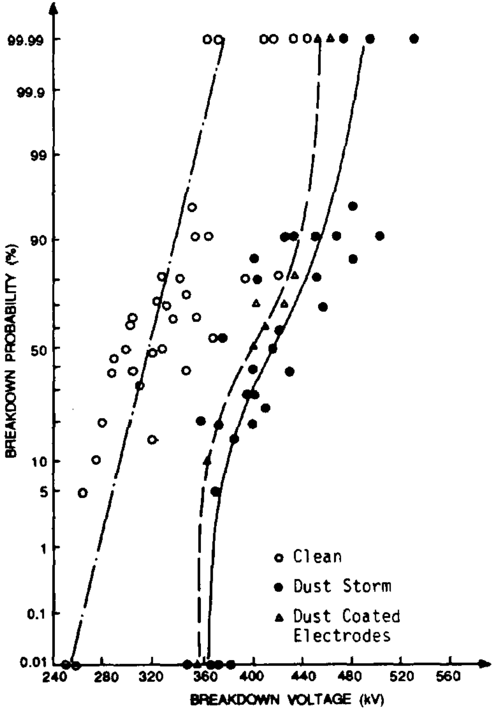

Fig. 5. Negative lightning impulse breakdown probability distribution for clean and dust contaminated air gap, r = 38 mm, d = 300 mm.

for lightning and switching impulses, respectively [10,11]. From these figures it is clear that for smaller gaps, there are significant (up to 35%) reductions in V_{50} whereas for medium gaps there is up to 75% increase in V_{50} due to atmospheric pollution. For larger gaps, atmospheric pollution has minimal influence. The results also show that for most of the gap length range employed in power lines, the breakdown voltages under negative polarity impulses are either higher or practically similar to the values observed under positive polarity impulses even under extreme particulate pollution. Only in very small gaps, negative polarity has lower breakdown voltages than the corresponding positive polarity values in contaminated gaps.

Figure 5 shows an example of breakdown probability distribution functions for a gap which exhibits an increase in negative impulse breakdown voltages due to dust contamination in the gap (dust storm curve) or due to dust coated electrodes (dust film curve). After extensive measurements and their analysis, it was concluded that most of dust related effect were due to dust particles deposited on the cathode. This was true for almost all electrode configurations.

Amongst lightning and switching impulse voltages, positive switching impulses have the lowest brakdown gradients. This is the reason that the insulation requirements of overhead power lines are determined by positive switching voltages for systems with rated voltages of over 300 kV_{rms}. Below this level, the insulation requirements are based upon the positive lightning impulse breakdown characteristics since at this voltage range switching overvoltages are not too excessive. The withstand voltage level (V_w) of a gap is generally defined as $V_w = V_{cr} - 3\sigma$, where V_{cr} is the critical or minimum V_{50} and s is the standard deviation. For lightning impulses, V_{cr} is practically the same as V_{50} and s is the standard deviation. For lightning impulses, V_{cr} is practically the same as V_{50} and can be obtained from equation (1). For switching impulses which can have a wide variety of waveform parameters, V_{50} depends upon the rise time of the impulse and can deviate from values given by equation (2) which is valid only for standard switching impulses (250/2500 μs).

Since positive polarity V_{50} as well as s are not significantly affected by pollution, the withstand voltages of air gaps are also not expected to change in the presence of sand/dust pollution. Hence, modification is not required for the design criterion to determine air clearances of overhead power lines to account for sand and dust storms in the arid regions for air clearances of up to 2 m. In such environment, positive impulse will have the lowest breakdown strength regardless of the type or severity of the air pollution. Consequently, positive lightning impulse will dictate the clearances for power lines of less than 300 kV_{rms} (line to line). It is not possible to speculate on the influence of air pollution on the required clearances for higher (> 300 kV_{rms}) voltage lines, as such lines are designed based on switching impulse breakdown characteristics of longer gaps having surge impulse level (SIL) of ≥ 800 kV. They could not be investigated thoroughly in the present study due to limitations of available voltage level. However, it is anticipated that such large gaps will not be significantly affected by air pollution as far as their switching impulse breakdown behavior is concerned.

Air clearances of station equipment

The outdoor substation equipment often uses large area electrodes to minimize corona effects and/or to grade voltage distribution uniformely. Such large electrodes result in air gaps with quasiuniform field distributions. As shown in Figs. 3 and 4, particle contamination can reduce significantly the negative lightning and switching impulse breakdown voltages of such quasiuniform field gaps. The results of the present study show that the gap length region where V_{50} is reduced due to particulate pollution is linearly related to the rod radius for both types of impulse as shown in Fig. 6. This figure shows that as the cathode radius is increased, the particulate pollution causes a reduction in the corresponding larger gap length region. Since station equipment can have electrodes of large radii, the gap length regions where atmospheric pollution may cause a reduction in the negative impulse breakdown voltages will also be correspondingly large. Consequently, under such conditions, in polluted environment the breakdown voltages under negative polarity impulses may become even lower than the corresponding positive polarity impulses. Therefore, under such conditions, the design criteria have to be modified. Hence, in the selection of proper clearances for station equipment, negative impulse may become more critical than the positive ones and if the equipment has to operate in an environment where sand/dust storms are frequent, the influence of atmospheric pollution must be carefully considered.

Performance of protective gaps

An important aspect of the insulation design of overhead lines and substation equipment is to ensure that the flashovers associated with over-voltages are restricted to protective gaps. Rod gaps of various configurations are widely used for this purpose. The most commonly adopted configurations are either square-cut or hemispherically terminated rod-rod electrodes. Recent report of IEEE working group [17] recommends to base the withstand voltages of protectives gaps on lightning impulse withstand voltages (BIL) for all system voltages of ≤ 3000 kVrms (line to line). For higher system voltage, switching impulse levels (SIL) are the criterion for protection.

In the present study the effects of atmospheric pollution have been studied for rod-rod gaps by employing hemispherically ended as well as square cut rod electrodes, up to a voltage level of ± 1000 kV for standard lightning impulses. Therefore, the study covers comprehensively the BIL for power systems operating up to 300 kV. Although, studies under standard switching impulses carried out so far have been confined to ± 750 kV, these results are of significant value, as they explain the complex mechanisms involved in the initiation of air breakdown in the presence of sand and dust pollution. The rod gaps and gap length ranges studied under different voltage waveforms are summarized in the following table.

Table. Empirical V_{50} breakdown voltage relations for different voltage waveforms in rod-rod gaps (voltage in kV and d in mm); LI = standard lightning impulse, SI = standard switching impulse. Relations given are valid in general for d ≥ 500 mm.

Voltage waveform (mm)	Gap range investigated terminated rods, V_{50} =	Hemispherically terminated rods V_{50} =	Square cut rods,
+LI	50-1250	0.6d + 75	0.6d + 50
-LI	50-1250	0.63d + 120	0.63d + 50
+SI	50-1200	0.58d + 70	0.564d + 60
-SI	50-900	0.73d	0.73d

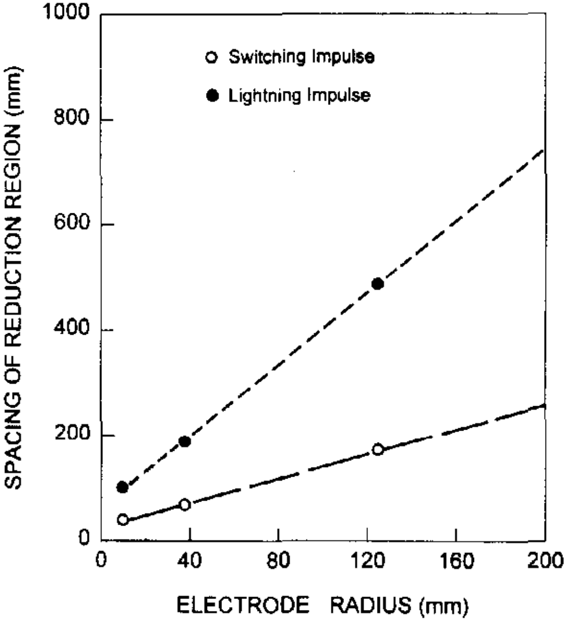

Fig. 6. Range of breakdown voltage reduction region as a function of cathode radius under negative lightning and switching impulses.

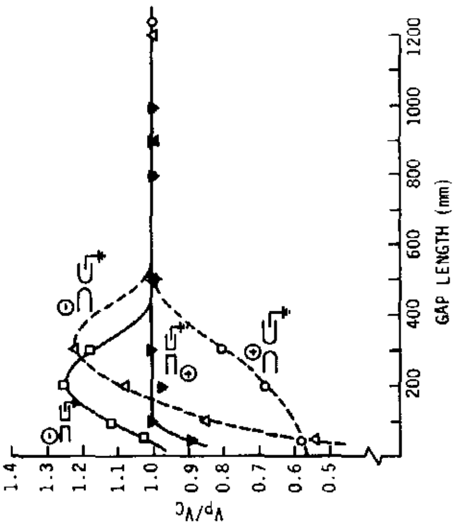

Fig. 7. The (V_p/V_c) ratio as function of gap length under negative and positive lightning impulses for hemispherical and square cut rod gaps.

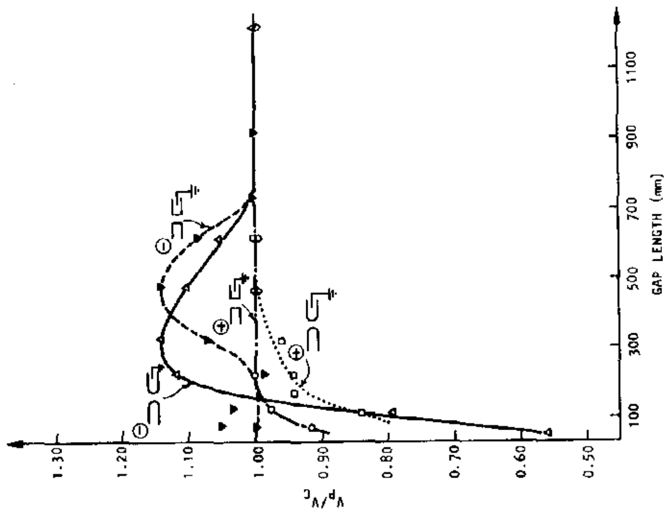

Fig. 8. The (V_p/V_c) ratio as a function of gap length under switching impulses.

The studies under lightning and switching impulses show that dust and sand pollution has a considerable effect on the average breakdown voltage gradient (V50/d). The magnitude of this effect is dependent on polarity, electrode shape and gap length. Figures 7 and 8 compare the V_{50} under clean and polluted conditions for lightning (LI) and switching impulses (SI), respectively for both polarities and for both rod end shapes [12,15]. It is clear that the pollution effect can be divided into three distinct regions. In case of LI, for small gaps in which $d/r \leq 4$, V_{50} for polluted gap (Vp) values for LI of both polarities are about 40% and 10% lower than the corresponding V_{50} for clean gap (Vc) values in hemi-spherically terminated and square cut rod gaps, respectively. For the medium gap region, which covers $4 < d/r < 30$, both types of rods exhibit an increase in V_{50} varying from 2 to 25% due to presence of dust particles under negative LI. However, under positive LI, hemispherically ended rods exhibit around 2-40% pollution related reductions in V_{50}. On the other hand, square cut rods are less affected by particles and difference between Vp and Vc is usually less than 3%.

A similar behavior is observed for both types of rods when subjected to SI voltages, as illustrated in Fig. 8. However, under SI voltages the boundaries of the three distinct regions are different. Small gap region ($d/r < 6$) exhibit pollution related reductions in V_{50} of about 45% under both polarities. The medium gap region lies in the range $6 < d/r < 45$ and in this gap region, the pollution related increases in V_{50} under negative SI voltages do not exceed 14%. Similarly, decrease under positive SI voltages in hemispherically ended rod gaps remains lower than 15%. However, square cut rods gap are least effected by pollution as Vp and Vc values are within ± 3%. It is interesting to point out that the gap range in which pollution displays severe effect, is confined to BIL level of around 450 kV. This is alarming since it corresponds to nominal operating voltages of ≤ 1132 kV. In particular, the systems operating at medium voltage levels of 33 and 66 kV are most susceptible to pollution related deviations in the protective gap performance characteristics. The performance of medium voltage protective gaps in the presence of sand/dust contamination is being investigated throughly and will be reported in the future.

The results show that in gap spacing of $50 \text{ mm} < d < 500 \text{ mm}$, it is not possible to express V_{50} versus d characteristic, by some simple mathematical relationship, under all types of voltage waveforms investigated. However, for larger gaps, V_{50} varies linearly with d as shown by different equations summarized in Table 1. It is an important and interesting finding, since for both types of rod gaps investigated the V_{50} values under polluted conditions do not vary by more than ±2% as compared to the clean gap values, if d/r is kept ≥ 30. This is equally applicable for both polarities and both types of impulse voltages. Similar to V_{50} studies for gaps with $d/r \geq 30$, the scatter in the values of breakdown time (T_b) is considerably reduced for polluted gaps while the mean T_b values do not deviate more than 3% for polluted gaps. Figures 9 and 10 show two examples of volt-time characteristics for clean and polluted gaps under lightning and switching impulses of positive polarity in hemispherically terminated rod, gaps. Similar to rod-plane gaps, it was also observed in rod-rod gaps that most of pollution effects can be attributed to surface adhering dust particles as shown in Fig. 9. American standard CD801-1968(R1973) gives V_{50} values for 20 ~ 2400 mm rod-rod gaps when subjected to lightning impulse with an accuracy of ±8%. Similarly results of V_{50} from several of the European laboratories for rod-rod gaps give differences as high as ±10% [18]. Therefore, changes of up to ±3% caused by sand and dust storms can be considered practically insignificant, and protective rod gaps can be safely designed for sand and dust storm hit areas, based on the clean gap criteria, provided the square cut rod electrodes are selected with $d/r \geq 30$. This conclusion is confined to rod gaps of up to 1.25 m which were investigated in this study. For larger gaps, definite recommendations can only be made after necessary investigations are carried out.

High voltage measurements using sphere gaps

Sphere gaps are commonly used for measurements of peak values of high voltages and have been adopted by IEC and IEEE as a calibration device with a measurement accuracy of ±3%. The presence of sand/dust pollution in the air gap or on the sphere surface can significantly influence its breakdown behavior. Figure 11 shows an example of the dust pollution effect on the breakdown probability distribution of sphere-sphere gaps under positive and negative switching impulses. From numerous such measurements, the results of Fig. 12 are derived which display the (V_P/V_c) ratio as a funcltion of d/D for spheres of two different diameters [14]. This figure shows that for the gaps which are employes as high voltage measurement devices ($d/D \leq 0.5$) air pollution causes a reduction in breakdown voltages. Similar results were obtained for lightning impulses. It is well known [16,19] that the sphere gaps should be adequatly irradiated to get reproducible results with an accuracy of ±3%.

It was confirmed in this study also, as it was observed that if the spheres are clean but "hidden" from the light generated by the impulse generator spark gaps, the breakdown voltages can be up to 100% higher than those given in standard tables [19]. If the gap receives enough ultraviolet light, the presence of dust pollution does not have any major influence on the breakdown voltages of such gaps. In unirradiated gaps, the sand/dust pollution makes the measured V_{50} values closer to those given in standard tables for irradiated gaps and therefore does not adversely influence the measurement accuracy. In fact, it improves the accuracy of impulse voltage measurement by reducing the scatter in the breakdown data. However, when measuring high AC voltages, the presence of pollution on the spheres or in the air gaps can influence the measurement accuracy by up to 6% and should be taken into account and the measuring spheres should be properly cleaned.

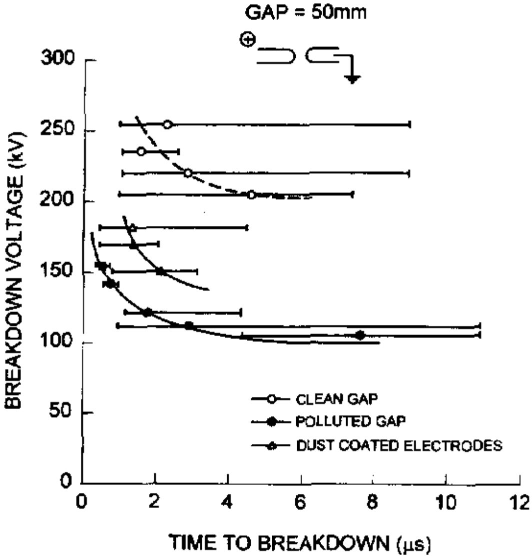

Fig. 9. Effect of dust pollution on V-t characteristics of hemispherical rod-rod gaps under positive lightning impulses.

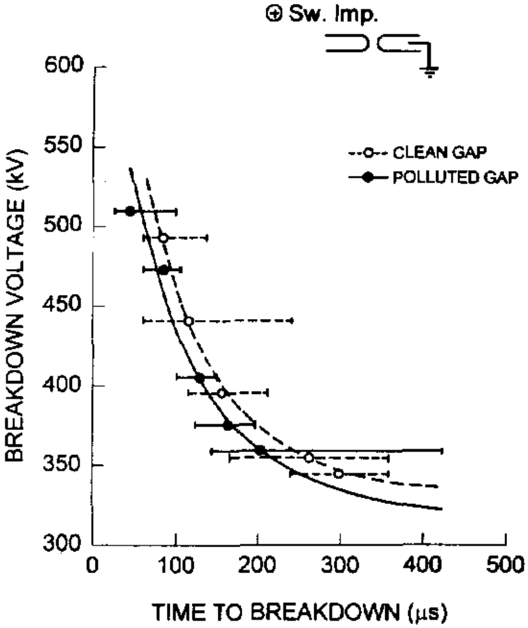

Fig. 10. V-t characteristics of a 600 mm rod-rod gap under positive switching impulses.

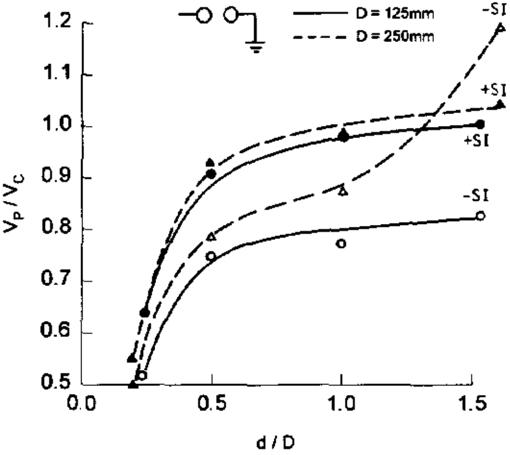

Fig. 12. The (Vp/Vc) ratio as a function of gap length (d) to sphere diameter (D) ratio (d/D) for two sphere diameters under switching

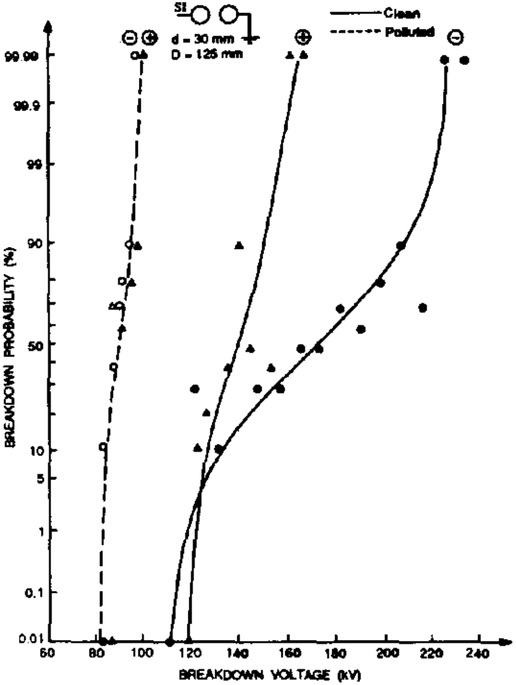

Fig. 11. Breakdown probability of sphere-sphere gaps for clean and polluted conditions under switching impulses.

Conclusions

The following specific conclusions can be extended from this study:

a) The presence of sand/dust pollution in the air and on the electrode surfaces has negligible effect on the allowable clearances for overhead power lines and the presence of such particles can be ignored in the design of high voltage distribution and transmission lines with BIL ≤ 1000 kV and SIL 850 kV. However, in polluted environment negative impulses can be more critical than positive polarity impulses in quasi-uniform field electrode gaps, such as those used in station equipment. Therefore, in the design of such equipment, the influence of atmospheric pollution should be carefully considered.

b) The pollution particles can significantly influence the design and pejrformance of rod-rod protective gaps, and, in areas where sand/dust storms are frequent, choice of rod shape and its diameter is very important. If square cut rod gaps are used with d/r ≥ 30, the pollution effects are minimal and reliable volt-time characteristics are obtained.

c) In the measurements of high voltages using sphere gaps, particulate pollution can adversely effect the accuracy of HVAC measurements by up to 6% and should be taken into account. When measuring high impulse voltages, the presence of pollution particles reduces the scatter in data and significantly improves the measurement accuracy which can be further improved to acceptable levels by using artifical ultraviolet irradiation.

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References

[1] Meek, J.M. and Craggs, J.D. Electrical Breakdown in Gases, New York: John Wiley and Sons, 1978.

[2] UHV Transmission Line Reference Book, California, USA, EPRI, 1982.

[3] Peier, D.W. and Groschopp, H. "Weuhselspannungsmessungen mit Kugelfunkenstrecken auf reiluftversuchsfeldern" PTB-Mitteilungen, 87, (1977), 396-398.

[4] Schulz, W. "The Influence of Dust on the A.C. Breakdown Voltage of a Rod Gap in Air". *6th Int'l Conf. on Gas Discharges and Their Applications*, Edinburgh, UK, (1980), 155-158.

[5] Al-Sayed, M.L. "Effect of pollution on the Breakdown Voltage of Air". *Proc. IEE*, 125, No.7 (1978), 714.

[6] Awad, A. "Breakdown Voltage of Medium Air Gaps under Sandstorms or Humidity Conditions in Desert". *6th Int'l Conf. on Gas Discharges and Their Applications*. Edinburgh, UK, (1980), 151-154.

[7] Schulz, W. "Erratic Breakdown in Air Due to Impurities in the Presence of Direct and Alternating Voltages". *3rd Int'l Symposium on High Voltage Engineering*, Milan, Italy, (1979), 52-05.

[8] El-Rafaie, A.S. and Awad, M. "Effect of Sand Particles on DC Breakdown Voltages in Air". ACTA Technica CSVA, 2, (1984), 133-137.

[9] Maartenussen, K.H. and Bozzoli, G.R. "Study of the Effects of Dust Particles on Breakdown Voltages in Air" *Trans. of the South African IEE*, 55, pt.4, (1964), 131-141.

[10] Al-Arainy, A.A., Malik, N.H., and Qureshi, M.T. "Influence of Sand/Dust Contamination on the Breakdown of Asymmetrical Air Gaps under Lightning Impulses". *IEEE Trans. on Elect. Insul.*, EI-27, No.2 (1992), 193-206.

[11] Al-Arainy,A.A., Malik, N.H. and Qureshi, M.I. "Influence of Sand/Dust Contamination on the Breakdown of Asymmetrical Air Gaps under Switching Impulses". *IEEE Trans. on Dielectrics and Electrical Insulation*, 1, No.2 (1994), 305-314.

[12] Qureshi, M.I., Al-Arainy, A.A. and Mallik, N.H. "Performance of Rod-Rod Gaps in the Presence of Dust Particles under Lightning Impulses". *IEEE Trans. on Power Delivery*, PWRD-6, No.2 (1991), 706-714.

[13] Qureshi, M.I., Al-Arainy, A.A. and Malik, N.H. "Performance of Rod-Rod Gaps in the Presence of Dust Particles under Standard Switching Impulses". *IEEE Trans. on Power Delivery*, 8, No. 3 (1993), 1045-1051.

[14] Al-Arainy, A.A., Malik, N.H. and Qureshi, M.I. "Influence of Dust Polution on the Switching Impulse Breakdown of Sphere Gaps". *The Arabian Journal for Science and Engineering*, 35, No. 3 (1995).

[15] Herbeck, G. and Menemenlis, C. "Switching Impulse Breakdown Voltage of Very Long Rod-Plane Gaps". *IEEE Publication 33.03-T F-03*, 13, 1975.

[16] IEC Publication 60-2, 4, *High-Voltage Testing Technique*. 1973.

[17] IEEE Working Group Report. "Sparkover Characteristics of High Voltage Protective Gaps". *IEEE Trans. on PAS*, PAS-93, (1974), 196-205.

[18] Batz, H. "Comparative Impulse Tests with Impulse Voltage on Rod-Gaps". *CIGRE Report No. 325*. (1962).

[19] IEC Publication 52, *Recommendations for High Voltage Measurement by Means of Sphere-Gaps (One Sphere Earthed)*, 1960.

تأثير الأتربة والغبار على التصاميم الهندسية لشبكات الجهد العالي المعزولة بالهواء

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ملخص البحث. تتعرض شبكات الجهد العالي الخارجية والمخصصة لنقل وتوزيع الطاقة الكهربائية إلى التلوث الصحراوي على شكل عوالق ترابية وطينية والتي قد تؤثر على عملية الانهيار للثغرات الهوائية وما قبله وخصائص عزلها.

تلخص هذه الورقة النتائج التي توصلنا إليها بعد دراسة مستفيضة عن تأثير الأتربة والغبار على خصائص جهد الانهيار النبضي لثغرات هوائية متباينة الأطوال والأشكال. ركّز تحليل هذه النتائج على تأثير العوالق الترابية والطينية وما يترسب منها على الأقطاب في التصاميم الهندسية حيث تحديد أبعاد الخطوط الهوائية ومحطات التحويل وكذلك الأبعاد اللازمة لقضبان الحماية والدقة في القياس عند استخدام الكرات المعدنية.