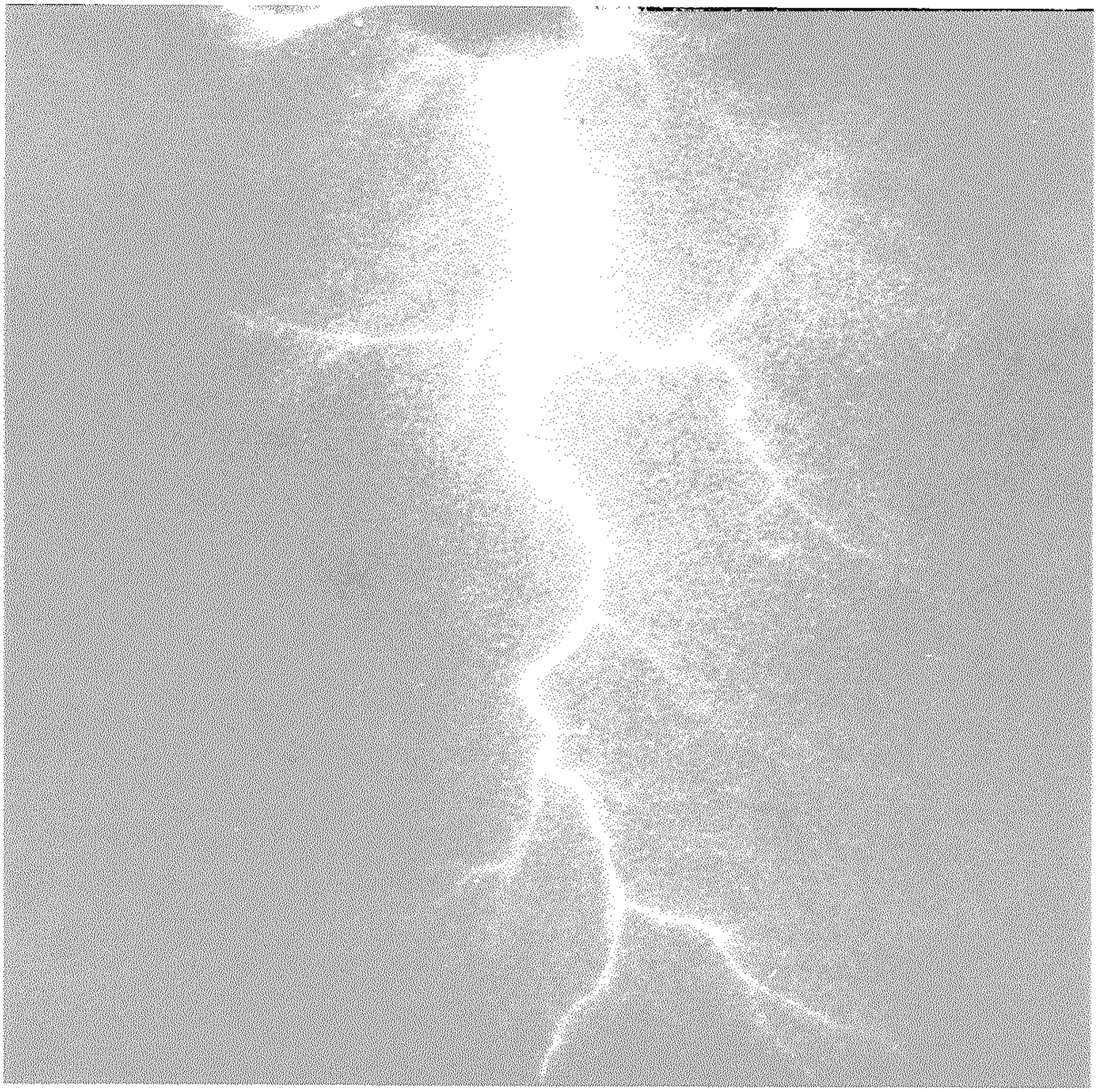
HAEFELY

Mechanism to explain the switching impulse phenomena

K. Feser



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1. Introduction

The problem of the dielectric strength of the air is best shown on figure 1. It is recognized that for a rod-plane spark-gap when a positive switching impulse is applied on the rod, the lowest air dielectric strength is attained. This figure is particularly interesting because all voltage stresses are measured on the same spark-gap in comparable surrounding conditions.

For the negative voltage stresses on the blunt edged electrode the 50% breakdown impulse voltages resp. the mean value of the breakdown voltage for the considered voltage stresses are about the same. In the case of the positive polarity on the blunt edged electrode, a linear rise of the mean value of the breakdown voltage resp. of the 50% breakdown impulse voltage is obtained with DC and lightning impulse voltages, while the reference line of the 50% breakdown voltage for switching impulses runs according to a parabola at a definite distance (a > 40 cm).

It is interesting to mention the transition region with short distances and positive switching impulses. In this range the breakdown can be caused by two different pre-discharges (1). The transition regions for other voltage stresses were also observed with changes of the predischarge. Nevertheless this change of the predischarge for the voltage stresses concerns lower voltages and is not taken here into consideration anymore. The 50% breakdown voltage for positive switching impulses for the following precisely examined stress phenomena is given by the relation:

$$U_{d\,50} = 100 \sqrt{\frac{a}{2} + 1} - 250$$

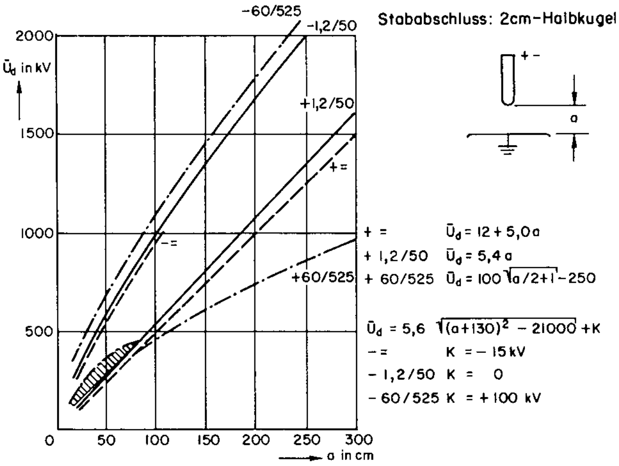


Fig. 1. Breakdown voltage of rod-plane-spark-gap in air. Influence of the wave shape

This equation is valid for the 50% breakdown switching impulse voltage for a gap distance range of 40 cm ≦ a ≦ 3000 cm. It is known since many years that the minimum value of the 50% breakdown switching impulse voltage rises to larger front durations if the distance is increased.

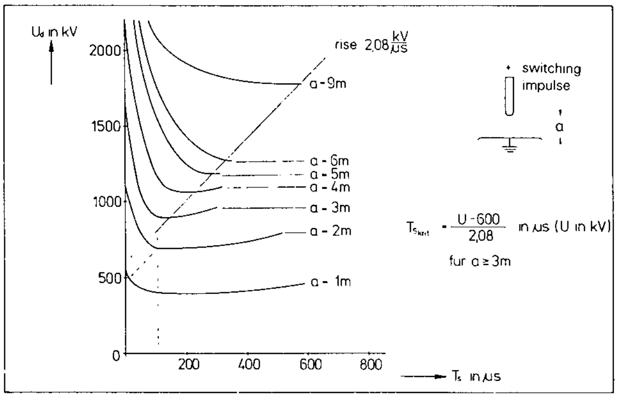


Fig. 2. Breakdown voltage of rod-plane-spark-gap in air. Influence of the front duration

On figure 2 the mean value of the breakdown voltage in relation to the front duration with the distance as parameter is again indicated according to Russian results (2) and a measurement from Watanabe (3) for a distance of 9 m. It can be remarked from this figure that the minimum breakdown voltage lies on a straight line for a distance of at least about 3 m. Therefore the critical front duration for any chosen amplitude of switching impulse of the dielectric strength of an insulating arrangement in the air can be given by the formula:

$$T_{S_{krit}} = \frac{U - 600}{2{,}08} \quad \text{in } \mu s \ (U \text{ in kV})$$

For example we obtain a critical front duration of 675 μs for a switching impulse of 2 MV. For small distances up to about 3 m the minimum breakdown voltage lies at about 110 μs. According to these considerations it is clear that for the dielectric strength of air insulation in an inhomogeneous field distribution the rise of a positive, unipolar impulse of 2,08 kV/μs is particularly critical. In order to be able to simulate the sharpest stress during electrical tests it is advisable not to use a definite front duration (i.e. 250 μs) but rather a wave with a voltage rise of about 2,08 kV/μs.

When the test voltage is reached, the linear increasing switching impulse must be suppressed on the test object by means of a suitable chopping device.

2. Influence of the predischarges on the breakdown voltage

If it is desired to explain the differences in the breakdown voltages of spark-gaps in the air in inhomogeneous fields, the predischarge process must be investigated as the breakdown phenomenon is much influenced by these predischarges (1), (5). In particular, and this is important for practical purposes, the breakdown voltage of a given arrangement, mainly regarding the voltage requirements, is dependent upon the predischarge occuring before the breakdown (4).

For the sake of completeness the various predischarge phenomena are shown in figure 3 for a positive, blunt edged electrode. Four different predischarge shapes are possible with a positive, blunt edged electrode, where the existence range for the various predischarge phenomena depends upon many parameters (5).

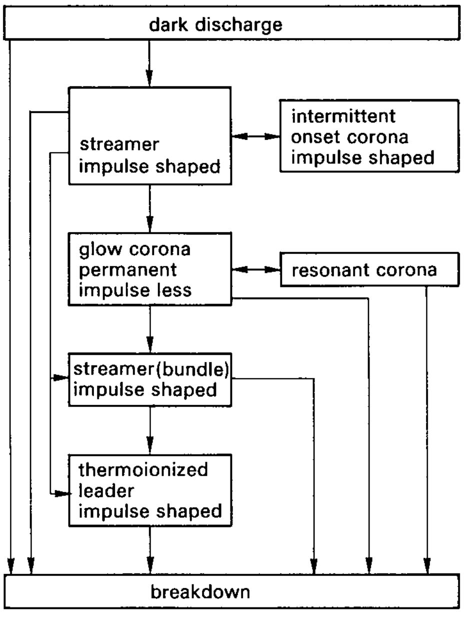


Fig. 3. Schematic representation of the various predischarge phenomena on a blunt edged electrode with positive voltages

Two discharge shapes are interesting for the breakdown process with positive switching surges; these will be considered in detail hereafter:

1. The streamer corona, because, as the discharge phenomena occurs after the onset voltage, with increasing voltage, it can follow
2. the leader corona.

According to which of the two predischarges takes place, a different breakdown voltage will occur. The relationship between the breakdown voltage and the predischarge is recognizable with the help of figure 4.

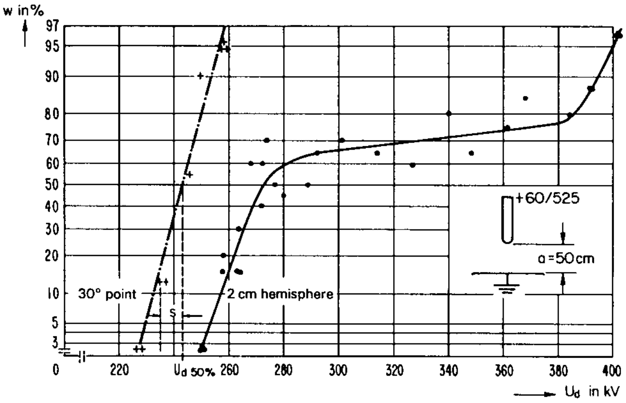


Fig. 4. Breakdown probability of a 50 cm rod-plane-spark-gap in air with switching impulses. Influence of the electrode shape

On this figure is shown the breakdown probability of a 50 cm rod-plane-spark-gap with 2 cm hemisphere as electrode termination on the anode, with a switching impulse stress of 60/525. The mixed distribution of the breakdown voltage shows clearly that two significant parameters influence the breakdown process.

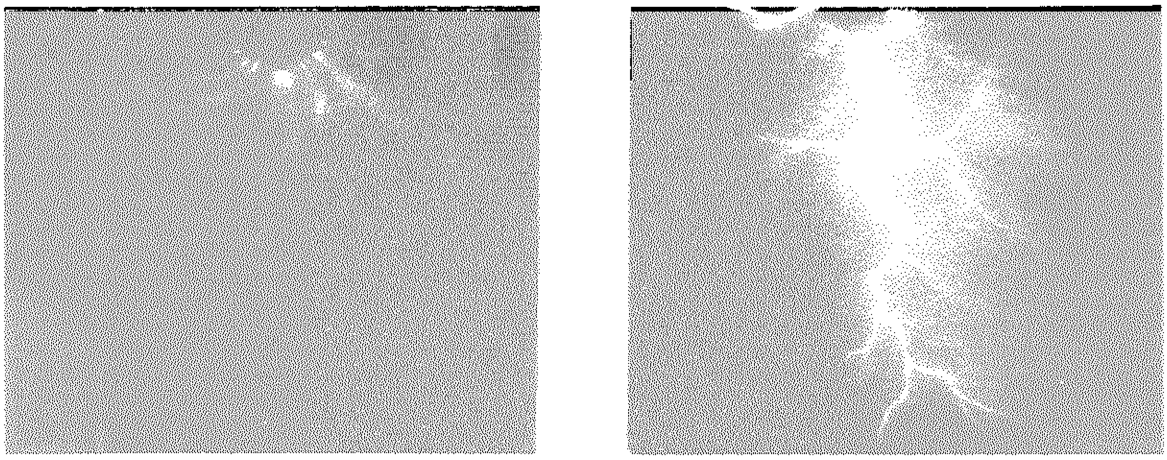
In this example the high breakdown values of about 380 kV correspond to the breakdowns due to streamer corona; the low values of about 270 kV occur when the stable leader corona precedes the breakdown.

Which of the predischarge occurs depends, in this electrode configuration and, for this voltage range, upon hazard.

On the contrary, for a 30° pointed electrode as positive electrode the breakdown occurs always form the leader predischarge; in this case the breakdown voltage with the lower voltage value can be correspondingly compared with the mixed distribution.

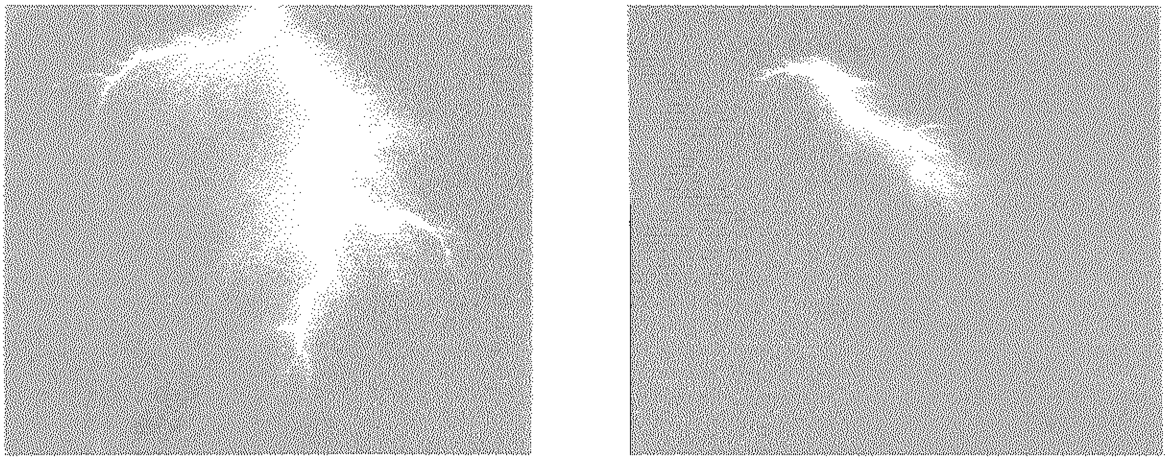
This allegation is evident, among others, by the photographic recording of the optical phenomenon of the corona. As shown in figure 5, with the 2 cm hemisphere and with the same voltage, both the leader corona and the streamer corona are observed, where about 50% of the voltage stresses show a leader corona; this fact corroborates with the breakdown probability of the preceding picture.

In the case of the 30° pointed electrode only the leader corona occurs and this fact can also be observed with much lower voltages. This figure permits also to recognize the optical difference between the two corona phe-



a
2 cm hemisphere 250 kV

b
2 cm hemisphere 250 kV



c
30° point, 250 kV

d
30° point, 190 kV

Fig. 5. Predischarge recordings from a 50 cm rod-plane-spark-gap in air with switching impulses a streamer predischarge, b–d leader predischarge

nomena. The streamer corona is composed of many channels which are relatively weakly lighted; the leader corona is composed of a relatively strongly lighted core which reveals a higher ionization meaning also higher conductivity. Streamer predischarges depart from its head making possible only in this way, with increasing voltage, the occurence of the leader predischarge (1).

It is known from the breakdown with lightning impulses that the breakdown at the 50% breakdown light impulse voltage of spark-gaps in the air with inhomogeneous fields occurs in the tail of the lightning impulse, i.e. with decreasing impulse voltage. Measurements with switching surges show that for this kind of stress the breakdown takes place with increasing impulse voltage; at least this is the fact with large gap distances (3). The breakdown can also occur after the peak of the switching impulse with small gap distances only if the streamer predischarge precedes the breakdown (1). This phenomenon is directly related with the development characteristics of the predischarges, as it will be shown at a later time.

The breakdown duration, i.e. the time between beginning of voltage till the breakdown instant for a rod-plane and rod-rod-spark-gap in relation with gap distance are given in figure 6a.

For a stress of the spark-gap with a switching impulse having a front time of 60 μs, the mean value of the speed of the leader predischarge is 4,2 cm/μs as it can be estimated from the constant rise of the breakdown time with increasing gap distance (1). Particularly important is the relation shown once more in figure 6b. In this case is shown the breakdown time over the distance for minimum breakdown voltage, i.e. with changing front duration. Here a linear rise with about 0,81 μs/cm is obtained, corresponding to a developing speed of the leader of about 1,24 cm/μs. This value corresponds very well with the measurements reported by Lemke (6) and Agapov (7).

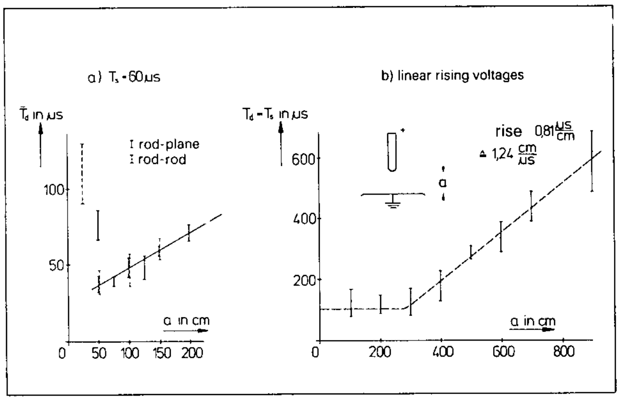


Fig. 6. Breakdown times with switching impulse stress. a front duration $T_s = 60\,\mu s$, b linear rising voltages

The quicker the rise of the switching impulse, i.e. the shorter the front duration, the larger will be the developing speed of the leader, in the same arrangement. Therefore the developing speed of the leader is larger with a front time of 60 µs.

The breakdowns occur also in the tail of the switching impulse in case of too rapidly increasing switching impulses with large gap distances because of the slow speed of the leader predischarge.

3. Schematic representation and characteristic values of the breakdown process with lightning and switching impulse voltages

Based upon the available measured results of the current and voltage process in the gas discharge gap and the optical representation of the gas discharge it is possible to present an hypothesis upon the basic development of breakdowns with lightning and switching impulse voltages. The breakdown due to a streamer predischarge is shown in figure 7 a, while the breakdown due to a stable leader predischarge is shown in figure 7 b.

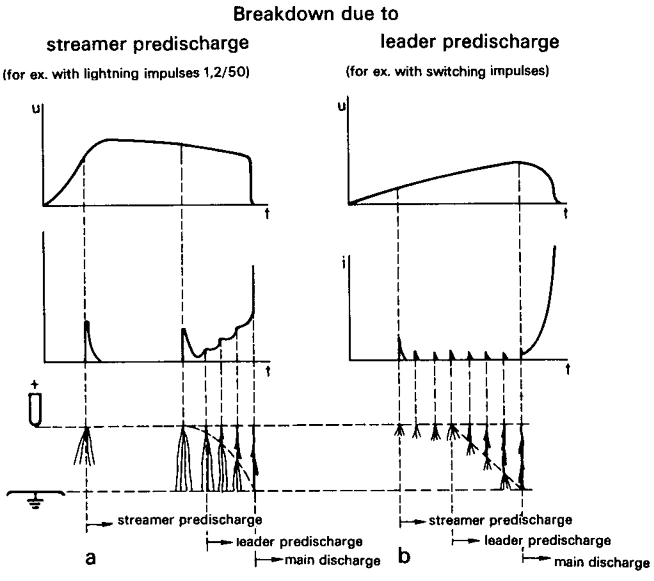


Fig. 7. Basic development of the breakdown due to the streamer and the leader predischarge

It is possible to recognize in both discharge cases, three important steps: the streamer step, the leader step and the main discharge step.

In the case of the lightning impulse 1,2/50, with increasing impulse voltage, when the field strength on the anode is large enough, the impulse corona is constitued, i.e. the streamer predischarge. It is made of a current impulse of a few amperes with a charge of max. 1 µC. Due to the swift rising voltage this current impulse occurs at a higher voltage as compared with slow rising impulses. For example the onset-field strength measured for a 2 cm hemispheric electrode with direct voltage or alternating voltage is 45,5 kV/cm while for a positive impulse 1,2/50 the onset-field strength is 88 kV/cm, that means twice as much.

In the tail of the first current impulse it is possible to observe still further impulses (8), (9). The amplitude of the first impulse is proportional to the onset-voltage. The more inhomogeneous is the field on the blunt edged electrode, the smaller the onset-voltage end therefore the smaller is the current impulse. The charge distribution of the streamer corona prevents for a certain time each further impulse. After the onset-field strength is reached on the anode once more, due to the wandering of ions or the rise of the voltage, further streamer predischarges can occur. When the streamer corona reaches the cathode it will heat up a leader channel outcoming from the positive electrode. Such an inner process is thus probable while, according to the results of the current and voltage oscillograms and the simultaneous recording of the optical phenomenon, the voltage for the development of the leader corona must not rise any more (figure 7 a). With strongly overshooting voltages or very inhomogeneous field the streamer corona can reach the negative-electrode already during the rising of the impulse voltage, and thus can produce a leader corona formation.

In the case of the switching impulse (figure 7 b) streamer predischarges currently occur after the onset-voltage with further rising voltage. Through further predischarges a leader will be formed on the anode (6), with a mean discharge current of 150 mA, although the streamer predischarges have reached the negative electrode.

For a mean discharge current of 150 mA the voltage drop in the leader predischarge amounts to about 1 kV/cm (4).

Through further current impulses the leader can develop with an about constant mean speed, while streamer predischarges continue to depart from the head of the leader. For the development of the leader predischarge the voltage must rise still more, so that in this case only breakdowns in the front of the switching impulse can occur, and with rising voltage, the critical front time is reached for the distance considered. The switching impulse rise must occur according to the leader predischarge voltage requirement.

From the critical voltage rise of 2,08 kV/μs and the increasing speed of the leader predischarge of 1,24 cm/μs a voltage requirement of 1,6 kV/cm results for the leader predischarge under the assumption that the whole voltage rise for the developing leader must be brought up. When the streamer predischarge reaches the negative electrode, a relatively conducting channel will exist between the electrodes which will now be heated.

In the case of the breakdown from the streamer predischarge, the voltage collapses practically instantaneously because in this case the leader is very low ohmic. On the contrary, in the case of the switching impulse, the leader channel bridges the spark-gap with a voltage requirement of about 1...2 kV/cm, and the following breakdown occurs due to the heating of the already available plasma. This phenomenon is recognized by the slow current rise of about 2 A/μs and the slow voltage collapse with high ohmic internal resistance (1).

The alteration from streamer predischarge into leader predischarge and, thereby, the extension of the leader occurs, according to an hypothesis from Petropoulos (10), from the fact that from the head of a leader predischarge outgoing streamers suddenly constrict radially with a field strength at the leader head of about 70 kV/cm. Thereby the conductibility is suddenly increased and the streamer becomes a part of the leader. This mechanism would necessitate a pre-development of the leader in individual stages; this has been considered as possible by some authors recently, for example Gänger (11) after measurements with image converters. The current process indicates also a back stage mechanism (12).

A comparison between the two mechanisms shows clearly the important differences in the building up of the discharge:

The leader discharge begins with a breakdown from the streamer predischarge only when the streamer has reached the opposite-electrode. The voltage drop in the leader discharge with a breakdown from the streamer predischarge is very much smaller. The developing speed of the leader discharge is thereby about exponential with streamer breakdown and does not need a further rise of electrode voltage for the breakdown. With switching impulses the developing speed of the leader predischarge is about constant. For the developing of the leader predischarge the electrode voltage must rise further.

As the voltage requirement of the predischarge occur-

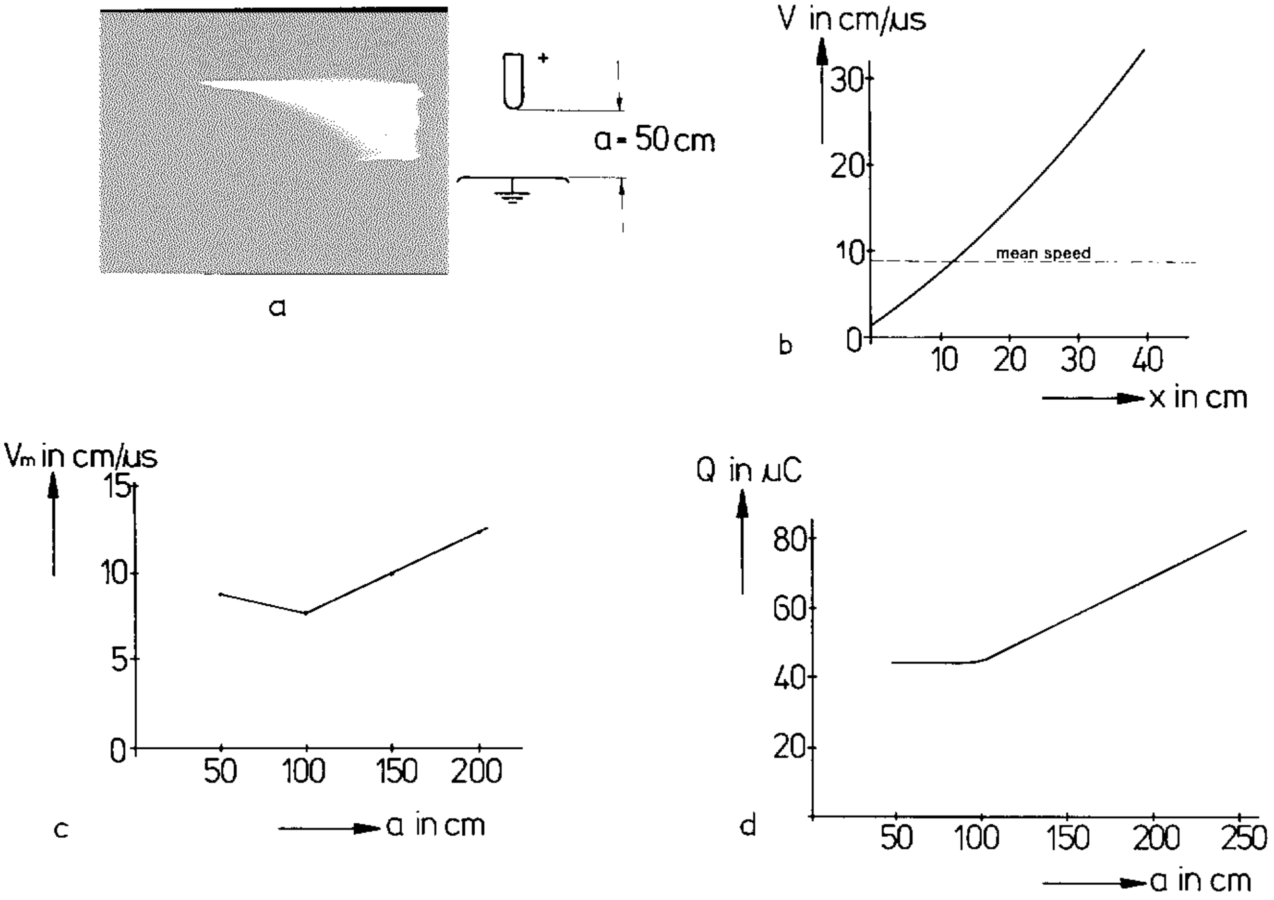


Fig. 8. Speed and voltage requirement of the leader predischarge with lightning impulses; arrangement: rod-plane
a image converter picture, $a = 50$ cm; b speed, $a = 50$ cm; c mean speed in relation to distance; d mean voltage requirement in relation to distance

ing before the breakdown determines the breakdown voltage, the breakdown voltage gap distance characteristic line can also with this figure be explained as follows:

a) in the case of the lightning impulse 1,2/50 the streamer predischarge must bridge the spark-gap with a voltage requirement of 4...5 kV/cm, before the breakdown can occur. Correspondingly the breakdown voltage gap distance characteristic line rises linearly with about 5,4 kV/cm (at normal conditions).

b) in the case of the breakdown due to the stable leader predischarge, part of the spark-gap will be bridged by the leader with a voltage requirement of 1...2 kV/cm and the remaining part of the spark-gap distance will be bridged by the streamer predischarge with about 4...5 kV/cm, before the actual breakdown. The larger the gap distance the larger will be the portion of the leader predischarge. Corresponding to this predischarge phenomenon the breakdown voltage gap distance characteristic line departs more and more from the linear characteristic line of the lightning impulse. For extremely large gap distances the characteristic line rises further only with 1 kV/cm because then the whole gap distance practically must be bridged by the leader predischarge before the breakdown.

The speed and charging requirement of the leader predischarge with lightning impulse stress are given in figure 8. Figure 8 a shows the speed of the expending channel. The leader begins with a speed of about 1...2 cm/μs and, as the voltage drop in the leader is very small [0,055 kV/cm (13)], the anode potential is transferred onwards and the speed of the leader increases always and reaches a value of a few 10 cm/μs (figure 8 b). The mean value of the leader discharge for a rod-plane-spark-gap increases also slightly with the distance and lies at about 10 cm/μs (figure 8 c). The charging requirement for the transfer and the heating of the leader amounts to about 25 μC/m (figure 8 d).

From these measurements and from known published results, the following characteristic values can be deducted for the streamer and leader discharge with lightning and switching impulses; the mean values are shown in figure 9.

The comparison of the voltage requirement shows that the leader has a voltage drop of 0,055 kV/cm with lightning impulse breakdowns (13), (14). With switching impulses the voltage drop is estimated at 0,5...2 kV/cm according to the mean discharge current. The voltage requirement of the streamer predischarges is about the same. The mean discharge current can be covered by the load capacitance if same is large enough (about 1000 pF) without a noticeable voltage break-through. It amounts for the leader predischarge with lightning impulses at a few amps, for the leader predischarge with switching impulses at only about 150 mA.

	Lightning impulse 1,2/50μs		Switching impulse	
	Streamer	Leader	Streamer	Leader
Voltage requirement	4.....5 kV/cm	0,055 kV/cm	4.....5 kV/cm	0,5 2 kV/cm
mean discharge current	—	a few amps	—	~ 0,15A
charge requirement	—	25 μC/m	—	1.....2 μC/m
mean developing speed	~100 cm/μs	5.....15 cm/μs	~ 100 cm/μs	1 .....10 cm/μs
mean speed of main discharge	100.:....1000 cm/μs		20.....30 cm/μs	

Fig. 9. Comparison between the characteristic values of streamer and leader discharges with lightning and switching impulse voltages

The charging requirement of the leader discharge with lightning impulses amounts to a value of about 25 μC/m. These values are at about power ten over the charging requirement of the leader predischarge with switching impulses (1), (4).

With strongly overshooting impulse voltages the charging requirement of the leader discharge increases still further and reaches a value of a few 100 μC/m (15).

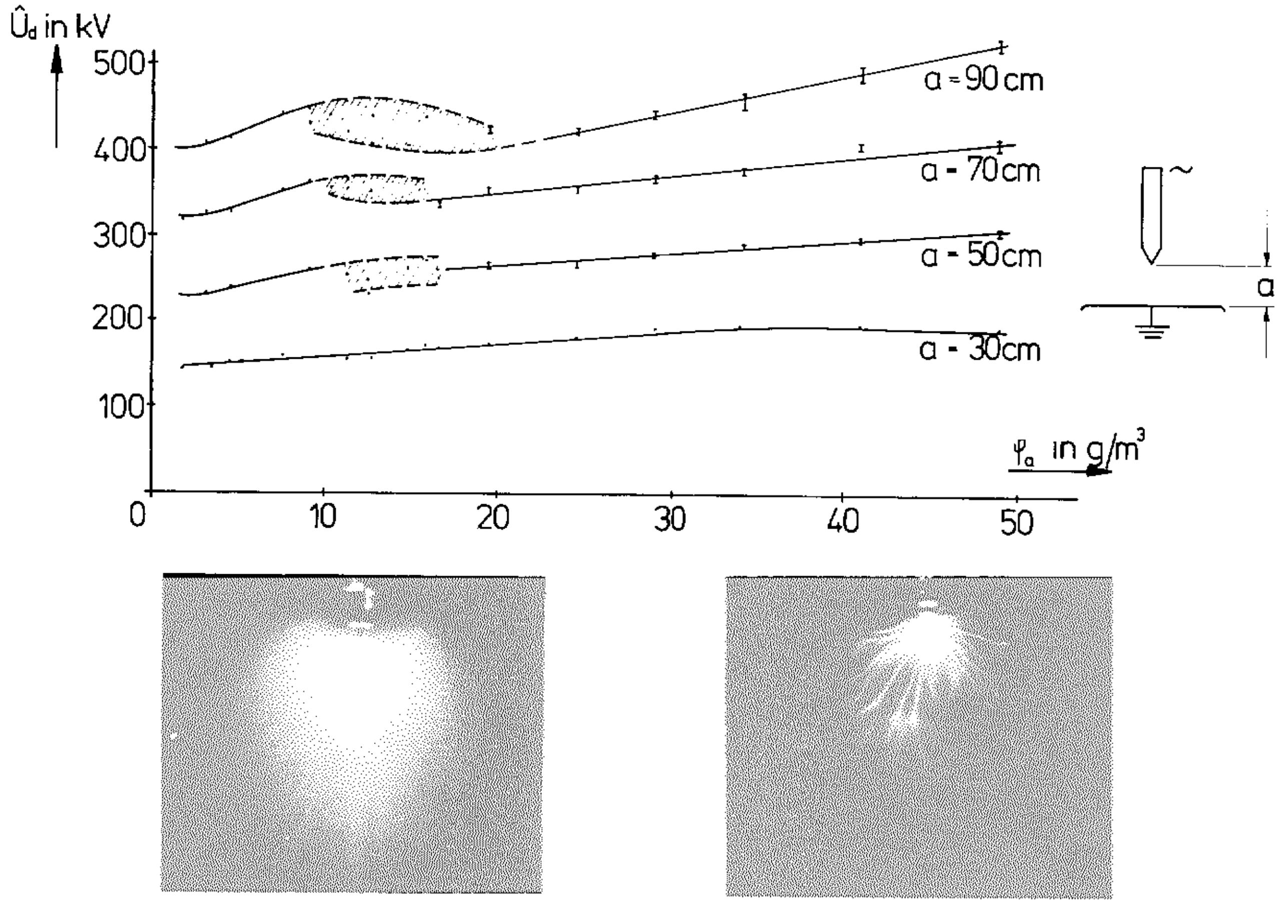
The mean developing speed of the streamer predischarge amounts for both voltage stresses to about 100 cm/μs (16). The mean developing speed of the leader predischarge for the 50% breakdown voltage range with lightning impulses has values of about 10 cm/μs, whereas for the leader predischarge with the minimum breakdown voltage with switching impulses, values of 1 cm/μs are reached. This speed is of course dependent upon the fronttime duration and the electrode shape, e.g. developing voltage.

For the mean value of the main discharge with lightning impulses speeds of 100...1000 cm/μs are obtained while with switching impulses mean speeds of 20...30 cm/μs were measured (4).

4. Influence of humidity upon the formation of the leader predischarge

Figure 10 shows clearly that the stable leader predischarge is not only a characteristic of switching impulses; in this figure the influence of humidity on the breakdown voltage with alternating voltage stress is indicated. It is recognized that also with alternating voltages and high humidity the leader predischarge occurs. The breakdown voltage rises in this range less, with absolute humidity, than in the case of the streamer predischarge range (17). A linear rise of the breakdown voltage with switching impulses is ascertained when the absolute humidity increases, the percent increase diminishes with larger distances (18), (19).

Physically these results mean that the streamer predischarge is influenced by humidity, whereas the leader predischarge is not (20). Therefore a limited influence of humidity is available which diminishes the range of the streamer at the head of the leader predischarge, where the range (free path length) of the photons is diminished and altogether heavy moving negative, discharge-preventing ions can build up at the leader head. This



Bundle discharge
$\varphi_a = 5\,g/m^3$

Leader predischarge
$\varphi_a = 32\,g/m^3$

Fig. 10. Alternating current breakdown voltage of rod-plane-spark-gap in air. Influence of humidity

influence diminishes with increasing distance because of the ever more predominant leader predischarge.

These results show particularly clearly that a humidity correction must be introduced for the predischarge process; thereby in the preceding example the leader predischarge at 11 g/m³ shows a reference figure which is fictive.

It must be supposed that with all voltage stresses, the stable leader predischarge can occur. The leader predischarge has been examined, up to now, mostly for switching impulses and alternating voltages but also for impulse voltages with short front durations 1,2 μs and long tail durations 2500 μs. With lightning impulses 1,2/50 and large gap distances stable leader predischarges occur also, but due to their limited speed they do not progress too far in the discharge space, because the short tail duration of 50 μs leaves hungry the developing channel.

It can be supposed nevertheless that at a few million volts the positive lightning impulses will also cause a deflection of the breakdown voltage-gap distance characteristic line. The protruding discharge observed by several authors (9), (4) can possibly be described as the beginning of the leader predischarge, but it would be interesting to know if the observed protruding discharge with dc and ac voltages is composed of a streamer predischarge and a leader predischarge. These predischarges cannot be determining in the breakdown voltages with the distances considered up to now because the protuberance is only a few centimeters long and evidently cannot develop (20).

5. Practical Conclusions

As a conclusion the practical consequences must still be discussed concerning the dimensioning of screen electrodes considering this breakdown process. Thereby it is recognized that the abnormal breakdowns observed at many places are due to the breakdown process resulting from the leader predischarge. It can be remarked from the mechanism of the breakdown due to leader predischarge that the breakdown voltage is practically independent from the bending radius of the electrode when, before the breakdown, a stable leader builds up.

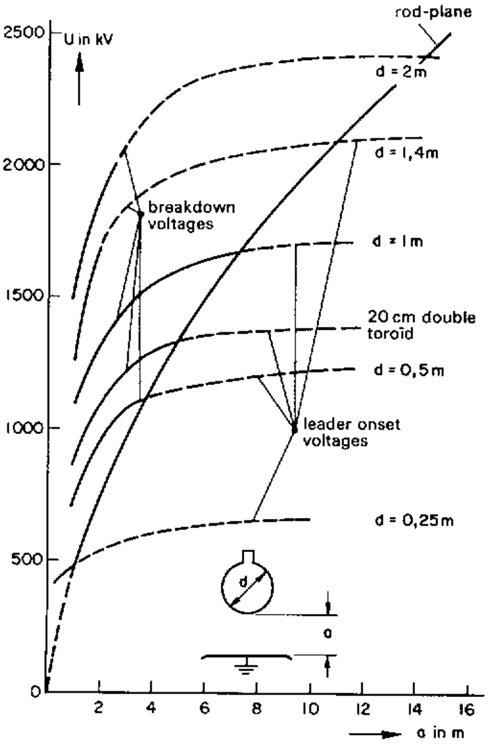


Fig. 11. Leader onset voltage and breakdown voltage of sphere-plane-spark-gap in air with switching impulse voltages

The breakdown voltage corresponds then always to about the minimum breakdown voltages of the rod-plane-spark-gap.

The measured results for various sphere-plane arrangements are given in figure 11. At the left of the characteristic line of the rod-plane-spark-gap the breakdown occurs without a stable leader predischarge while at the right side of this characteristic line the stable leader predischarge can be observed and thus the breakdown occurs, with increased voltage, at about the value of the rod-plane-spark-gap with the same distance.

For the dimensioning of the screening electrodes the following important points must be taken into consideration:

If a predischarge is admissible, the value of the load capacitance must be calculated in such a way that a voltage break-through does not occur due to the predischarge (therefore at least about 1000 pF); further, the distances to all earthed objects must be at least in accordance with the rod-plane-spark-gap characteristic line; that means, for a switching impulse voltage of 2 MV that a distance of about 10 m to the earthed objects is required. The conditions with increasing switching impulse voltages are still more defavourable. It can be seen from figure 12 that a leader predischarge on the toroïdal screen of a voltage divider can lead to a remarkable voltage break-through if the effective load capacitance is too small (450 pF).

This leader predischarge on a screen electrode can be avoided through a properly dimensioned electrode. A particular suspension of the test object is shown on figure 13 for a sphere-plane-spark-gap with a distance of 2,5 m. It should be possible to apply a maximal switching impulse of 2 MV on the test object. In case the suspension is chosen with a screen sphere of 1 m diameter a leader predischarge may occur on the sphere which can provoke a breakdown to the wall or to the ceiling with a distance of over 10 m (figure 13).

According to these conditions the dimensions of the high voltage laboratory must be chosen in such a way

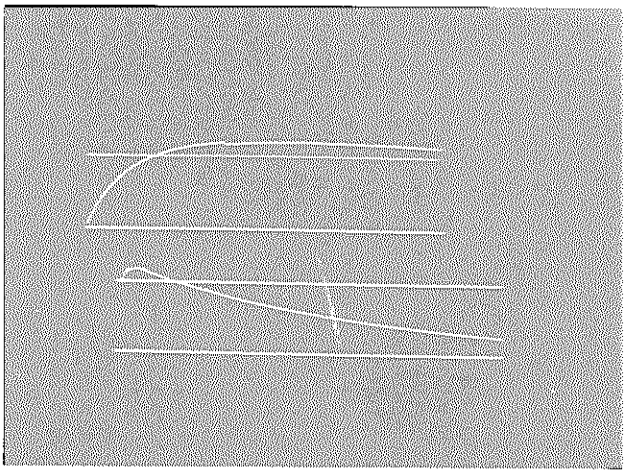


Fig. 12. Voltage process with switching impulse stress 150/2500 μs of a toroïdal electrode against a plane electrode (a = 4 m). Voltage amplitude U = 1320 kV

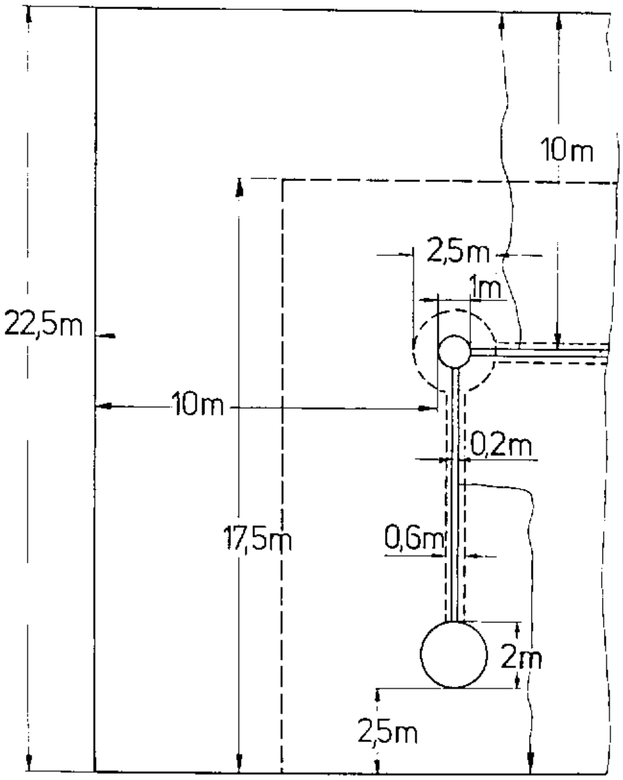


Fig. 13. Suspension of test object and dimensions of laboratory for 2 MV switching impulse voltage

that everywhere from the test object to earthed objects a minimal distance of 10 m is available.

If a larger screen electrode is chosen, for example a 2,5 m sphere, no leader predischarge occurs on this sphere with a switching impulse up to 2 MV. When the connecting conductors are so designed, that no leader predischarge can occur on these conductors, the high voltage laboratory, in this case, may have much smaller dimensions without the risk of breakdowns (figure 13).

In practice the dimensions of the necessary screen electrodes and connecting conductors must be determined, taking into consideration a given height of the high voltage laboratory and the desired value of the switching impulse voltage.

References

1. *K.Feser:* Inhomogene Funkenstrecken in Luft bei Beanspruchung mit Schaltstossspannungen. Bull. SEV 61 (1970), 711–719.
2. *I.S.Stekolnikov, E.N.Brago, E.M.Bazelyan:* Decrease of discharge potentials over wide gaps by use obligue angle waves. Zh. Tekhn. Fiz. 32 (1962), 993–1000.
3. *Y. Watanabe:* Switching Surge Flashover Characteristics of Extremely Long Air Gaps. Trans. JEEE Paper No. 31, 66–420 (1966).
4. *E.Lemke:* Die Leaderentladung und ihre Bedeutung für das Durchschlagverhalten langer Luftfunkenstrecken. Wiss. Zschr. der Elektrot. 13 (1969), 77–91.
5. *K.Feser:* Einfluss der Spannungsform auf das Durchschlagverhalten von Luftfunkenstrecken mit inhomogenem Feld. Energie und Technik 22 (1970), 319–324.
6. *E.Lemke:* Der Durchschlagmechanismus von Luftfunkenstrecken bei Schaltspannungen. Wiss. Zschr. der TU Dresden 17 (1968), 105–115.
7. *W.G.Agapov, Wan Zsun-Dsjan, W.P.Larianov:* Über die Entladungsentwicklung in Luftfunkenstrecken bei Stossspannungen mit langen Anstiegszeiten (russ.). Arbeiten MEJ, Ausgabe 70, Moskau (1968), 173–183.
8. *A.Fischer:* Vorentladungen bei Stossspannung an Stabfunkenstrecken. Diss. TH Stuttgart (1962).
9. *G.Baller:* Vorentladungen bei Stossspannungen verschiedener Stirnsteilheiten an einer Stabfunkenstrecke in Luft. Diss. TU Stuttgart (1968).
10. *G.M.Petropoulos:* Zusammenschnürung einer Funkenentladung beim Stossdurchschlag. Brit. J. Appl. Phys. 15 (1964), 169–176.
11. *B.Gänger:* Elektrische Festigkeit von Luftisolation bei hohen Schaltspannungen. Bull. SEV 62 (1971), 227–236.
12. *E.Lemke:* Der Durchschlag im inhomogenen Feld in Luft bei Schaltspannungen. Periodica Polytechnika Vol. 11 (1967), 229–239.
13. *V.S.Komelkov:* Struktur und Parameter der Leaderentladung. Bull. Acad. Sci. USSR 8 (1947), 955.
14. *W.Lampe:* Der Durchschlagmechanismus positiver, langer Funken in atmosphärischer Luft bei Stossspannung. Arch. für Elektrot. 47 (1963), 388–408.
15. *K.Feser:* Das Durchschlagverhalten von Luftfunkenstrecken mit inhomogenem Feld bei Mischspannungen. Bull. SEV 62 (1971), 320–329.
16. *R.T.Waters, T.E.S.Rickard, W.B.Stark:* Electric field and current sensity in the impulse corona discharge in a rod/plane gap. Proc. Roy. Soc. A 304 (1968), 187–210.
17. *K.Feser:* Einfluss der Feuchtigkeit auf das Durchschlagverhalten bei Wechselspannung. ETZ-A 91 (1970), 584–586.
18. *T.Harada:* Humidity Corrections of Lightning and Switching Impulse Flashover Voltages. Interim Report, High Voltage Section, Criepi (1969).
19. *A.J.Kachler, J.J.La Forest, L.E.Zaffanella:* Switching-Surge Results from Project UHV-Influence of Humidity and Grading Shields. Transaction Paper No. 71 TP 175-PWR.
20. *G.Schmiedl:* Einfluss der Luftfeuchte auf die Durchschlagwechselspannung meterlanger Luftisolierstrecken. Elektrie 25 (1971), 19–21.

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