Breakdown in SF_6 influenced by Corona-Stabilization

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Abstract

Corona-Stabilization in SF_6-insulated systems is a known phenomenon, but up to now not fully understood. In case of slow-rising impulse voltage stress, a stabilization mechanism, mainly depending on the steepness of the applied test voltage, occurs. Essential for the phenomenon is a space-charge accumulation in front of the probe tip. The space-charge reduces the field near the rod and thus an increased voltage level is needed to initiate the leader process. This paper presents experimental results. An imaging system consisting of 2 still-video CCD cameras has been used to record the paths of spark breakdowns across a positive point/plane gap. With subsequent computer image processing and analysis the dimension of the space-charge cloud could be estimated.

Studies have been done for various probe tip lengths, gas pressures and steepnesses of the applied test voltage. The probability of corona-stabilization was determined for each test sequence. It was found that this probability decreases with the steepness of the applied test voltage only for certain gas pressures.

Introduction

Nowadays SF_6 has been established for the use in gas insulated substations due to its high insulation withstand level and good arc quenching capability. The insulation properties are essential for the design of metal encapsulated switch-gear (GIS). Especially the reduction of withstand levels in case of inhomogeneous fields caused by free-moving particles or fixed protrusions is of interest. Furthermore the shape of the applied overvoltage has great influence on the discharge development.

In the last years a lot of theoretical and experimental work was done to determine the physical processes during the discharge under such voltage stress. As a result different breakdown models were developed. In case of positive LI and FTO stress the precursor mechanism [1], [2] describes the streamer to leader transition. For VFTO and composite voltage stresses an energy mechanism [3] was found which allows a calculation of the leader propagation for all steep transients.

In case of slowly rising impulse voltage a stabilization mechanism happens. It depends on the parameters steepness of the applied test voltage, gas pressure and tip geometry and results in producing a space-charge accumulation in front of the fixed protrusion.

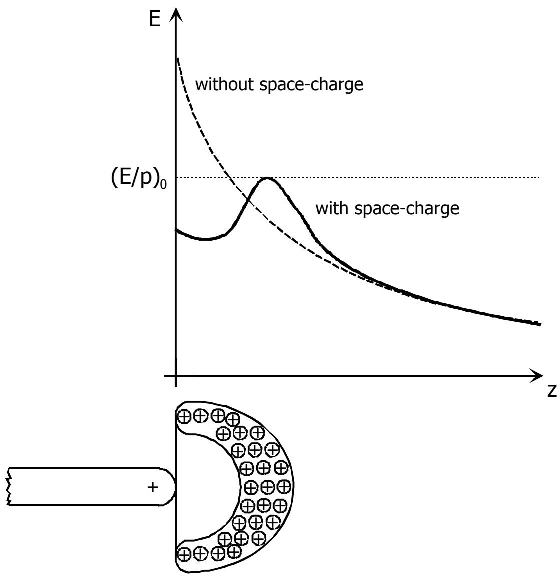

Figure 1: Field distribution

As shown in Fig. 1 the space-charge reduces the field near the rod and thus an increased voltage is needed to initiate the leader process and the breakdown voltage is raised.

Test set-up

The experiments were realized in a test set-up consisting of 420 kV GIS components (Fig. 2).

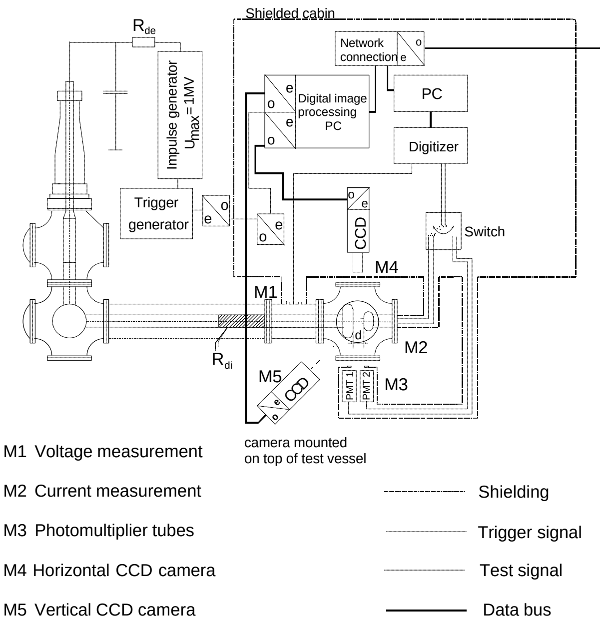

Figure 2: Test set-up

The test voltage was generated by a 1MV-surge generator. To achieve slow-rising impulse voltages responsible for corona-stabilization an external resistor R_{de} was used. An additional inner resistance R_{di} limits the discharge current flowing over the probe tip and avoids deformations of the tip due to melting processes. With this configuration the steepness of the applied test voltage could be varied from 350 kV/µs down to 1 kV/µs, resulting in rise times between 1.3 µs and 400 µs.

The needle/plane gap is located at the end of the bus duct with the plane on negative potential. In the test vessel different types of needles can be used. For the measurements presented in this paper a tungsten needle with a length of 25 mm, a tip radius of 0.5 mm and a resultant remaining gap width of 75 mm was applied.

The voltage was measured at point M1 using a modified capacitive voltage sensor [4] with adapted lower cut-off frequency. The two photomultiplier tubes are sensitive in the UV and IR range, which allows to detect the corona onset and to distinguish between leader steps and leader reilluminations. All the signals were aquired with a maximum sample rate of 1 gigasample per second.

The low ion density of the space charge in front of the needle prevents the direct recording of the charge distribution. Therefore an indirect optical recording technique consisting of two orthogonal mounted CCD-cameras has been used to get a 3-dimensional picture of the final spark path. Equipped with appropiate macro optics each camera aquires an area of 30 x 24 mm^2 in front of the probe tip.

Experiments: V-t curves

The discharge development out of the tip is strongly influenced by the distribution of space charge in front of the needle. This cloud consists of positive ions and influences the local electric field [5]. Therefore a straight leader propagation is nearly impossible. This results in a higher breakdown voltage and a longer time to breakdown. An increase of the withstand level can be seen in the aquired V-t curves. Also the probability of active corona-stabilization raises if the rise time of the test voltage is increased. This behaviour is significant for gas pressures of 0.1 MPa and 0.2 MPa (Fig. 3, 4).

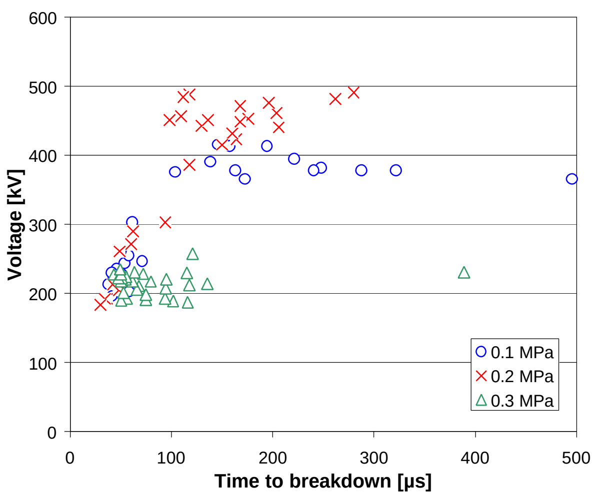

Figure 3: V-t curve, 200µs rise time

Also for longer rise times and a gas pressure of 0.3 MPa the effect of corona-stabilization seems to be weaker, because the breakdown voltage reaches only about 50% of the breakdown level in case of active stabilization (0.1 MPa, 0.2 MPa). Furthermore with increasing gas pressure the decreasing leader inception voltage has to be considered, which also reduces the breakdown voltage.

Assuming the precursor mechanism according to [2] the critical charge necessary for leader inception is

$$Q_{crit} = 45\left(\frac{p}{0.1MPa}\right)^{-2.2} nC \cdot$$

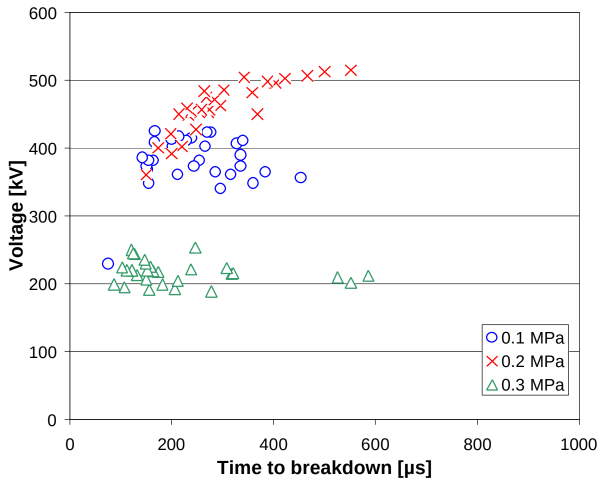

Figure 4: V-t-curve, 400µs rise time

In addition the higher gas pressure reduces the mean free path

$$l_{mi} \approx \frac{1}{4pr_B^2} \cdot \frac{kT}{p}$$

for positive SF_6 ions. This results in a lower mobility and slows down the developement of the positive space charge.

Experiments: Spark paths

The size of the space charge in front of the needle caused by the mentioned phenomena can only be estimated by recording the 3-dimensional spark path. Two orthogonal views were recorded simultaneously using the cooled CCD-cameras triggered synchronized with the surge generator. In order to obtain a 3-dimensional view an image processing technique similar to [6] has been used. After aquisition the discharge channel was extracted from the images and reduced to a width of 1 pixel. Combining these two data sets gives about 1200 xyz coordinates describing the spark path. The tip of the needle was defined as the origin of the xyz-axes. As shown in figure 6 the x-axis is vertical to the plane electrode, while the y-axis and the z-axis are pointing from and upwards the observer. In addition the spatial launch angle of the spark path was measured for each breakdown which results in a certain launch angle distribution for a given steepness of the applied test voltage.

Fig. 7 shows superposed spark paths for LI stress. The course of the discharge channels is nearly straight, only small launch angles occur.

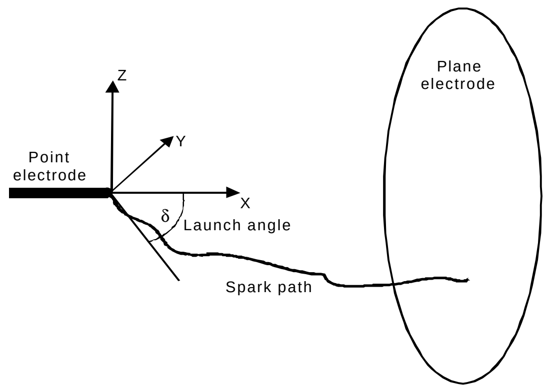

Figure 6: Electrode system

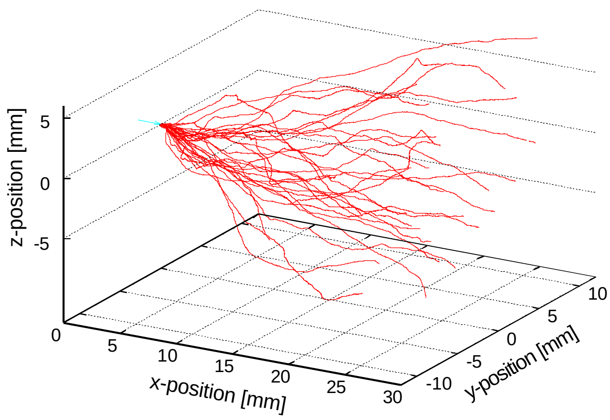

Figure 7: Spark paths, 0.2Mpa, 1.3 µs rise time

In Fig. 8 the paths of 50 sparks for a gas pressure of 0.2 MPa and a rise time of 400 µs are shown. The influence of the space charge cloud on the course of the sparks is clearly visible.

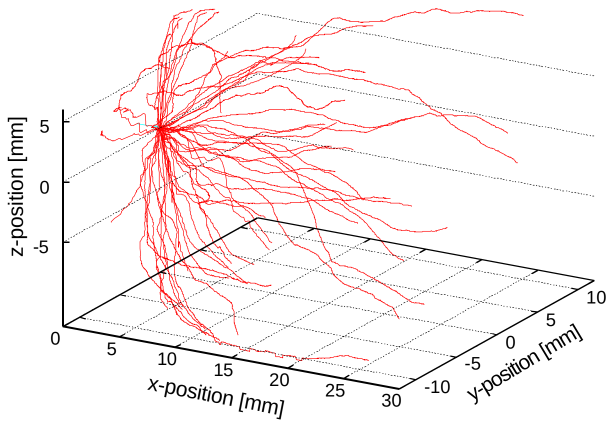

Figure 8: Spark paths, 0.2MPa, 400 µs rise time

The space-charge in front of the needle results in appearance of high spark launch angles (Fig. 9). Assuming a gaussian angle distribution like in [7] the standard deviation can be regarded as an indicator for the presence of corona-stabilization.

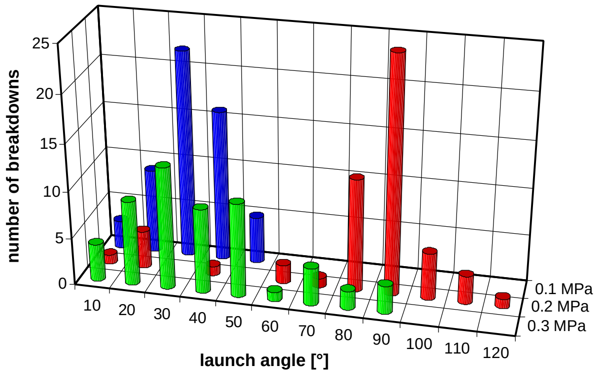

Figure 9: Launch angle distribution, 400 μs rise time

s [°]	0.1 MPa	0.2 MPa	0.3 MPa
350 kV/μs	**12.3°**	**12.2°**	**13.6°**
16 kV/μs	**27.7°**	**17.5°**	**12.6°**
10 kV/μs	**18.2°**	**19.9°**	**12.8°**
4 kV/μs	**14°**	**18.3°**	**21.5°**
1 kV/μs	**9.8°**	**23.6°**	**20.8°**

Table 1: Standard deviation of spatial launch angle

For a gas pressure of 0.1 MPa and a steepness of the applied test voltage of 16 kV/μs the standard deviation is about twice the value for 0.3 MPa. In contrast to this for longer rise times the maximum of the standard deviation and the probability of corona-stabilization shifts to higher gas pressures. Whether this observations can be generalized has to be proven by further experiments.

Conclusion

For slow-rising impulse voltage stresses with steepnesses below 16kV/μs and gas pressures between 0.1 MPa and 0.3 MPa breakdowns can occur with and without corona-stabilization.

Only for gas pressures about 0.2 MPa the probability of corona-stabilization increases with falling steepness of the test voltage.

In addition to the statistical time lag in case of active corona-stabilization an additional time delay occurs. This delay is caused by the positive ion cloud in front of the probe tip which weakens the local electrical field. The discharge path circumvents the space-charge cloud leading to a higher formation time and therefore a higher voltage level is needed to initiate the final breakdown.

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