Gas Insulated Substation (GIS) for HVDC

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Abstract

The paper deals with the topic of Gas Insulated Substation (GIS) optimized for HVDC. The electric field distribution of DC systems is mainly controlled by the conductivity κ of the dielectric media. Surface charge accumulation is leading to field distortion. In order to prevent this phenomenon on the spacer of such systems, a conducting coating has been realised. Investigations are made with real 145kV - GIS - setup. The influence of the surface coating on the field distribution can be proved with this experimental setup. Numerical calculations based on the Boundary-Element-Method (BEM) are made to investigate the influence of surface resistivity and surface charge on the field distribution of a spacer. The charge accumulation on an uncoated spacer is measured, simulated and discussed. With a coated spacer it is possible to prevent this charging.

Introduction

The high reliability and compactness achieved by compressed gas insulation in HVAC systems, has led to the development of HVDC Gas Insulated Substations [1]. As in case of HVAC GIS, the basic insulation components of HVDC GIS are SF_6 gas and solid spacers. In this respect, it has been recognized that the breakdown strength of GIS is mainly influenced by the spacers. For HVDC GIS stress control designs based on dielectric interfaces with no trapped charges are not valid, since charges get accumulated on spacer surfaces. In contrary to HVAC GIS, the electric field distribution at steady-state in HVDC GIS is mainly controlled by the conductivity κ of the dielectric media, studies on the influence of volume and surface resistivities on the electric field distribution around GIS spacers have been done [2]. It has also been suggested that a conducting coating on the spacer surface may help to obtain a controlled current density on the spacer surface and also to reduce the surface charge accumulation [3].

Theory

The numerical field calculation is based on the Boundary Element Method [4]. The boundary conditions are modified to calculate capacitive-resistive fields [5].
Investigations show that a coating with a surface resistivity of about $10^{11}\Omega$ improves the field distribution.

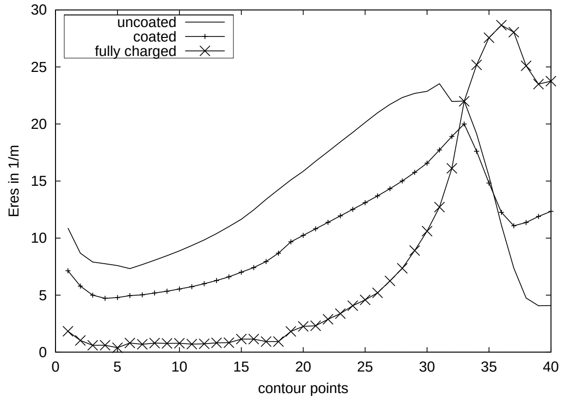

Figure 1: Resultant field distribution

Figure 1 shows the resultant field stress of a coated and uncoated spacer in a HVDC GIS. The field is normalized to 1 kV. A field reduction of about 25% for the coated spacer compared to the uncoated can be achieved.

During voltage increase the field distribution of an epoxy spacer and its surrounding is controlled by the ratio of the permittivity of the epoxy and SF_6 (capacitive distribution).

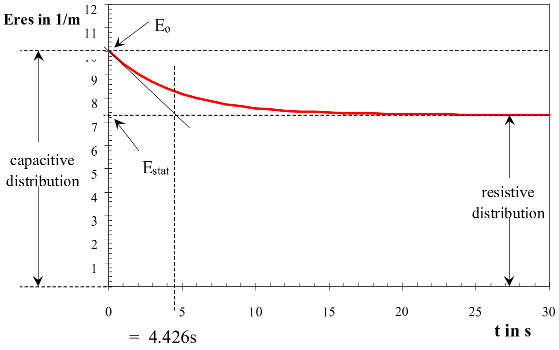

Figure 2: Transient field development

Some time after the DC voltage is reached the stationary field distribution is gained which is controlled by the conductivity κ of the epoxy (resistive distribution). The intermediate transitional field development can be described by equation (1).

$$\kappa E(t) + \varepsilon_r \varepsilon_o \frac{\partial E(t)}{\partial t} = 0 \qquad (1)$$

The time constant τ is defined as $\tau = \varepsilon_o \varepsilon_r \rho$. In fig. 2 the surface resistivity is set to $\rho_{sur} = 10^{11}\Omega$ and therefore the time constant is 4.4 seconds. E_0 is the value of capacitive and E_{stat} of the resistive field distribution.

Experimental Setup

The experiments are made in a high voltage laboratory with a max. DC voltage of 500 kV. The 145 kV-system is installed in a 420 kV-GIS to enable investigations concerning only the 145 kV-spacer. The maximum gas pressure of SF_6 is 0.3 MPa. Fig. 3 shows the principal experimental setup. It is possible to measure the current of the coating on both sides of the spacer. A special Electrometer (Keithley 6517A) is used which can detect currents up to 10^{-18} A. Furthermore the voltage and the temperature of the gas and the enviroment is measured. It is not possible to measure the electric field stress directly on the spacer.

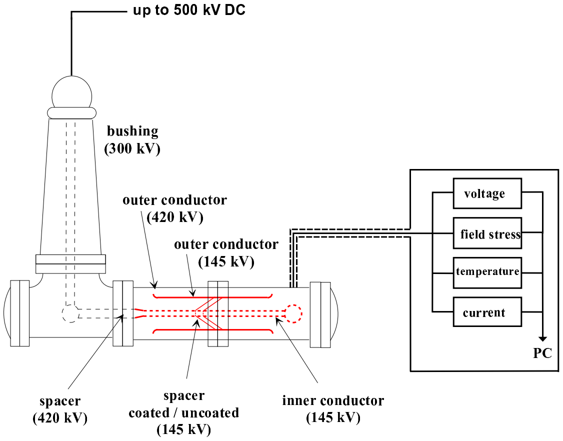

Figure 3: Experimental setup

Therefore a different method is used. If the electric field on the spacer changes, the electric field on the outer conductor changes similarly. Fig. 4 shows the electric field stresses on the outer conductor for a coated and uncoated spacer. There are the same influences as on the spacer in fig. 1. The field of a coated spacer compared to an uncoated spacer is reduced about 25%. Therefore the electric field is measured on the outer conductor. Two electrostatic field sensors are applied, which can measure the field in the range of 0 to 10 $\frac{kV}{cm}$. One sensor detects the electric field adjacent to the spacer. The second sensor, placed in the coaxial cylinder field, is used to calibrate the other, because the electric field can be calculated analytically.

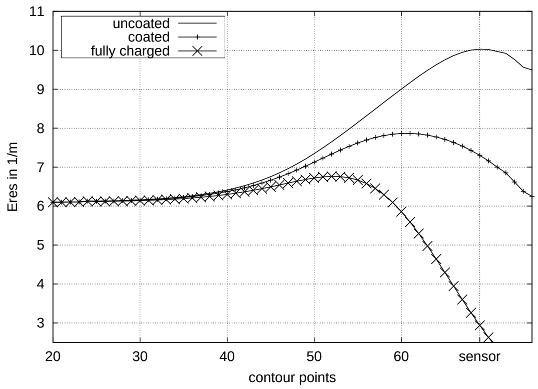

Figure 4: Field stress at the outer conductor

Results

Intermediate Transitional Field Development

To study the behaviour of DC GIS spacers different surface resistivities are tested. An uncoated spacer (Nr. 4 in table I) shows a static capacitive field distribution (fig. 5). The transitional stage is investigated by changing the surface resistivity.

Nr.	R in Ω	τ in min	E_0 in 1/m	E_{stat} in 1/m	Field red.
1	$9 \cdot 10^{12}$	7	9.2	6.8	26 %
2	$8 \cdot 10^{13}$	59	9.4	6.9	26 %
3	$3 \cdot 10^{14}$	221	9.6	7.9 [1]	16 %[1]
4	$1 \cdot 10^{20}$	–	9.6	9.3	–

[1] not the final steady state condition

Table I: Diffferent surface resistivity

The spacers 1-3 have different resistivities, therefore the transitional field development will have different time constants τ (see table I). The starting capacitive value E_0 is nearly the same for all spacers and the final resistive value E_{stat} is also the same, except for spacer 3, where the final state was not reached, because of the high time constant of nearly 4 hours.

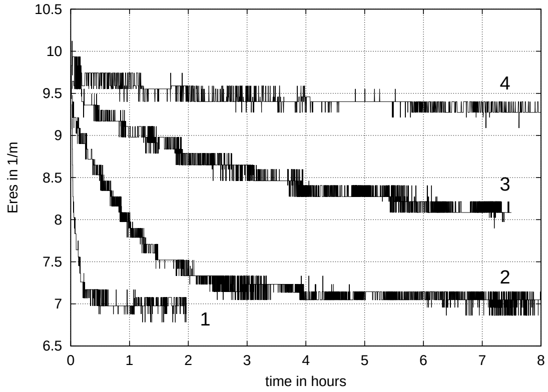

Figure 5: Transient field development

The measured field stresses deviate compared to the numerical field calculations. But the achieved field reduction is exactly the same as simulated. The sensors are very sensitive to little mechanical deviations at the setup. A difference of 0.5 mm has an influence of about 7% on the field measurement.

Fig. 5 shows the transient field development for the various spacer. The field drop is dependent on the resitivity and the theoretic time constants τ of table I are confirmed. The result of the numerical simulations that a conductive coating in the range of $10^{10} - 10^{15}\,\Omega$ improves the field distribution is confirmed too [2]. The field of HVDC systems is reduced about 26% by using such a coating. The final resistive field stress is independent on the surface resistivity.

Surface Charge Accumulation

A further point of interest is the surface charge accumulation on coated and uncoated spacers. Fig. 6 shows the results of a 36 hour test with an uncoated spacer applied to 100 kV DC. The spacer field is reduced from 10 down to 9 $\frac{1}{m}$ after 36 hours. That indicates that such a standard uncoated spacer cannot be applied in a HVDC GIS.

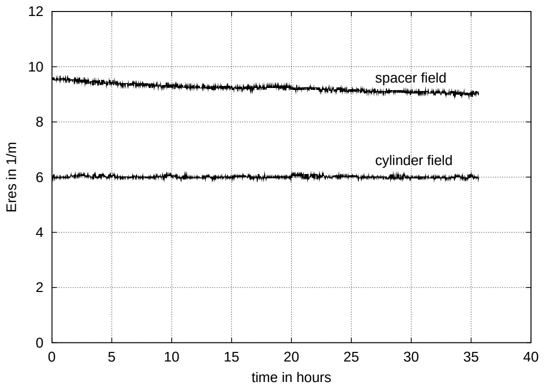

Figure 6: Charging of an uncoated spacer

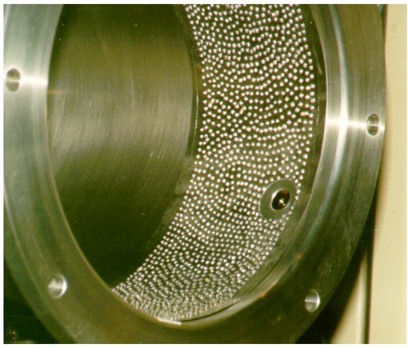

Figure 7: Accelerated charging with defects

To accelerate the charging a sheet of metal with many sharp edged protrusions is installed at the outer conductor (fig. 7). The charging is investigated in air as insulation media to increase the charging process.

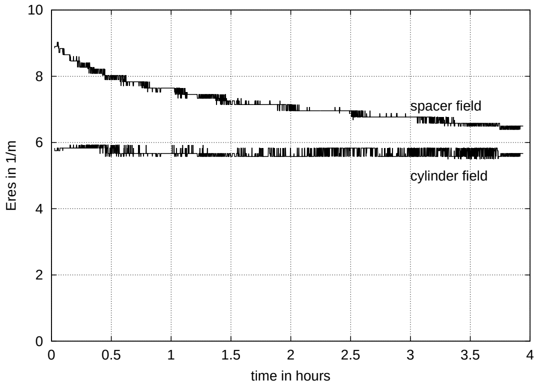

Figure 8: Uncoated spacer with defects

Fig. 8 shows the results of a 4 hour test. The cylinder field, measured with the second sensor, remains constant. The field at the sensor (spacer field) is continously decreasing starting from $9\frac{1}{m}$ down to $6.5\frac{1}{m}$. This proves the charging of the spacer. Fig. 1 also shows the resultant field for a fully charged spacer. The field is enhanced at the high voltage side and the sensor field (fig. 4) is reduced in case of a charged spacer.

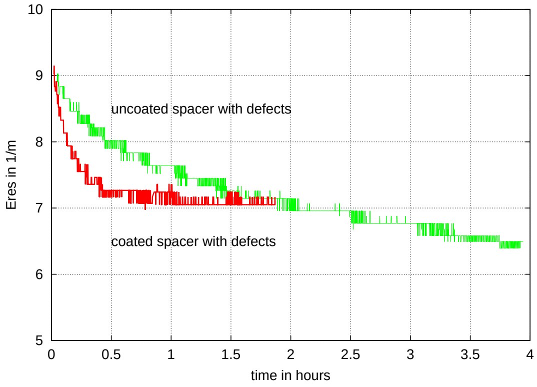

Figure 9: Comparison of coated and uncoated spacer with defects

To prevent this charging a conductive coating is used. Fig. 9 shows the field stress for a coated and uncoated spacer tested in case accelerated charging. Surface charge accumulation on the uncoated spacer decreases the (sensor) field. Using the conductive coating no charging takes place. The field is exactly the same as for a coated spacer tested without accelerated charging. A final steady state condition (resistive distribution) after the intermediate stage is reached.

Numerical Simulations

To investigate the influence of surface charge on the field distribution numerical calculations are made. It is possible to define for every node an additional accumulated surface charge. For the calculations a constant surface charge density for the whole spacer has been applied. Fig. 10 shows the influence of positive and negative surface charge layer of the spacer. A negative charge density of $-300\frac{pC}{m^2}$ reduces the resultant field stress, a positive enhances the field stress.

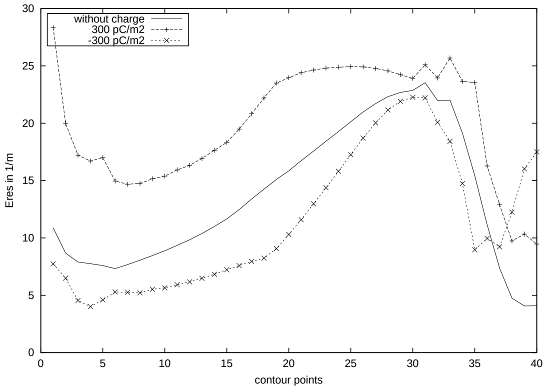

Figure 10: Influence of surface charge

With these calculations it is possible to get more information about the condition of the spacer. If there is a constant surface charging in progress, you can calculate the charge grade of the spacer.

σ in $\frac{pC}{m^2}$	sensor field in 1/m	field reduction
0	10.0	–
-100	8.9	11 %
-250	7.3	28 %
-500	4.6	53 %

Table II: Influence of surface charge

For example the measured field of $6.5\frac{1}{m}$ (fig. 8) that means a field reduction of 28% will be reached for a constant surface charge density of $-250\frac{pC}{m^2}$.
Furthermore the final condition for a fully charged spacer can be simulated with the additional boundary condition $E_n = 0$. Fig. 1 shows the resultant field stress for this final condition. The field is dramatically enhanced at the high voltage side of the spacer.

Conclusions

Investigations concerning the behaviour of GIS-system applied to HVDC are made. The main results are:

- A conductive surface coating in range of $10^{10} - 10^{15}\Omega$ improves the field distribution about 26%.
- The starting value E_0 (capacitive distribution) and the final steady state value E_{stat} (resistive distribution) are independent on the surface resistivity of the conductive coating.
- The intermediate transitional stage is defined by the time constant τ which is dependent on the surface resistivity of the coating.
- Surface charge accumulation on an uncoated spacer is leading to field distortion.
- The charge grade of the spacer can be investigated by numerical field calculations.
- The fully charged spacer can be simulated with the additional boundary condition $E_n = 0$.
- A sufficiently conductive coating prevents surface charge accumulation.
- A conductive coating defines a fixed final steady state of the field distribution on the spacer.

References

[1] CIGRE Working Group 15.03
Gas Insulation Properties in Case of VFT and DC Stress, CIGRE paper 15-201, Working Group 15.03, 1996

[2] F. Messerer, W. Boeck
Field Optimization of an HVDC-GIS-Spacer, Annual Report CEIDP, pp. 15-18, 1998, Atlanta

[3] F. Messerer, W. Boeck
High resistance surface coating of solid insulating components for HDVC metal enclosed equipment, 11th ISH London, 1999, Vol.4, pp. 63-66

[4] Z. Andjelic, B. Krstajic, S. Milojkovic, A. Blaszcyk, H. Steinbigler, M. Wohlmuth
Integral Methods for the Calculation of Electric Fields. Scientific Series of the International Bureau, Vol. 10, Forschungszentrum Jülich GmbH, Germany, 1992

[5] S. Chakravorti, H. Steinbigler
Capacitive-Resistive Field Calculation around a HV Insulator using Boundary Element Method, 10th ISH Montreal, 1997, Vol.3, p. 49-52

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