Field Optimization of an HVDC-GIS-Spacer

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Abstract

The paper deals with the optimization of a spacer for HVDC-Gas-Insulated-Substations (GIS) by means of 2D-axisymmetric field calculation.
For high voltage DC conditions the field is mainly controlled by the conductivity κ of the insulation material. Therefore investigations on the influence of volume and surface resistivity on the field distribution of the spacer are made. The field distribution can be improved by a certain resisitivity. In addition to the calculations with a constant resistivity of the whole spacer surface, computations with varying resistivities have been made, leading to an even better field distribution. The influence of volume resistivity are also investigated and discussed.

Introduction

Gas-Insulated-Substation (GIS) are successfully used for High-Voltage-AC equipment. More and more DC transmission lines are installed and used [?], but the isolation medium is still air. In order to use the advantages of the GIS for DC-voltage, additional problems have to be considered. There is the problem of surface charge accumulation, which leads to a field distortion and the breakdown voltage of the system is reduced [?]. Furthermore in contrary to AC voltage, the electric field is mainly controlled by the conductivity κ.
This paper reports about optimization of a spacer under DC-stress. In order to improve the field resolution, the electrical conditions of the spacer have to be changed. The surface and volume resistivity of the spacer are modified and the results of the field stress are investigated.

Basics

The field calculation is based on the Boundary Element Method (BEM) [?]. According to [?] the boundary conditions are modified to calculate fields with volume and surface resistivity. Therefore each boundary element can be defined with a certain volume and surface resistivity.
During the 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). Some time after the moment the DC voltage is reached the stationary final field distribution is gained which is controlled by the conductivity κ of the epoxy (resistive distribution). Furthermore the surface charge accumulation due to ion motion in the gas is leading to a field distortion. In order to obtain a controlled current density on the spacer it is necessary to realise a conducting coating on the surface of the spacer.

Application Example

The field calculations are carried out with a standard 420 kV epoxy spacer for Gas-Insulated-Substation as shown in figure ??. For the field calculation the spacer has to be described in a 2D-axisymmetric system (fig. ??). The geometry of the original spacer has not been changed

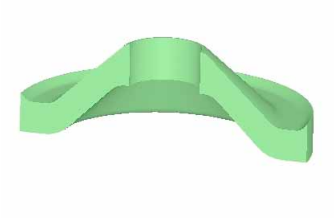

Figure 1: 3D model of the spacer

for the field calcultion. All further results are presented for the concave side of the spacer.

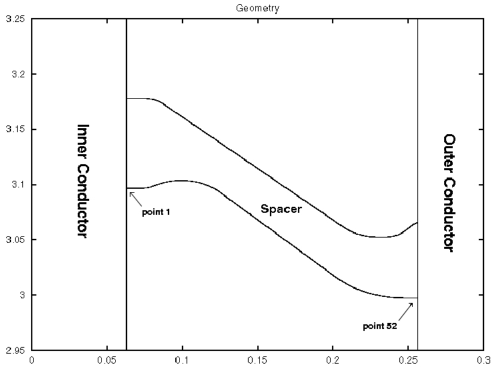

Figure 2: Geometrie for the field calculation

Surface Resistivity

The basic idea is to change the surface conditions to improve the field distribution. The calculations for the surface resistivity (ρ_{sur}) are made with a fixed value of volume resistivity ($\rho_{vol} = 10^{21}\Omega m$). The spacer without a surface conductivity is labeled as *s10e21* which means $\rho_{sur} = 10^{21}\Omega$.

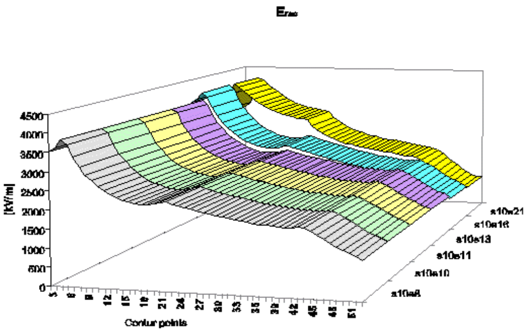

Figure 3a: Effect of constant surface resistivity to E_{res}

Figure 3a presents the resultant electrical stress E_{res} on the concave side of the spacer and figure 3b the tangential electrical stress E_{tan}.

The field distribution of E_{res} and E_{tan} for the coated surface is more homogeneous than without coating. The peak value of the resultant stress has only been slightly reduced from 4.115 kV/m to 3.824 kV/m. But along the part adjacent to the internal conductor (contur point 7 - 22) the resultant stress is reduced about 500 kV/m (fig. 5a). It is remarkable that there is no change of the field distribution between 10^8 and $10^{13}\Omega$.

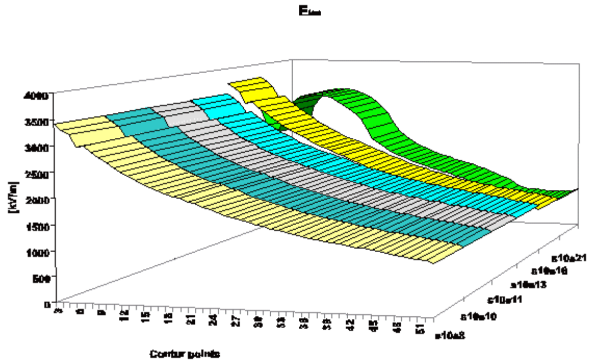

Figure 3b: Effect of constant surface resistivity to E_{tan}

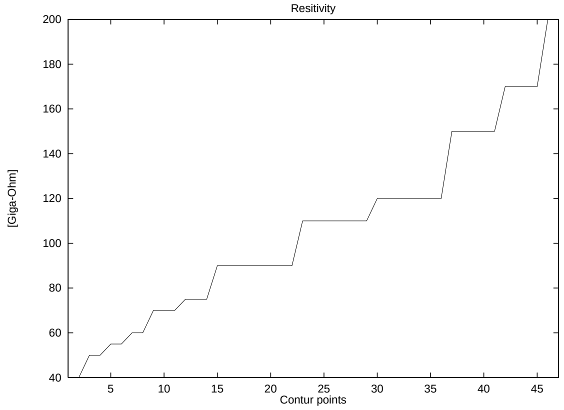

Figure 4: Gradual Resistivity

In addition to that the tangential stress has been increased at the high voltage side of the spacer (fig. 5b). Therefore additional optimization is necessary. In order to obtain better results near the high voltage electrode by a reduction of the electrical field stress it is useful to make a gradual coating on the surface of the spacer.

The current density j can be described as a function of the radius r ($j = I/2\pi r$). The electric

Field distribution in case of a gradual surface resistivity according to figure 4

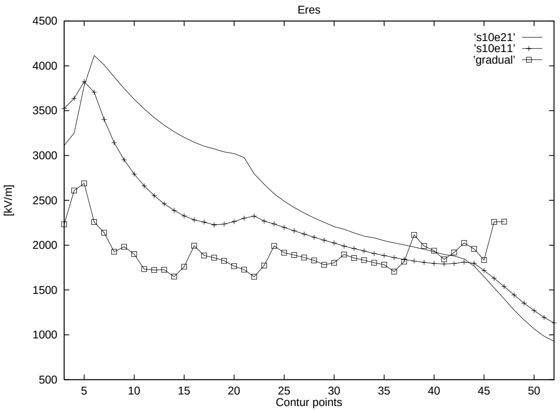

Figure 5a: Resultant field E_{res}

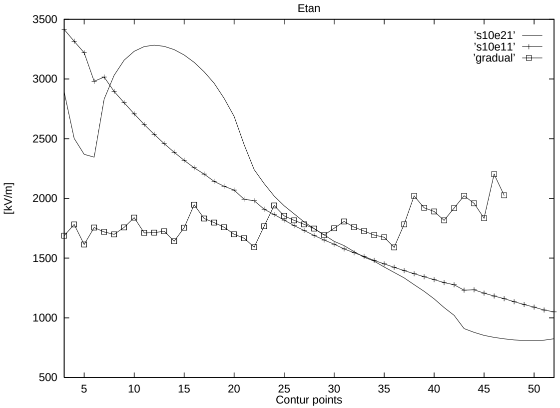

Figure 5b: Tangential field E_{tan}

field $E = j * \rho = I/2\pi r * \rho$. Where the resistance load is reduced, the local potential and therefore the local electric stress will be decreased. The total potential between the electrodes is constant ($U = \int Eds = const.$). Therefore using a coating with a resistivity distribution like in figure **??**, the resistance and therefore the potential drop is rised next to the grounded conductor. This leads to a lower field stress close to the high voltage electrode. For the field calculation it is necessary to assume a discontinueous coating. In practice it is of advantage to realise a uniformly rising coating.

The surface resistivity on the spacer starts with a value of $4 * 10^{10}\,\Omega$ and ends at the grounded conductor with $2 * 10^{11}\,\Omega$.

Figure 5 shows the result of the gradual coating. The peak value of the resultant and tangential stress is considerably reduced. The whole field distribution is very homogeneous. This is the optimum that can be reached.

Volume Resistivity

Investigations on the influence of the volume resistivity on the field distribution of the epoxy spacer are also made. The first calculations are carried out with a constant surface resistivity of $\rho_{sur} = 10^{21}\,\Omega$. The values of the volume restivity are varyied from $\rho_{vol} = 10^{11}$ *to* 10^{21} Ωm.

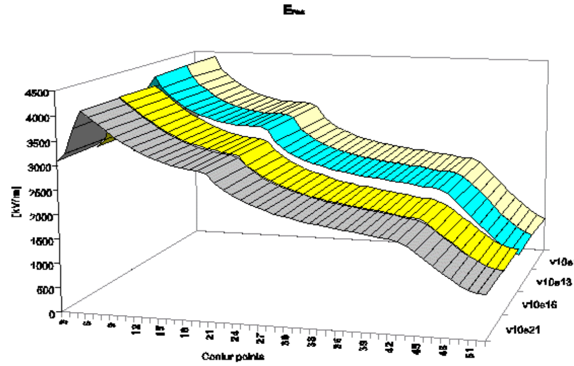

Figure 6: Effect of volume resistivity

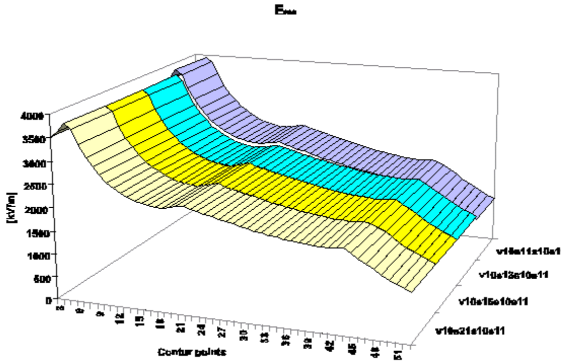

Figure 7: Effect of volume in addition to surface resistivity

Figure **??** shows that there is nearly no influence of the volume resistivity on the field distribution of the spacer. Further calculations are made with a fixed surface resistivity of $\rho_{sur} = 10^{11}\Omega$. The values of the volume resistivity are also varyied, but again there is no remarkable influence on the field distribution (fig. ??). Therefore this technique has not been investigated furthermore.

Further Possibilities

There are additional possibilities to optimize the field of a spacer for HVDC-GIS.
Regarding the results of the surface resistivity, a gradual coating is the optimum. It can be realised be varying the resistivity or by using a special coating with a voltage-dependent conductivity. The resistance has to increase with lower voltages.
A different way to improve especially the tangential field stress is to change the geometry of the spacer. Investigations on this topic were made. For example if the slope of a conical spacer is reduced the tangential field will be decreased. Numerical methods for optimization of the shape of the spacer are in use [?].

Conclusions

Several methods to improve the field distribution of a spacer for HVDC-GIS are investigated and discussed in this paper.

- *Volume resistivity*
  By varying the volume resistivity of the spacer, no remarkable change of the field distribution can be achieved.

- *Surface resistivity*
  By an uniform surface resistivity only minor improvements of the field distribution can be achieved. As to the tangential field even an increase of the maximum field may happen.

- *Gradual coating*
  This coating can be obtained by varying the resistivity on the spacer surface or by using non-linear voltage-depending material. This is a promissing technology to improve the field stress on the spacer.

- *Spacer shape*
  Changing the shape of the spacer is a usual method to improve the field distribution. But HVDC GIS have to withstand transient overvoltages. For such stresses the shape has been optimized. Therefore it is of advantage to apply such standard spacers and to modify the stationary field distribution by surface coating.

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