INVESTIGATION OF TRANSIENT PHENOMENA IN INNER- AND OUTER SYSTEMS OF GIS DUE TO DISCONNECTOR OPERATION

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ABSTRACT

This paper describes numerical models which give an accurate prediction of the transient behaviour of GIS-systems. Therefore a modern Gasinsulated Substation, containing three-phases in one encapsulation, has been modelled with regard to the coupling between the phases. With the help of this model several phenomena have been calculated and measured; the generation and the propagation of transients inside GIS has been modeled with regard to transient overvoltages in voltage- and current transformers and its datalines which are connected to the substation control and protection system. Furthermore the transient fileds which are linked to Transient Ground Potential Rise - TGPR have been calculated and measured.

1 INTRODUCTION

High voltage switchgear installations with operating voltages up to 800kV are used for distributing electricity in towns and cities, regions and industrial centres, and also for power transmission. SF_6-gas-insulated switching stations have the important advantage of taking up little space and being unaffected by pollution and environmental factors. Therefore SF_6-gas-insulated switching stations are favoured for supplying load centres in cities and industrial complexes. Transients caused by disconnector switch operations in SF_6-gas-insulated switchgear (GIS) are a potential source of electromagnetic interference to the installed substation control and protection system, [3, 5]. For the transients the coaxial character of GIS offers an excellent high frequency distribution network. Due to the skin effect, the currents are constrained to flow along the surface of conductors and do not penetrate through the conductors. Thus, two systems can be defined: an inner transmission line system consisting of the surface of the bus duct to the interior surface of the enclosure and an outer transmission line system consisting of the outer surface of the enclosure and ground. Essentially, there are two paths on which transients can reach the secondary equipment of the substation, [1, 2, 3].

The first coupling is wireless via electromagnetic field radiation. Transients generated within the GIS cannot appear on an exterior surface of the enclosure, i.e. there is no coupling between the inner and outer transmission line systems until discontinuities in the sheath are encountered. A traveling wave generated by the disconnector operation reaching such a discontinuity in the metallic enclosure, for instance GIS-bushings etc., results in a Transient Ground Potential Rise of the outer system, [1]. The electromagnetic fields linked to the Transient Ground Potential Rise - TGPR introduce part of their interference energy into secondary circuits, e.g. control data lines connected to the above mentioned substation control and protection system.

The second coupling works by wire via secondary cables. A certain part of the transients which are generated in the inner system, is transmitted via strew capacitances to the control and data lines of the installed current- and voltage-transformers. These transients occuring on the data lines travel to connected control- and protection systems of the substation, [3, 5, 6]. The transients are called transient overvoltages. In certain cases, these occurrences cause unwanted interference to the control- and protection system. The determination and lastly the improvement of the susceptibility of these systems in the presence of these transient overvoltages requires an exact knowledge of the transient behaviour of the inner and outer GIS-systems.

The phenomena which is mentioned above has been investigated in a 123kV-GIS. The GIS-system contains tree-phases in one encapsulation. The reproduction of such a setup in a appropriate model is quite difficult, because the interphases-interferences must be taken into account.

2 MODELLING OF THE 123KV-GIS

2.1 The 123kV-GIS

The investigated GIS, as it is shown in figure 1, is installed in Karlsruhe/Germany by Badenwerk AG and works as an utility in order to distribute electrical power. The nominal voltage of the device is 123kV.

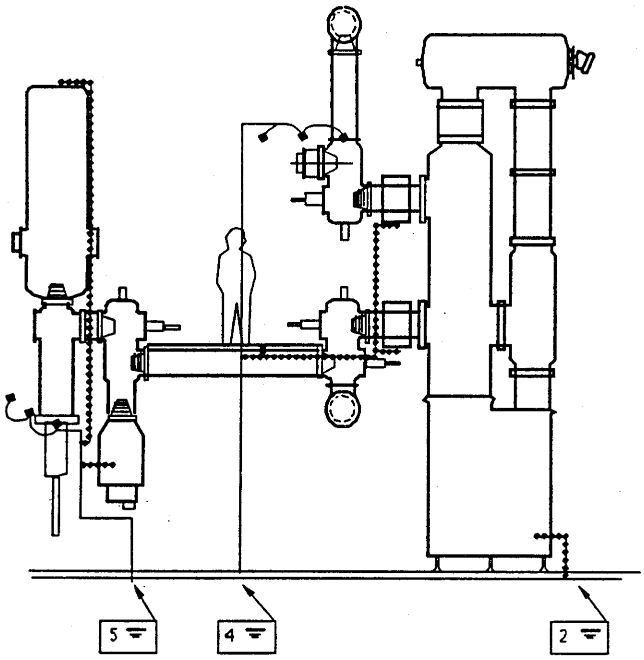

Figure 1: Shape of the investigated 123kV-GIS

In order to predict the transient behaviour of these devices, several networkmodels of GIS-components and physical effects in the GIS have been developed at the Institute of Electrical Energy Systems and High-Voltage Technology. With the help of the models the simulations of transients in GIS due to disconnector operation have been carried out. The following subsections present the most important models.

2.2 The Arc-model of the disconnector operation

Reffering to the real generation of transients in GIS, the disconnector operation has been modeled with the help of the modified Kopplin-model which describes the disconnector arc resistance. The resistance of the arc-discharge represents a substantial part of the damping of the whole GIS-system. Normally the resistance is a frequency dependent parameter due to the skin effect. In the case of arc-discharge there exists a strong time-dependency according to temperature, diameter and losses of the discharge. Thus the time-behaviour of the spark's resistivity has to be evaluated correctly. The time behaviour of the conductivity g(t) is mainly influenced by the time dependent temperature function $\tau(g)$ of the arc-discharge. Both functions are displayed in (1).

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau(g)}\left(\frac{u\cdot i}{P(g)}-1\right),\quad \tau(g)=\tau_0\left(1-e^{-\frac{g}{g_0}}\right) \qquad (1)$$

This description of the physical arc-discharge process is valid from the begining of the discharge up to its end. The model was implemented by means of a computer program.

2.3 Modelling of the inner system

The inner system, which consists of the high voltage bus duct and the inner surface of the encapsulation, is modeled with the help of transmission lines which consists of distributed elements. The phases and their inter phase coupling have been investigated with the help of modal components. This method permits the calculation of each phase and its coupling to the other phases seperately, [6].

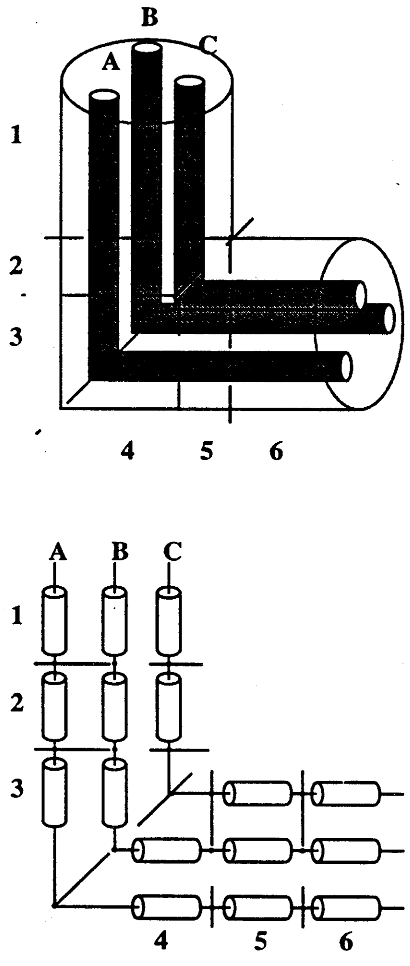

Figure 2: A corner-inhomogeneity of the inner system and its corresponding model

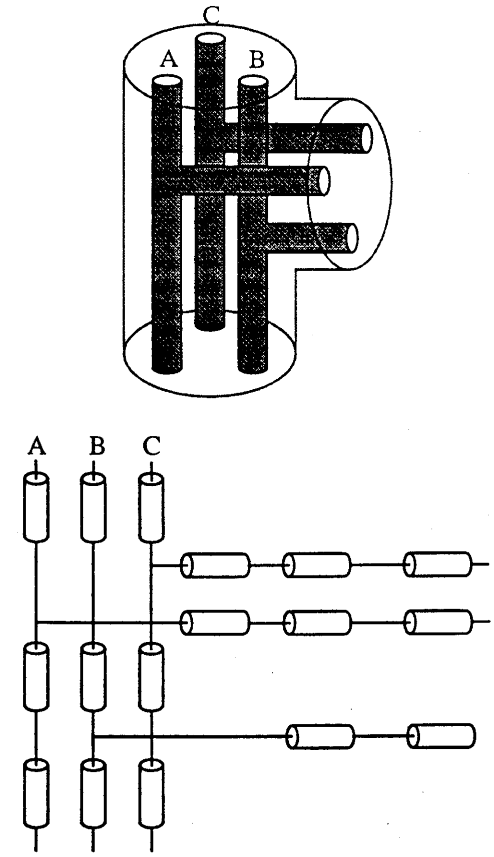

Figure 3: A Tee-junction inhomogeneity of the inner system and its corresponding model

Inhomogeneities in the inner systems are corners and Tee-junctions. Figure 2 displays in its upper part the schematic of a corner and in its lower the corresponding model. Figure 3 shows a Tee-junction and its corresponding model.

2.4 Modeling of the outer system

In the outer system the wave impedance Z of inhomogeneous places can be calculated on the basis of equations (1).

$$Z = \sqrt{\frac{L'}{C'}}$$

$$L' = \frac{\mu_0}{2\pi} \cdot \ln \frac{2h}{GMR} \qquad (2)$$

$$C' = \frac{2\pi\varepsilon_0}{\ln \frac{2h}{GMR}}$$

In this formula h is the height of an encapsulation element above the floor and GMR is the Geometric Mean Radius of the regarded GIS-element. The equations (2) are valid for horizontally orientated sections of the GIS-encapsulation. The spread per unit length of inductance (L') and capacitance (C') are mainly determined with the parameter h. The calculation of vertically orientated GIS-sections is performed under the assumption of their mean height above floor and equation (3) which describes the wave impedance of a vertically orientated pipe.

$$Z_A = 60 \cdot \frac{\sqrt{\mu_r}}{\sqrt{\varepsilon_r}} \ln \frac{4h}{D_A} \qquad (3)$$

Whereas h means the height of a vertically orientated element above ground D_A represents its diameter.

An inhomogeneity of the outer system is the cable junction plate. Figure 4 shows in which manner transient electrical fields penetrate the metallic encapsulation of the GIS at such an inhomogeneous place. A model of the cable junction has been developed according to figure 4. Four sections have been defined. Every section has its own wave impedance due to the local reflection coefficient. Figure 5 displays an equivalent circuit of the cable junction.

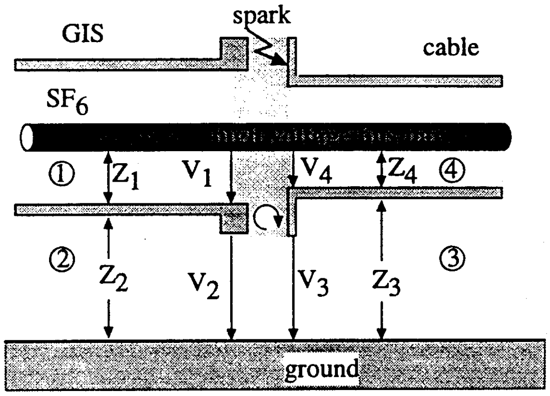

Figure 4: Inhomogeneities in the outer system: cable junction

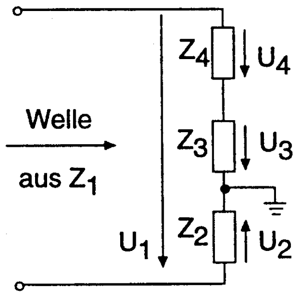

Figure 5: Equivalent circuit of cable junction

Generally the strew coefficients of this strew matrix are calculated according to equation (4):

$$s_{ij} = \begin{cases} \dfrac{\pm\ 2Z_i}{Z_1 + Z_2 + Z_3 + Z_4} & ,\ \text{für}\ \ i \neq j \\[2ex] 1 - \dfrac{2Z_i}{Z_1 + Z_2 + Z_3 + Z_4} & ,\ \text{für}\ \ i = j \end{cases} \qquad (4)$$

and $\qquad i, j \doteq 1, 2, 3, 4$

With the help of equations (4) the 4x4-strew matrix has been developed. The equations of the matrix describe the refraction of the waves, which are generated from the other lines and which reach the point of reflection. Equation (5) displays the strew-matrix of this four gates:

$$S=\begin{pmatrix} s_{11} & s_{12} & s_{13} & s_{14} \\ s_{21} & s_{22} & s_{23} & s_{24} \\ s_{31} & s_{32} & s_{33} & s_{34} \\ s_{41} & s_{42} & s_{43} & s_{44} \end{pmatrix} \quad (5)$$

S_{21} und s_{31} define the TGPR of the encapsulation of GIS the cable junction plate and the connected cable shield.

2.5 The current and voltage transformer

The transients are transmitted to the secondary lines of the GIS by strew capacitances which result of the construction of the protection electrodes in the transformers. The equivalent circuit of the current transformer is shown in figure 6. Figure 7 displays the equivalent circuit of the voltage transformer.

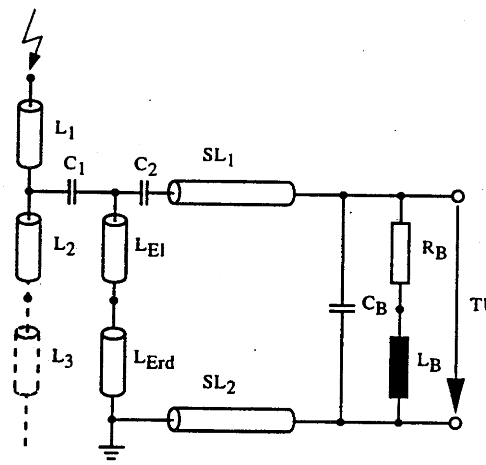

Figure 6: A model of the current transformer

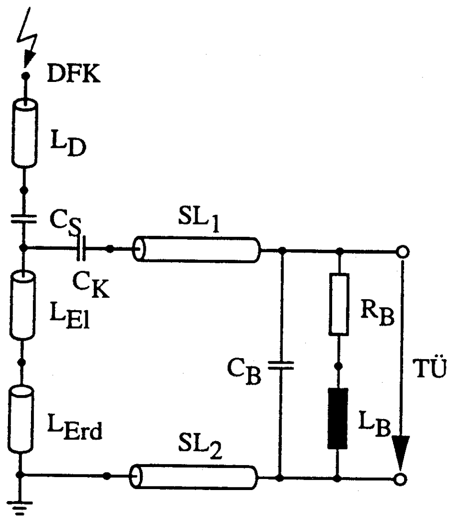

Figure 7: A model of the voltage transformer

3 CALCULATED RESULTS BY SIMULATION

Simulations have been carried out by applying the models which are described above. Figure 8 presents the simulation of the transient overvoltages from the secondary cable of the protection system.

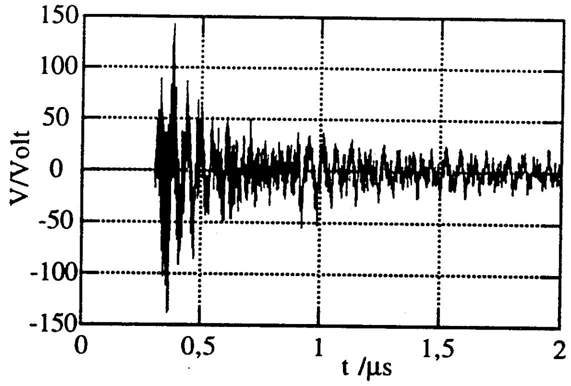

Figure 8: Calculated transient overvoltages at the protection system

Figure 9 displays the simulation of the transient electrical field which is connected to the TGPR. The calculation of this field has been performed under the assumption of a TGPR on the surface of the cable junction, which is correlated to the measurements in the next section.

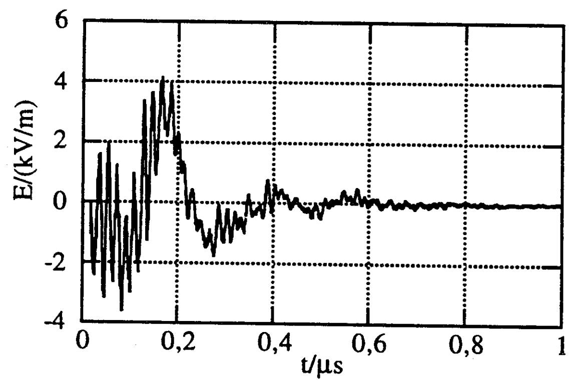

Figure 9: Calculated transient field under the cable junction

4 MEASUREMENTS IN THE 123 KV-GIS

During disconnector switch operations, the transient electrical fields and the transient overvoltages have been detected in the 123kV GIS, [6]. The measurements are divided in two parts: the detection of transient fields in the outer system and the measurement of the transient overvoltages at the interface of the control system to the secondary lines.

4.1 Transient overvoltages

The transient overvoltages have been measured at the terminal board of the protection system at the secondary lines with the help of a voltage divider and a transient digitizer.

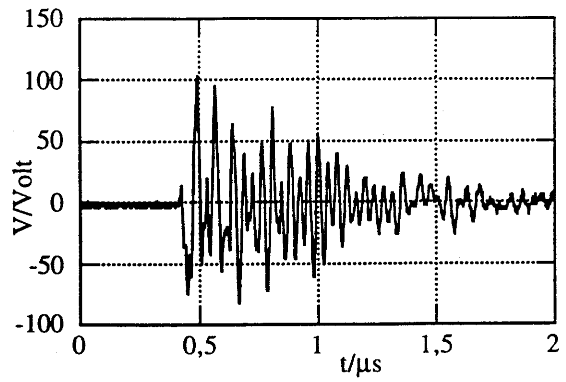

Figure 10: Detected transient overvoltages at one phase of the current transformer's protection core

Figure 10 shows the time function of the transient overvoltages which have been detected in the secondary cable of one phase of the current transformer's protection core.

4.2 Transient fields and TGPR in the outer system

The transient electrical fields in the outer system have been detected using a spherical transient field probe.

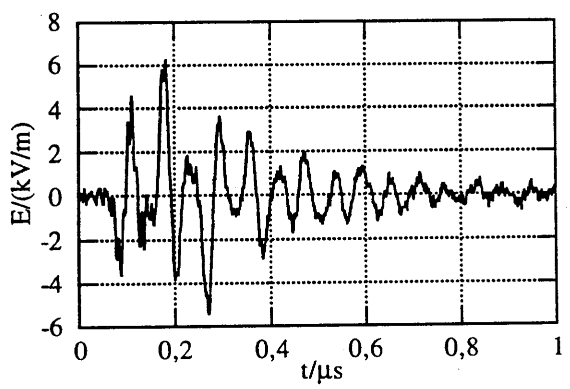

Figure 11: Detected transient electrical field under the cable connection plate

One result of the transient electrical field measurements is presented in figure 11. The fields have been detected under the cable junction plate of the GIS. The information has been transmitted via a dielectric fibre optical cable from the probe to a transient digitizer. The usage of a fibre optical transmission cable minimizes the distortion of the probe´s setup upon the field under consideration. The time function of the transient elecrical field carries the information of the TGPR. The TGPR can be calculated from the transient electrical field using the electrical field distribution in the surroundings of the probe during the measurements.

5 DISCUSSION

The measurement of the transient overvoltages generated at the interior GIS-system, figure 10, and its corresponding calculations, figure 8, confirm the validity of the applied simulation method for the inner system. Besides this, the comparison of the corresponding frequency spectra demonstrates the quality of the models. Figure 12 shows the frequency spectrum of figure 8 in the frequency range up to 100MHz and figure 13 the accordingly frequency spectrum of figure 10. In the frequency range from up to 20 MHz either the calculation as well as the measurement have level values of about 7 volts to 8 volts and between 20MHz and 30 MHz there exists a second maximum. The calculation delivers values at the upper frequencies whereas the mesured results do not.

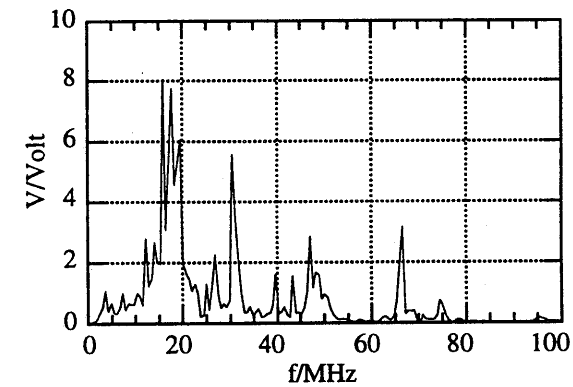

Figure 12: Frequency spectrum of calculated transient overvoltages

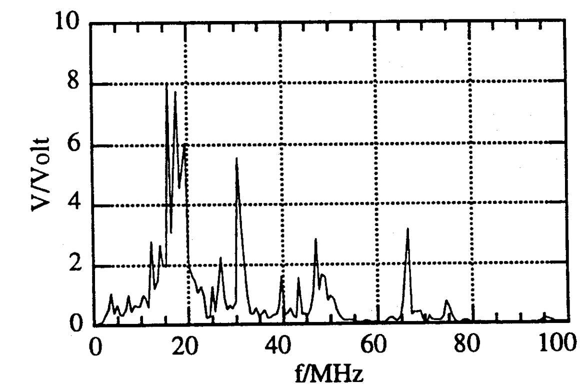

Figure 13: Frequency spectrum of measured transient overvoltages

In order to get a closer congruence between measured and calculated results the measurement technique which is used to detect the transient overvoltages should be improved. Particularly the voltage divider and its connection to the terminal board of the protection system must be developed in order to get a higher pulse fidelity.

The calculated time function of the transient electrical field is quite different from the measured results. Whereas the amplitudes are in the same level range the oscilation of the field points to aberrations between simulation and measurement. In order to minimize these differences the model which has been used to calculate the transient electrical fields will be improved.

6 CONCLUSION

Both, the calculated results by simulation and the detected overvoltages at a termination board of the digital protection system in GIS, presented in this paper, agree sufficiently and confirm the validity of the applied simulation method for the inner system of GIS. To achieve better results the measurement technique, which is used to detect the transient overvoltages, must be improved. Especially the voltage divider and its connection to the terminal board of the protection system must be developed in order to get a higher pulse fidelity.

The calculated time function of the transient electrical field is quite different from the measured results. Whereas the amplitudes are in the same level range, the oscilation of the field shows aberrations between simulation and measurement. In order to minimize these differences the model which has been used to calculate the transient electrical field will be improved.

7 LITERATURE

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