Numerical Simulation of Transient Fields

F. Messerer, C. Trinitis*, W. Boeck, G. Schöffner

Institute of High Voltage Engineering and Electric Power Transmission
*Lehrstuhl für Rechnertechnik und Rechnerorganisation
Technische Universität München
GERMANY

Abstract

The paper deals with the numerical simulation of transient fields using Boundary-Element-Method (BEM) and Discrete Fourier Transformation (DFT). Instead of solving the Maxwell equations for transient fields in the time domain a numerical method using the DFT algorithm for solving in the frequency domain is developed.
Impulse voltages and polarity reversal for HVDC systems are simulated as examples for the transient stresses. The application example is a standard spacer for Gas Insulated Substation (GIS) used in 145 kV systems. Investigations are made concerning the sampling rate and frequency. The behavior of conductive and non-conductive spacer surfaces due to transient fields are made.
Furthermore for the calculations a parallel numerical solver based on PVM (Parallel Virtual Machine) is used. Results are proving the advantage of this tool to reduce the calculation time.

Introduction

Transient field stresses are important for the development of HV equipment. Therefore it is useful to have a tool to simulate transient fields with numerical methods. Instead of solving the Maxwell equations in the time domain a numerical method using the DFT algorithm for solving the equations in the frequency domain is developed. Due to [1] the field distribution of an HVDC system can be improved with a certain surface resistivity. With such a resistivity it is not sufficient to consider only the electrostatic field because the time dependency of the applied voltage affects the field distribution [2]. Therefore the behaviour of capacitive-resistive fields in case of transient stresses is of importance.

Theory

The numerical field calculation is based on the Boundary Element Method (BEM). According to [3] the boundary conditions are modified to calculate fields with surface resistivity of solid insulators. For the calculation of the transient fields an algorithm based on the Discrete Fourier Transformation is developed.
The transient voltages have to be discretized with N discrete values. The sampling (with the sampling time T_a) yields N spectral values at discrete frequencies $\omega_k = k\Delta w = \frac{2\pi k}{NT_a}$. The transient voltage is transformed into the frequency domain and back to the time domain according to equations (1,2).

$$\underline{U}[\omega_k] = \sum_{n=0}^{N-1} u[n] e^{-j\omega_k n T_a} \tag{1}$$

$$u[n] = \frac{1}{N} \sum_{k=0}^{N-1} \underline{U}[\omega_k] e^{j\omega_k n T_a} \tag{2}$$

The sampling causes a periodical continuation of the signal in the time domain. Therefore transient voltages have to be sampled with their complete impulse duration to avoid aliasing. Figure 1 shows the influence of the sampling time on the spectrum of a lightning impulse voltage. Sampling 8 and 64 μs with $N \cdot T_a$ leads to a wrong sprectrum. For a correct sampling it is necessary to sample the whole impulse (512 μs).

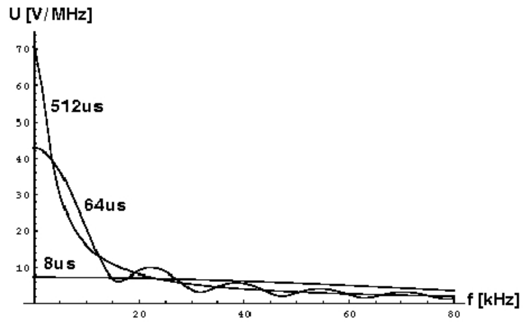

Figure 1: Influence of sampling time

Application example

The application example for the investigations is a standard spacer manufactured by SIEMENS for Gas Insulated Substation (GIS) used in 145 kV systems. The simulation model (figure 2) shows the inner conductor, the spacer and the outer conductor of such a system.

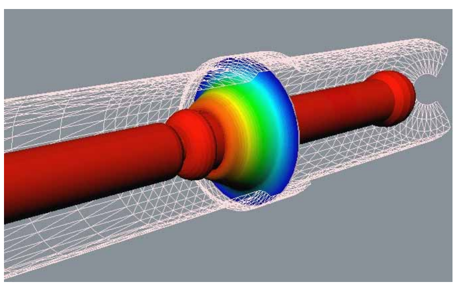

Figure 2: Modell of the GIS-spacer

To investigate the influence of the conductivity on the applied transient voltage the surface resistivity of the spacer is varied from 10^7 (s7) to $10^{13}\Omega$ (s13). A surface resistivity of $10^{20}\Omega$ (s20) stands for a non-coated surface, i.e. for an ideal insulator. The numbering of the contour points starts at the high voltage electrode. The results are presented for the contour point with maximum value of resultant stress on the concave side of the spacer.

Impulse voltages

The investigated impulse voltages like lightning and switching impulse can mathematically be described with a double-exponential equation (3) with the constants U_0,T_1 and T_2 shown in the table below.

$$u(t) = \begin{cases} U_0 \cdot (e^{-\frac{t}{T_1}} - e^{-\frac{t}{T_2}}) & for\ t \geq 0 \\ 0 & for\ t < 0 \end{cases} \qquad (3)$$

Impulse	U_0	T_1 [μs]	T_2 [μs]
LI (1.2/50)	1.0371	0.405	68.5
SI (250/2500)	1.1043	62.48	3155.02

Figure 3 shows the influence of the frequency on the field distribution. For 0 Hz there is a resistive, for $0 < f < 10$ Hz a capacitive-resistive and for frequencies higher than 50 Hz a capacitive field distribution. For a surface resistivity of $10^{11}\Omega$ there is a treshold frequency of 100 Hz. There is no change in the field distribution above this frequency.

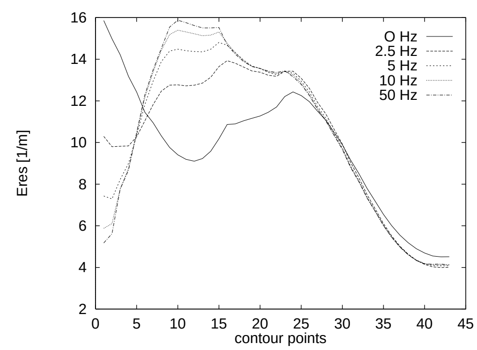

Figure 3: Influence of frequency (with surface resistivity $10^{11}\Omega$)

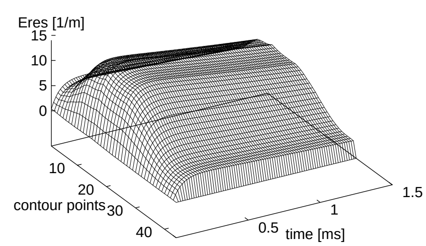

Figure 4: Transient field stress

Regarding a lightning impulse voltage the main part of the spectrum is above the treshold frequency due to its short duration of some 10 μs.

Therefore the field distribution is nearly the same as for a static capacitive distribution. The surface resistivity has no influence. For a switching impulse voltage with a duration of some ms the surface resistivity has an influence. The calculations for such a switching impulse are made with a sampling time $T_a = 12.5\,\mu$s and with $N = 2^{12}$ discrete spectral values. Figure 4 shows the results for a spacer with a surface resistivity of $10^{11}\,\Omega$. The influence of surface resistivity in case

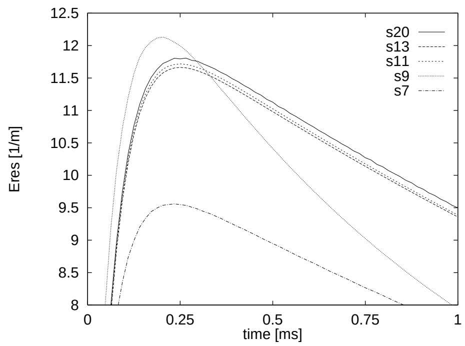

Figure 5: Influence of resistivity

of a switching impulse voltage is shown in figure 5. The peak value of the resultant stress has a maximum for a capacitive-resistive field with $10^9\,\Omega$ and is clearly lower for a resisitive field of $10^7\,\Omega$.

Polarity reversal

A further point of interest is the simulation of polarity reversal for HVDC systems. The simulated voltage changes between +/- 1 kV in a reversal time of 125 ms. The duration of the whole simulated voltage is 16 s and is sampled with $N = 2^{10}$ discrete values. Figure 6 shows the influence of surface resistivity on the polarity reversal. For both a purely capacitive field (s20) and a purely resistive field (s9) the electric field stress is similar to the applied voltage. However, for capacitive-resistive fields (s11-s13) the resultant electric stress exceeds the static value temporarily after the reversal. This peak approaches the final static value with a time constant that depends on the resistivity.

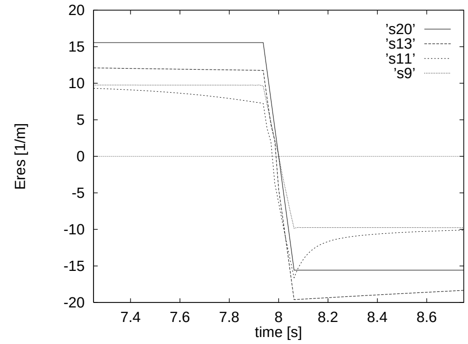

Figure 6: Influence of resistivity

Improving calculation time

One major drawback when doing numerical simulation of transient fields is the high amount of calculation time. According to table 1 it takes about nine hours even on a 180MHz R5000 SGI workstation. An acceleration of the computation may be achieved by parallel processing. Parallel processing has been successfully used to speed up field calculation in [5] and [6]. The target hardware environment is a cluster of one R5000 based SGI workstation (the one that has been used for the sequential computations) and two LINUX based PCs, one with a 200MHz PentiumPro CPU, the other one with a newer 400MHz AMD K6 CPU. This environment is supposed to be representative of contemporary standard resources which are available to engineers. The widely spread parallel programming library PVM (Parallel Virtual Machine) [4] has been used to implement the parallelization of the code.

Parallelization of the Code

After transforming the (discretized) transient voltage into the frequency domain a set of N frequencies is obtained. For each of these frequencies the field calculation has to be done separately. Since all frequencies can be calculated independently from each other the task can easily be parallelized based on a master slave approach. One node (i.e. computer) is assigned the master (who has to coordinate the parallel job) while the others are the slaves (who are waiting to receive a task from the master). Each slave is assigned a frequency that is has to calculate. Since the administrative part of the algorithm is not very CPU intensive a slave task can also be started on the master node. Whenever a slave has finished its calculation it informs the master that it is ready to calculate a new frequency. The parallel program has finished its job when all frequencies have been processed.

Results of Parallelization

Table 1 shows the overall calculation times for one node (sequential calculation), two nodes and three nodes. The calculation example in this case is a polarity reversal with $N = 2^{10}$ frequencies.

SGI R5000-180	Linux PPro200	Linux AMD K6-400	time
in use	off	off	9h23'
in use	in use	off	3h55'
in use	in use	in use	1h21'

Table 1: Results of parallelization

The time can be significantly reduced by parallelization. Since there is almost no communication between the tasks on the parallel cluster during the actual calculation a very high parallel efficiency can be achieved as for instance by using the R5000 SGI and the PentiumPro PC which have similar performance for such applications. By an additional 400MHz AMD PC a considerable improvement can be achieved.

Conclusions

- A simulation tool for the calculation of several transient fields is developed and tested.
- Impulse voltages can be calculated. The investigated surface resistivity has only influence on the field distribution for switching impulse voltage.
- Polarity reversal voltage is simulated. Capacitive-resistive fields have an influence on the field distribution.
- An acceleration of the computations can be achieved by parallel processing of the field calculation. The calculation time can be significantly decreased.

References

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

[2] H. Singer
Impulse stresses of conductive dielectrics, 4^{th} ISH Athen, 1983, 11.02

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

[4] A. Geist et al.
PVM 3 User's Guide and Reference Manual, Oak Ridge National Laboratory, Tennessee, 1994

[5] A. Blaszczyk, Z. Andjelic, P. Levin and A. Ustundag
Parallel Computation of Electric Fields in a Heterogeneous Workstation Cluster, pp. 606-611, Lecture Notes in Computer Science 919, HPCN Europe, Springer Verlag, 1995

[6] A. Blaszczyk and C. Trinitis
Experience with PVM in a Industrial Environment pp. 175-179, Lecture Notes in Computer Science 1156, EuroPVM'96, Springer Verlag, 1996

Address of author

Frank Messerer
Lehrstuhl für Hochspannungs- u. Anlagentechnik
Arcisstrasse 21
Technische Universität München
D-80290 München, Germany
E-Mail: frame@hsa.ei.tum.de