Choice of Electrical Field Calculation Method According to the Dielectric Design Criteria

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The use of simulation programs has given high security and confidence in predicting and investigating the performance of transformer insulation systems. Two most commonly used methods for electrical field calculation are finite element method and boundary element method. Each of the two methods has its advantages, depending on the applied dielectric design criteria. In this paper both methods will be analyzed and presented on real case study of power transformer main insulation. Maximum and cumulative design criterion will be applied in order to conclude which method and criterion combination provides adequate results.

Index Terms—**Power transformers, Finite element methods, Insulation**

I. INTRODUCTION

Electric field analysis plays an important role in the design and development of insulation systems. Practical electrode systems are complex and require numerical techniques for field analysis. [1] The use of simulation software in predicting and investigating electric field responses of particular insulation elements has saved a lot of money and time and also provided significant security to insulation breakdown calculations. [2]

Most commercial tools for electric field calculation use one of the two following calculation methods – Finite Element Method (FEM) [3] or Boundary Element Method (BEM) [4]. At the same time, two possible criteria are used for the analysis of the calculation results – maximum field criterion and cumulative field criterion. [5] Therefore it is necessary to analyse both methods as well as apply both criteria on the results to conclude which method and criterion combination gives adequate results.

II. OVERVIEW OF THE METHODS

In this section, both methods, FEM (Finite Element Method) and BEM (Boundary Element Method) will be presented and compared.

FEM is based on dividing a complex problem/model into a number of elements which are then solved in relation to each other. It is a good choice for solving partial differential equations over complex domains, for cases when the domain changes, when the desired precision varies over the entire domain or when the solution lacks smoothness. In such cases it is possible to increase accuracy in areas of interest by dividing those areas into a larger number of elements. [6]

BEM denotes any method which uses the given boundary conditions to fit boundary values into the integral equations. Such solution has a distinguishing feature that it is an exact solution of the differential equation in the domain and is parameterized by a finite set of values placed on the boundary. [7] Once the solution is obtained, the integral equation is used again to calculate the values at any desired point in the interior of the solution domain. [8]

The differences between the two methods are shown in TABLE I. [9]

TABLE I
COMPARISON OF FEM AND BEM

FEM	BEM
An entire domain mesh is required	Only a mesh of the boundary is required
Entire domain solution is calculated as part of the solution	Solution of the boundary is calculated first; solution at domain points are found as a separate step
Reactions on the boundary are typically less accurate than the dependent variables	Both values are of the same accuracy
Differential equation is being approximated	Only boundary conditions are being approximated
Sparse symmetric matrix generated	Fully populated nonsymmetric matrices generated
Element integrals easy to evaluate	Integrals more difficult to evaluate, some contain integrands that become singular
Widely applicable; handles nonlinear problems	Cannot handle all linear problems; unsuitable for nonlinear problems
Relatively easy to implement	Much more difficult to implement

III. TRANSFORMER MAIN INSULATION MODEL

Transformer main insulation consists of a large number of elements. The example used in this calculation is shown in Fig. 1. The model contains two windings – high voltage winding (HV) with potential ring (PR-HV), both at a certain potential; and low voltage winding (LV) which is earthed. There is also a significant amount of vertical and horizontal barriers, caps and cylinders. The potential and field values are analyzed across the four specific blue lines shown in Fig. 1.

The model is created in the Electro 2D/RS software by Integrated Engineering Software. An Intel Core 2 Duo 2.66 GHz computer was used. Both FEM and BEM calculation were conducted in the same software. This implies that all

obtained differences are the result of the application of different methods, and not caused by software or model differences.
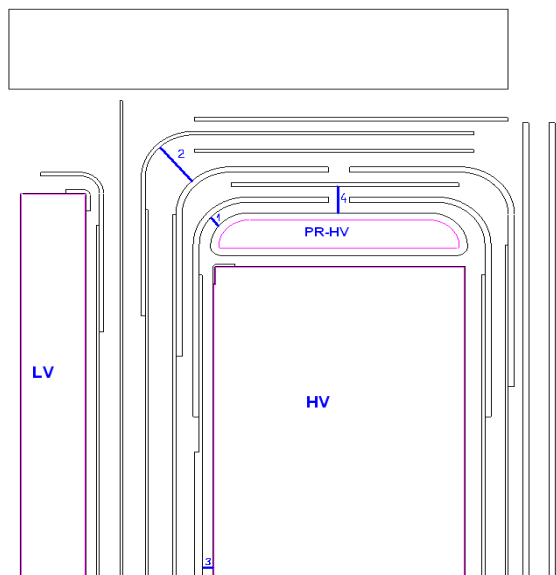

Fig. 1. Transformer main insulation model

Electric field calculation has been conducted for both methods.

The field graph for both methods along each of four streamlines is qualitatively same with good coincidence. Comparing the results obtained with FEM and BEM, some differences can be noticed. The biggest difference can be seen on field graph for streamlines 1 and 4. This is expected because these streamlines are near electrode boundaries where BEM method gives accurate results while FEM provides only approximate values. Streamline 2 is away from the electrode boundary so the difference between the methods is not so significant. Streamline 3 is chosen in the area where the electric field is homogenous; therefore significant differences were not expected.

The effect of these differences is analysed by applying dielectric design criteria on conducted results.

IV. MAXIMUM AND CUMULATIVE CRITERION

According to literature, two dielectric design criteria are curently being used in transformer insulation dimensioning: maximum criterion and cumulative criterion, both named according to the type of field values used for comparison with the standard withstand levels. [10]

The maximum field values can be conducted direct from the software while cumulative field values must be calculated for each oil duct within the selected contour. [11]

The overview of the conducted results for each streamline (1-4, blue on Fig. 1) is presented in TABLE II. The withstand levels are not taken into account due to the fact that they are a reference for comparison. The table considers only cumulative and maximum field values along each of the streamline in the specific oil duct.

As already stated, results for streamlines 1 and 4 have significant deviation depending on the method used for the calculation. Also, the differences between maximum field values are not as significant as those obtained by applying cumulative criterion.

TABLE II
RESULTS ANALYSIS ACCORDING TO THE MAXIMUM AND CUMULATIVE CRITERION

DIFFERENCE (BEM-FEM)/BEM [%]	Difference between maximum field values	Difference between cumulative field values
Streamline 1	1.56 %	2.86 %
Streamline 2	0.08 %	1.57 %
Streamline 3	0.15 %	0.15 %
Streamline 4	5.65 %	9.21 %

Since BEM by definition gives accurate results at electrode boundaries where the maximum field values are normally expected, it can be assumed that it is more efficient for the maximum field criterion. However, the choice of method for application of cumulative criterion is not as clear and requires additional analysis. The results indicate that the choice of method has a direct and significant impact on the insulation design and its optimization.

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