Voltage Presence Indicating System for Medium Voltage Switchgear

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Abstract: - This paper describes the development and testing of a new voltage detecting system for medium-voltage switchgears. This system is to indicate the voltage presence of. It consists of epoxy pin insulators with a capacitive voltage divider and an electronic indicator unit.

For the voltage indicators that entirely ensure no voltage conditions (shielded, invisible parts), the new IEC standards define the necessary capacitance, which is much higher than it was in the previously made indicators. The electrodes of voltage indicators that fulfil the above-described requirements have been selected on the basis of electric field computations. These computations have also been used to achieve the most suitable electric field strength distribution. A new version of a voltage indicator has been developed by redesigning the existing one.

Numerical computations of the electric field have been confirmed by practical tests on the prototype of a new voltage indicating system for building into medium voltage switchgear.

Key-Words: - Computer-Aided Design, Finite Elements Method, Application, Voltage Indicating System, Medium-Voltage Switchgear

1 Introduction

Insulators made of epoxy resin have very good insulation characteristics, mechanical and thermal properties, as well as high resistance against damaging impacts of chemicals. They are also characterised by small sizes, various design shapes and long service life.

In switchgears they are used either as insulation elements for galvanic separation of energized and earthed parts, or as construction elements for mechanical fixing of switchgears elements [3].

Pin insulators are also used to indicate voltage in medium voltage switchgear. Such indicators give a continuously visible information on the presence of voltage, which ensures the safety of people performing manipulations on the switchgear, prevents wrong manipulations and increases the reliability of operation.

Voltage indicator's electrodes in a medium voltage switchgear for indoor use are usually built into pin insulators, supporting the switching device or any other energized element.

Previous versions of pin insulators with built-in capacitive dividers have been designed to have a relatively small capacitance. So far, there were no limitations. The new IEC 61985 [5] standard requires the voltage indicators to be made in compliance with the IEC 61243-5 [4] standard, which defines the adequate values of capacitance. The manufacturer has to specially specify this value. According to the above mentioned standard, the voltage indicator's capacitance should be between 74 and 88 pF. Therefore, it is necessary to modify accordingly the existing voltage indicators to comply with these requirements. In our case this has been achieved by optimising the electrodes of the capacitive voltage divider on the basis of electric field computations. Other parts of the pin insulator have remained unchanged.

2 Voltage presence indicator

Three-phase voltage indicators of energized shielded parts are used in medium voltage switchgears, where energized elements are covered by screens and are therefore not visible in normal operation. Such examples are all types of metal clad switchgear, all functional units with metal or insulation partition walls, and other electrical devices.

Voltage indicators in medium voltage switchgear consist of three standard shape epoxy pin insulators with capacitive voltage dividers built into them and an electronic indication unit in the enclosure [6]. This indication unit has the shape of a standard measurement instrument. On the front panel of the unit there are LE diodes, the pulsation of which indicates the presence of voltage of each phase. There is also a button for testing the connection of the indication unit with the capacitive dividers and the correct operation of the unit.

Other types of voltage indicators are single-phase "plug-in" indicators that are used in medium voltage switchgear in combination with capacitive voltage divider. They are simpler, do not need auxiliary supply, and are therefore cheaper. A glow lamp is used as source of light. It is only necessary to install adequate pin insulators with capacitive voltage dividers into a functional unit of switchgear. Three single-phase sockets have to be mounted to the door and connected with coaxial cables with the voltage dividers. Sockets are in normal operation short circuited by means of short circuit rings. Voltage indication is performed by removing the short circuit rings and plugging the indicator into the sockets.

3 Electric field computation

Electromagnetic field is described with the basic Maxwell's equations:

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad (1)$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{D} = \rho ,$$

where:

H – magnetic field strength vector,
J – electric current density vector,
D – electric flux density vector,
B – magnetic flux density vector,
E – electric field strength vector,
ρ - volume electric charge density.

The above equations describe electromagnetic phenomena in any area Ω, limited by boundary Γ, as seen in Figure 1 [1].

With regard to the actual problem and data available, Dirichlet's (Γ_1) Neumann's (Γ_2) boundary conditions are used:

- on the part of the boundary Γ_1, which limits area Ω, the following equation can be written for the tangential component of E:

$$\mathbf{E} \times \mathbf{n} = 0 , \qquad (3)$$

- on the part of the boundary Γ_2, which limits area Ω, the following equation can be written for the normal component of the electric flux density:

$$\mathbf{D} \cdot \mathbf{n} = 0 . \qquad (4)$$

Area Q represents the area of sources (in our case electrical).

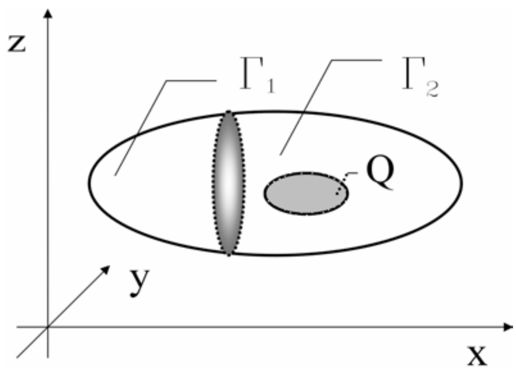

Figure 1. Observed area with sources and boundary values

Such problems are nowadays solved numerically using the finite elements method (FEM). Our problem has been treated as a three-dimensional problem. To solve three-dimensional problems in practice, either tetraedric or hexaedric elements can be used. In our case isoparametric second-order finite elements with twelve nodes have been used to model the 3D problem. Such elements also enable modelling of curved structures.

Figure 2 shows such an element with numbered nodes.

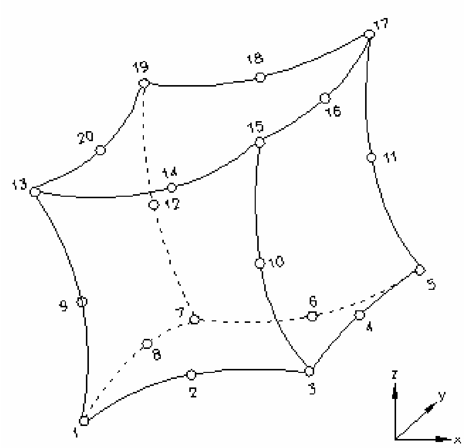

Figure 2. 20-node hexaedric element, represented in global co-ordinate system

4 Design of voltage indicator with electric field computation

Voltage indicator electrodes that are placed inside the pin insulator usually consist of metal inserted pieces that are fixed to the upper and lower surface of the insulator, and of a cylindrical electrode made of metal mesh or sheet. Metal inserted pieces can also have electrodes of various shapes welded onto them.

The voltage indicator electrodes have been optimised using the program package **Ele**ctromagnetic **F**ield **An**alysis **T**ools, developed by IGTE, TU Graz (EleFAnT3D) [2]. The program package is designed for solving electromagnetic field problems using FEM.

The program enables us to solve stationary, time-dependent electromagnetic and thermal fields. The three-dimensional graphic pre-processor enables inputting of data relating to type and geometry of the problem, boundary conditions, material and sources.

The main program named Solver enables solving of problems on the basis of various approaches (scalar potential, vector potential, T-Ω, etc.), depending on the type and shape of each individual problem. Thus solutions can be sought in individual nodes of finite elements or alongside the edges of elements, where edge elements are used in the computation as a special case of Whitney's elements.

The post-processor both numerical and 3D or 2D graphical presentation of scalar and vector quantities of the solved problem, either entirely or partially. Additional post-processing in our case enables calculating the volume integral of the problem, which yields the quantity of energy accumulated in the material. On the basis of this energy it is possible to obtain the capacity on the basis of the following equation:

$$C = \frac{Q}{U} \tag{5}$$

$$C = \frac{2W}{U^2} \tag{6}$$

where:
C – capacitance,
Q – electric charge,
U - voltage,
W - electric energy.

The actual problem has been solved using a PC with Pentium IV/1,4 GHz processor, 512M RAM, as a 3D electrostatic problem using the scalar potential approach. The basic structure has been modelled by means of 1360 macroelements (they represent the basic "rough" structure) that have been further subdivided in 3 parts in the directions of all three axes (*x, y* in *z*). This division has yielded 36,720 final elements, in which the solution of the problem has been sought.

The basic input data and calculating data have been as follows:

- number of macroelements 1,360,
- number of finite elements 36,720
- number of computation nodes 151,021
- number of coefficients in the system of equations (after reduction) 4,289,071
- number of CG (Cholesky-Gauss) iterations 81
- total computing time 44 s

5 Result of optimisation and electric field computation

All electric field computations have been performed for 125 kV potential. This value of potential equals lightning surge test voltage for 20 kV pin insulators. Below are some figures showing the distribution of electric field in the pin insulator. Colour scale for electric field strength magnitude is shown in the right-hand side of these figures. Parts of the pin insulator in which electric field strength exceeds the above value are shown in white colour.

The highest permissible value of electric field strength, which causes neither dielectric breakdown nor flashover, is called dielectric strength. Dielectric strength of epoxy resin and air amounts to 30 MV/m and 3 MV/m, respectively. The calculated values of electric field strength should never exceed these values. In the opposite case it is necessary to continue the process of optimisation of electrodes' position and selection.

Figure 3 shows the grid structure of the previous version of capacitive divider electrodes and interior of the pin insulator. Metal inserted piece, which serves as an element for mechanical fixing on the upper side, is elongated with a special electrode that has electric potential of conductive parts. Metal connection for mechanical fixing to the earthed part (lower connection) is on the lower part of the insulator. Around this metal inserted part an electrically insulated cylindrical metal mesh having electrical potential 0 V is located. This mesh represents the second electrode of the indicator's capacitive divider.

Figure 4 shows the grid structure of final elements of the pin insulator's exterior. Due to insulator's axial symmetry, better illustration of the results and simplicity of the computation, all electric field computations have been made for one quarter of the pin insulator.

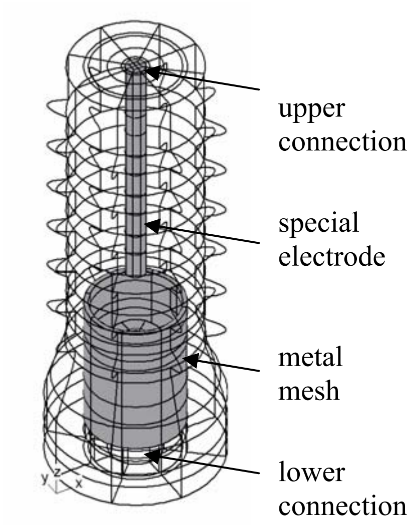

Figure 3. Grid structure of capacitive divider electrodes and insulator interior

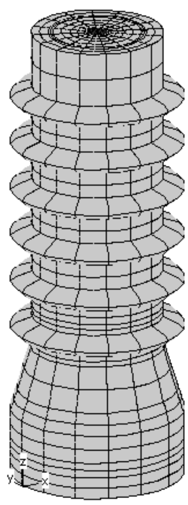

Figure 4. Grid structure of final elements of pin insulator exterior

Figure 5 shows electric field strength for the previous version of electrodes. It can be seen that neither in epoxy resin nor in air the dielectric field strength of 30 MV/m and 3 MV/m, respectively, is not exceeded. The problem of this shape of electrodes lies in the capacitance, which amounts to 12 pF, while IEC 61243-5 requires this value to be between 74 and 88 pF. For this reason it has been necessary to perform optimisation which is presented below.

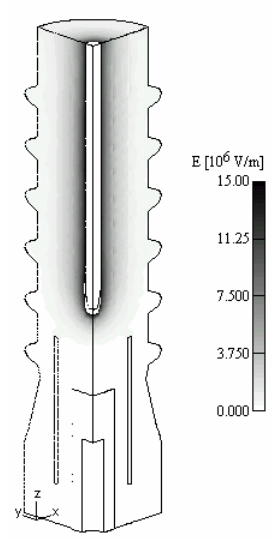

Figure 5. Electric field strength in the pin insulator with previous version of electrodes

In the first phase of optimisation the length of metal mesh and the radius of special electrode have been increased. Figure 6 shows conditions for the case of two-fold increases of the mesh's length and the special electrode's diameter. Electric field strength in epoxy resin does not exceed 20 MV/m, and in air it is below 1.5 MV/m. Capacitance is still outside the interval, required by standard.

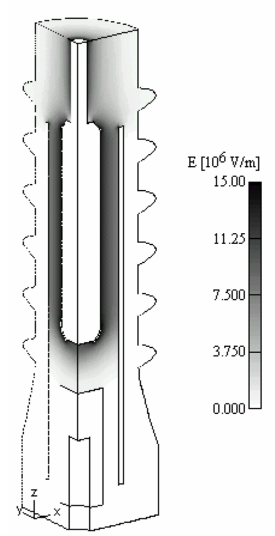

Figure 6. Electric field strength in the pin insulator with thickened electrode and elongated mesh

The next step of the optimisation has been to shorten the thickened end of the electrode only to the lower part and to additionally increase the diameter by 20%. This measure has increased capacitance to

83 pF, which is in accordance with the IEC requirements. Electric field distribution in the pin insulator around the metal electrodes is shown in Figure 7. The values of electric field strength have nowhere exceed dielectric strength.

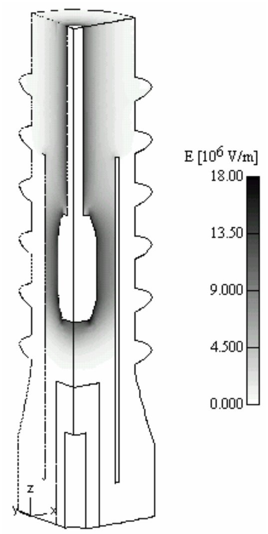

Figure 7. Electric field strength around metal electrodes of the pin insulator, which complies with the IEC requirements

Figure 8 shows electric field distribution inside epoxy insulation, between the metal electrodes and the outer surface of the insulator. The electric field strength has remained below the dielectric strength.

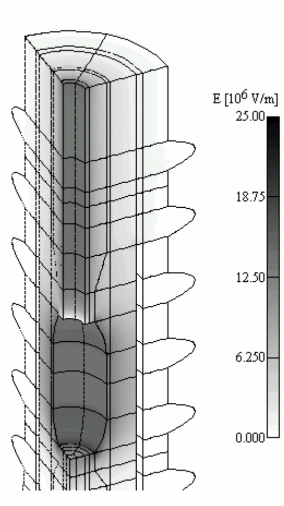

Figure 8. Electric field strength distribution inside the pin insulator

Situation outside the pin insulator is shown in Figure 9. Even in the 1 cm thick air layer around the insulator electric field strength does not exceed dielectric strength.

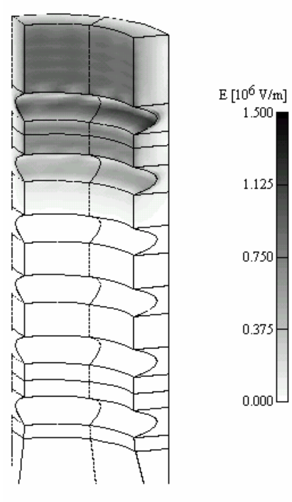

Figure 9. Electric field strength on the insulator surface and in the air around the insulator

Figure 10 shows a vector presentation of electric field distribution inside the pin insulator.

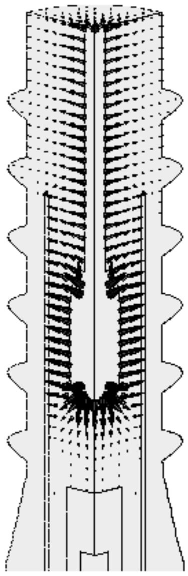

Figure 10. Vector presentation of electric field distribution

The highest values of electric field strength in epoxy insulation have appeared in the area between the electrode connected to the upper metal inserted piece and the mesh electrode. The reason for this lies in a relatively short distance between these two elements and high difference of their potentials. The problems have also arisen at the crossing of electric field from epoxy insulation into air. This has happened due to the high value of electric field strength at the edge of the metal mesh.

Figure 11 shows a cross section of the pin insulator with capacitive divider electrodes, metal inserted pieces for mechanical fixing of conductive parts on the upper side of the insulator and lower inserted piece for mechanical fixing, after the optimisation of electrodes. Pin insulator now completely complies with the requirements of the IEC standard.

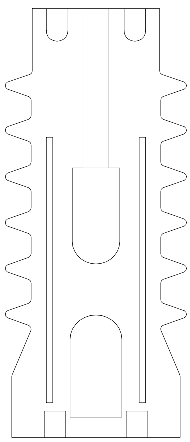

Figure 11. Optimised shape of capacitive divider electrodes for 24 kV switchgear

6 Conclusion

The paper presents the results of theoretical design of voltage indicators on the basis of electric field computation.

The existing voltage indicator has been redesigned to comply with new requirements. The outer appearance of the insulator with a built-in voltage indicator has not been changed in this process. The process of redesigning has been focussed on the optimisation of inner electrodes with respect to their shape and position inside the pin insulator. From the above described optimisation process it can be seen that the length of the metal mesh has been increased, as well as the thickness of the upper electrode. This has brought a reduction of distances between individual metal elements inside the insulator. In the determination of these distances, the recommendations of the insulator's manufacturers regarding the minimum values have been taken into account. These distances are important for the subsequent casting of epoxy insulator in the manufacturing process. If they are shorter than the recommended values, shrinkage cavities can appear in the thin insulation layer.

Electric field strength has increased due to the short distances between individual electrodes. Nevertheless, the computations have shown that it nowhere exceeds the dielectric strength of 30 MV/m for epoxy resin and of 3 MV/m for air.

Following the theoretical computations, the manufacturer has made prototypes on the basis of our designs. The prototypes have undergone partial discharge tests in our laboratories. They have proved that the quality of insulator manufacturing is adequate (no presence of cavities in thin insulation layers between metal electrodes). The prototypes have also undergone tests with lightning impulse voltage and with 50 Hz power frequency voltage. After all high voltage tests, the adequacy of the signal obtained from the electronic indication unit has also been verified.

All the tests have been positive, which entirely verified the results of the theoretical research.

Acknowledgement

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