Analysis of Electric Stress in High Voltage Cables Containing Voids

Prashant S. Patel
M.E. Electrical (Power System), Electrical Engg. Dept.
Parul Institute of Engg.and Tech., Limda, Waghodia
Vadodara, India

Viral S. Chaudhari
Assistant Professor, Electrical Engg. Dept.
Parul Institute of Engg.and Tech., Limda, Waghodia
Vadodara, India

Hiren M. Patel
Assistant Professor, Electrical Engg. Dept.
Faculty of Tech. &Engg.,The MSU of Baroda,
Vadodara, India

***Abstract*— High voltage cables are used for the transmission and distribution purpose for electric power. In high voltage cables, the main reason for the breakdown is partial discharge due to the voids inside the insulation. Electrostatic stress varies due to the presence of void inside the insulation material. So, for the analysis of high voltage cable insulation, analysis of stress distribution or electric field distribution with void effect is desirable. The stress distribution in the insulation containing a void is influenced by the size of the void, shape of the void, location of the void, dielectric permittivity of insulation material and operating voltage. This paper presents the results of all kind of these variations. Finite element analysis technique is used in this work.**

Keywords—Void, Maximum void stress(E_{max}), Cross linked polyethylene (XLPE)

I. INTRODUCTION

In modern world, wide range of high voltage cables of improved design and performance are used. The age of the cable is considered by the status of the insulation. The cable insulation has to be continuously exposed to the variety of stresses. One of the major problems, which shorten the life of the cables, is the presence of void of air or water inside the insulation material of the cables [1]. Due to void, bubble or defect, partial discharge is caused that can be resulted in reduced life of the cable. The voids may be formed during manufacturing, fabrication, installation, and energization or operation process. The void can be formed in the power cables insulation like Paper oil insulation, cross linked polyethylene (XLPE) and Ethylene propylene rubber (EPR) [5]. Paper cables are relatively resistant to partial discharge activity but XLPE cables are not[2]. So, XLPE cables are more concern for this effect. In the study of partial discharge activity, electrostatic stress within the void should be calculated and analyzed [4]. The breakdown strength of the void is lower than the insulation because of the lower permittivity of the void so the presence of void leads to insulation breakdown[5]. The electric field and stress inside the void is higher so the possibility of breakdown increases. In this paper, electric stress within the insulation with void is calculated. This paper considers stress analysis with different size of the void, shape of the void, location of the void, dielectric permittivity of insulation material and operating voltage.

II. ELECTROSTATIC STRESS IN A SINGLE CORE CABLE

It is known by the theory that in a single core cable of having 'r' radius of conductor and 'R' inner radius of insulation, the potential gradient 'g' at a distance 'x' from the center of the conductor within the dielectric material is

$$g = \frac{q}{2\pi\varepsilon x} = \xi_x \qquad (1)$$

Where, ξ_x is the electric field intensity,

q is the charge per unit length,

ε is the permittivity of the dielectric material.

So, the potential of the conductor will be,

$$V = -\int_R^r \xi_x \cdot dx \qquad (2)$$

$$= \int_R^r \frac{q}{2\pi\varepsilon x} \cdot dx$$

$$= \frac{q}{2\pi\varepsilon} \cdot log_e \frac{R}{r} \qquad (3)$$

Since, $\frac{q}{2\pi\varepsilon x} = \xi_x$ (From eq. (1)). So,

$$\xi_x = \frac{V}{x \, log_e \frac{R}{r}} \qquad (4)$$

Here, 'x' is the only variable in the equation, the maximum stress in dielectric material occurs at the minimum value of the radius (here, x=r) [6]. So,

$$\xi_{max} = \frac{V}{r \log_e \frac{R}{r}} \quad (5)$$

III. METHODS FOR CALCULATING ELECTRIC STRESS AND FIELD VALUES

Electric fields or stress calculation requires the solution of Laplace's and Poisson's equations with the boundary conditions satisfied. The solution of these equations can be done by either analytical or numerical methods. In many cases, the situation is so complex that the analytical solutions are difficult or impossible. The analytical method takes much time for solving the equations. So, numerical methods are commonly used for engineering applications. Some widely used numerical methods are: Finite Difference Method (FDM), Finite Element Method (FEM), and Charge Simulation Method (CSM) [5]. Among these methods Finite Element Method is most suitable for its some advantages. So, this method is used here for the calculation of the electric stress.

A. Finite Element Method

For almost all fields of engineering, this method is useful. This method divides the whole region into small finite elements and calculates for each element and so whole region is considered. Finite element method is suitable for estimating fields at highly curved and thin electrode surfaces with different dielectric materials. This method is more useful for uniform or weakly non-uniform fields and which can be represented by two dimensional geometries. For two dimensional as well as three dimensional problems, Finite element method is easier to apply and requires less time for computation. It is capable of working with regular or irregular geometries[5]. This method is best suited for the electro static problems. Various types of computer software are also available those are using finite element method for solving various types of problems. So, for the electric field and stress analysis Finite element method is considered here for the analysis. Finite Element Methods Magnetics (FEMM) software is used here for the calculation. Finite Element Method Magnetics (FEMM) software is a finite element package. This software is used for solving 2-dimensional planar and axisymmetric problems in electrostatics, current flow, heat flow and low frequency magnetics. It is a very convenient program. The problem is broken down in large number of regions with finite elements of simple geometry. Here triangles are considered for discretization. The potential values are interpolated at the three vertices of the triangle and the solution is obtained for each element. Automatic mesh generation is provided in this software.

IV. CABLE CONFIGURATION AND STRESS DISTRIBUTION

The cable configuration in present work consists of inner conductor of cross sectional area of 8.55 cm^2 (1.65 cm radius) and outer insulation of thickness of 2.85cm is considered so that the ratio of conductor radius to the whole cable radius is 2.72. The material of Cross Linked Polyethylene (XLPE) is considered as the insulation material with relative permittivity of 2.5. The cable configuration of a conductor at 66 KVand the insulation material kept at ground potential for the analysis in this paper. The artificial void of air (permittivity of 1) of 0.6 cm diameter is considered between the conductor surface and the insulation outer surface. The cable configuration and its stress with mesh creation are as shown in the figure 2.

From Fig.1and Fig.2, it can be seen that more stress is concentrated at the conductor surface due to the voltage applied to it. Void of air of 0.6cm is considered in the insulation as shown in the Fig.2. The stress distribution from the conductor surface to the insulation outer surface is obtained as shown in the Fig.3 and 4.

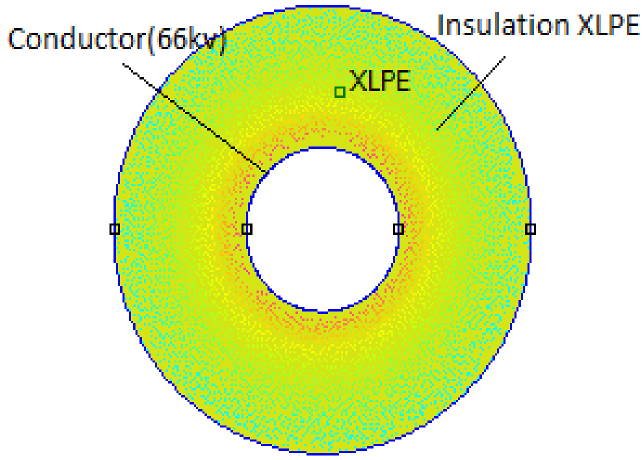

Fig. 1. Cable without void

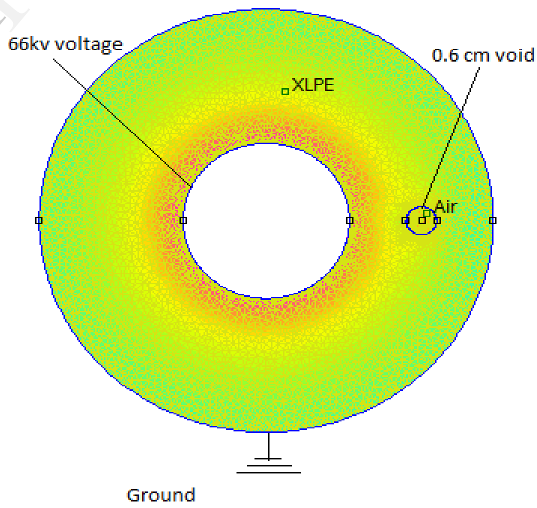

Fig. 2. XLPE cable with void

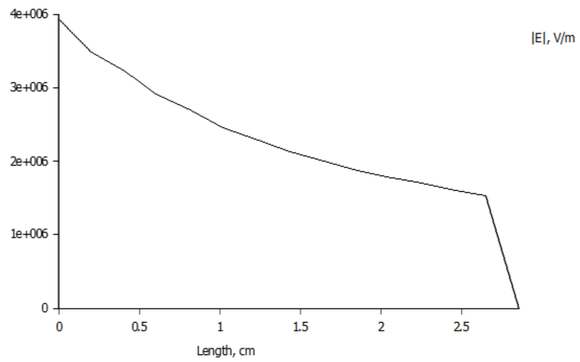

Fig. 3. Stress distribution without void

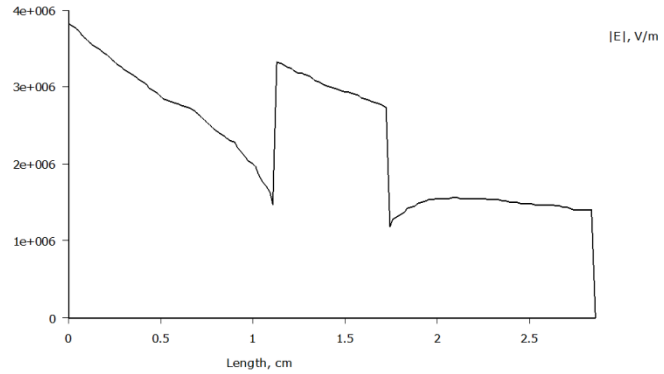

Fig. 4. Stress distribution with void

If the void is not present in the insulation, the stress is decreasing from conductor surface to the insulation outer surface as shown in Fig.3. The maximum stress (E_{max}) is obtained at closest to the conductor surface. When void is present in the insulation, the stress at the void location is increased as shown in Fig.4.The maximum stress (E_{max}) across the void is 3.25 MV/m. Electric field at the void is higher due to the lower permittivity than the insulation material and so that insulation material has to withstand more stress at the location of the void. Breakdown strength of void (air) is lower than the insulation material due to the lower permittivity of it. So, the breakdown strength of the insulation material is decreased due to the void inside it. When the maximum stress (E_{max}) at the void exceeds certain level of it, the electron avalanche occurs and it is the main component of the partial discharge event. Partial discharge can lead to breakdown of the insulation. The maximum void stress (E_{max}) values are considered for the breakdown strength of the material. So that the analysis of stress values in cable insulation with void and without void is necessary for partial discharge study and life of the cable. The maximum stress (E_{max}) inside the void changes according to the change in some parameters like diameter or size of the void and shape of the void defect. It also depends on the location of the void inside the insulation material [2] [3]. Due to the change in operating voltage of the conductor, the maximum void stress is varied and the relative permittivity of the insulation material is also responsible for that. By these different parameters the exact idea of the case of the maximum stress (E_{max}) due to the void can be obtained. All these cases are analyzed and results are discussed here in this work.

V. SIMULATION RESULTS AND DISCUSSION

A. Effect of different void sizes (Diameter)

In normal case of Fig.2 the void size (diameter) of 0.6cm is considered and the stress value is plotted. The Cross Linked Polyethylene (XLPE) insulation material with relative permittivity of 2.5 is taken into consideration. The maximum void stress (E_{max}) of 3.25 MV/m is obtained in that case. When the size (diameter) of the void is changed, there will be a change in maximum void stress (E_{max}) values. This change is shown in the plot of Fig.5

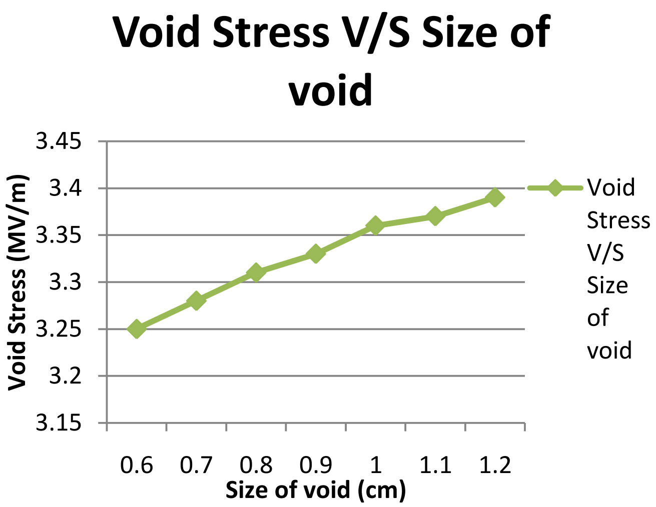

Fig. 5. Effect of different void sizes (Diameter)

The result indicates that the maximum void stress (E_{max}) is stronger when the diameter of the void increases and so that the breakdown strength of the material will decreased. If the diameter of the void increases, the thickness of the insulation decreases with respect to the size of the void. It means that by decreasing the thickness of insulation the void stress will be stronger and vice versa.

B. Effect of distance of void from conductor surface

The maximum void stress (E_{max}) with respect to the orientation of the void inside the insulation is shown in the Fig.6. In this case, the orientation of the void is considered by the distance between the conductor surface and void center. XLPE insulation material is considered. In normal case of Fig.2 the void center is in the center of the conductor surface and the insulation outer surface.

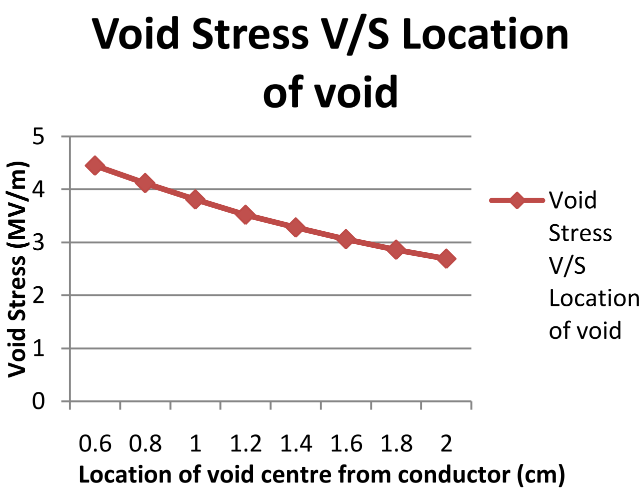

Fig. 6. Effect of distance of void from conductor surface

The plot gives the value of maximum void stress (E_{max}) by changing distance of the void from the conductor surface. It can be seen that the maximum void stress (E_{max}) decreases with increasing the distance of the void center from the conductor surface. Void stress is stronger with the void nearer to the conductor surface and if the void is far away from the conductor surface the maximum void stress will be less [3]. So the void nearer to the conductor surface is dangerous for the breakdown of the cable insulation.

C. Effect of shape of void

In this case 2-D shapes of three major types of voids are considered for the analysis. Spherical, Elliptical and Cylindrical shapes of voids are taken inside the insulation. The maximum void stress (E_{max}) value is obtained for each shape and compared with the other shapes.

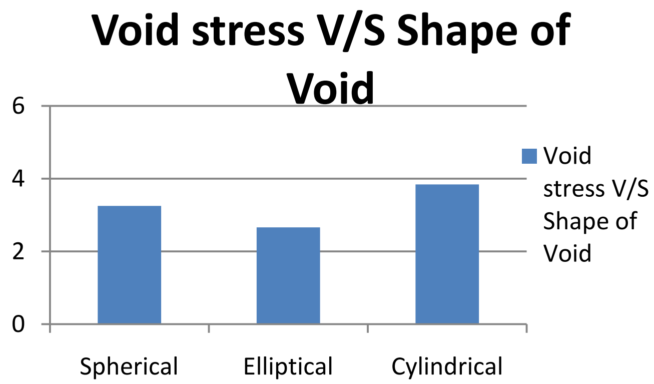

Fig. 7. Effect of shape of void

The result indicates that the cylindrical void has highest maximum void stress (E_{max}) value than other two shapes of void. Elliptical void has lower maximum void stress value than other two shapes. So they are less dangerous compared to other two shapes. And the spherical void has the maximum void stress (E_{max}) lower than the cylindrical void and higher than the elliptical void shape. In these normal shapes of voids the cylindrical voids are very dangerous compared to other two types.

D. Effect of permittivity of insulation material of cable

In normal case Cross Linked Polyethylene (XLPE) with relative permittivity of 2.5 is considered as the insulation material. In that case the maximum void stress (E_{max}) of 3.25 MV/m was obtained. Now maximum void stress (E_{max}) values are calculated with the change of relative permittivity of the insulation material and compared with each other or maximum void stress values are considered with changing the material with different permittivity. Fig.8 shows the result of this case.

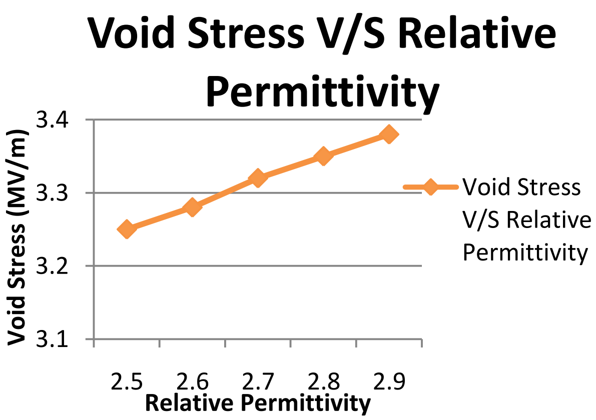

Fig. 8. Effect of permittivity of insulation material of cable

From this plot, it can be seen that the maximum void stress (E_{max}) increases with increasing the relative permittivity of the insulation material of the cable. The permittivity of air void is very low so by increasing the value of relative permittivity of insulation material the difference between the permittivity of void and material increases. So, the relative permittivity of void is decreased as compared to the permittivity of insulation material when increasing the permittivity of insulation material. So, the stress is higher at the lower permittivity. This results in higher maximum void stress (E_{max}) inside the insulation. And if the permittivity of void increases the stress will be decreased.

E. Effect of operating voltage of conductor

The operating voltage of 66kV is considered in normal case. Now the values of maximum void stress (E_{max}) are obtained and plotted by changing the operating voltage of the conductor as shown in Fig.9.

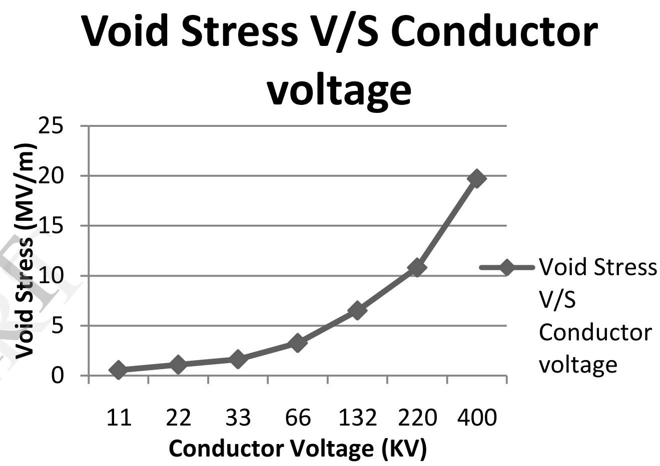

Fig. 9. Effect of operating voltage of conductor

By the above figure it can be seen that by increasing the operating voltage of the conductor without changing other parameters, the maximum void stress (E_{max}) increases. So, the chance of breakdown of insulation increases. From this result it can be said that for the same size of cable with the same size of void, higher operating voltages results in increased maximum void stress. So that effective conductor size and insulation thickness should be considered for the change in higher operating voltages.

VI. CONCLUSION

The Finite Element Method can be easily used to calculate the maximum stress inside the void. For the breakdown of cable insulation and partial discharge activity, the calculations of the maximum stress inside the voids are the important. When the size (diameter) of the void is increased, the increase in maximum void stress is obtained. The maximum void stress decreases as the distance of void from the conductor surface increases. The maximum void stress is higher in the cylindrical type of void than spherical and elliptical shape. Void stress increases while increasing the relative permittivity of the insulation material used. While increasing the operating voltage with same size of cable, the maximum void stress will increase.

VII. REFERENCE

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