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Analyse the Electric field of symmetrical and asymmetrical concentric electrodes

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Abstract

The different between two potential voltages can cause the electric field. The electric field is normally distributed along the radius of electrode, and hence it depends on the shape of electrodes. This paper analyses the distribution factor of electric field of symmetrical and asymmetrical concentric electrodes by using Finite Element technique. This allows an analysis the optimum safety clearance distance between two concentric electrodes. The symmetrical concentric electrode refers to Spherical-Spherical concentric electrodes and Cylindrical-Cylindrical concentric electrodes. It must be noted that the symmetrical electrodes are mostly applied for Gas Insulated Substation (GIS) equipments. The asymmetrical electrodes mention to Spherical (inner)-Cylindrical (outer) concentric electrodes and Cylindrical-Cube concentric electrodes, which present as the connection point of High Voltage (HV) cable. The simulations is also complies with the existing standards and regulations in order to ensure the accurate results.

Key words: *Electric field, High Voltage, Symmetrical concentric electrode, Asymmetrical concentric electrode, Finite Element technique*

1. INTRODUCTION

In practical, the electric field is usually occurred around all electrical equipments with the concentric electrode shape. Hence, the insulation of this equipment can be damaged by the high maximum electric field stress. This phenomenon can be clearly seen at the corona discharge point. It can be noted that the electric filed can be defined by the electric forces are exerted on any electrically charged particles, and hence the different between two potential voltages is happened. This value is equal to the electric force per unit charge. Moreover, the direction of the electric field is taken to be the direction of the force on the positive electric charged that places inside the electric field at that specific point. This allows the shape and potential voltage of electrodes to be a function of the electric field. All these can be described by the Electromagnetic theory. In order to analyse the distribution factors of electric fields of symmetrical and asymmetrical concentric electrodes, the electric flux and equipotential line (electrostatic potential) are needed to consider.

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The electric flux is the number of electric lines of force passing through the electrode surface area, which is held perpendicular to the direction of electric lines of force. This means that the distance between field lines increase (and the magnitude of the field thus decrease) in proportional function. In addition, the equipotential line refers to a scalar potential in three-dimensional space. Therefore, the relationship between electric flux and equipotential line can be clearly seen by interacting between the electrically charged particles, and hence it can be explained by using Coulomb's Law as shown in figure 1 [1-3]. This law can be used to derive Gauss's Law that uses to analyse the distribution factor of electric field in this paper.

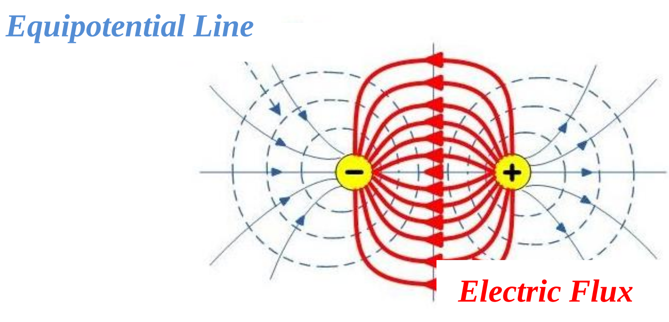

Figure 1. The relationship between electric flux and equipotential line

This paper analyses the two significant configurations of symmetrical and asymmetrical concentric electrodes, which are the radius of the inner concentric electrode (R) and the distance between the inner concentric electrode and outer concentric electrode (S). Figure 2 shows the symmetrical concentric electrodes, which is Spherical-Spherical concentric electrodes and Cylindrical-Cylindrical concentric electrodes. This type of concentric electrode is mostly applied for Gas Insulated Substation (GIS) equipments.

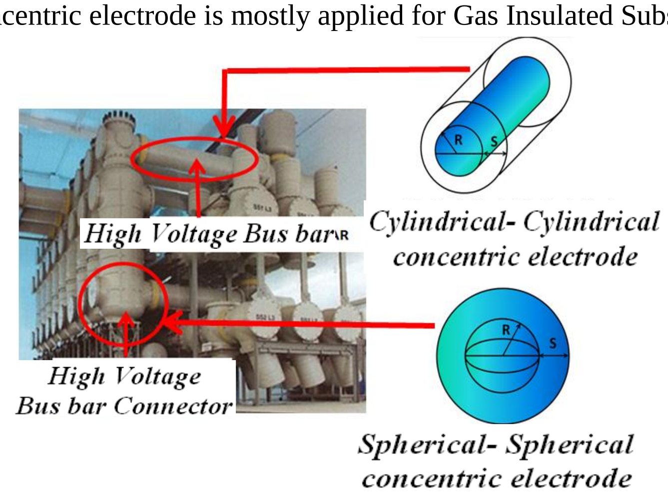

Figure 2. Comparison between practical equipments and symmetrical concentric electrodes

However, the asymmetrical electrodes, which are Spherical (inner)-Cylindrical (outer) concentric electrode and Cylindrical (inner)-Cube (outer) concentric electrodes (here refers to the connection point of High Voltage cable) are shown in figure 3.

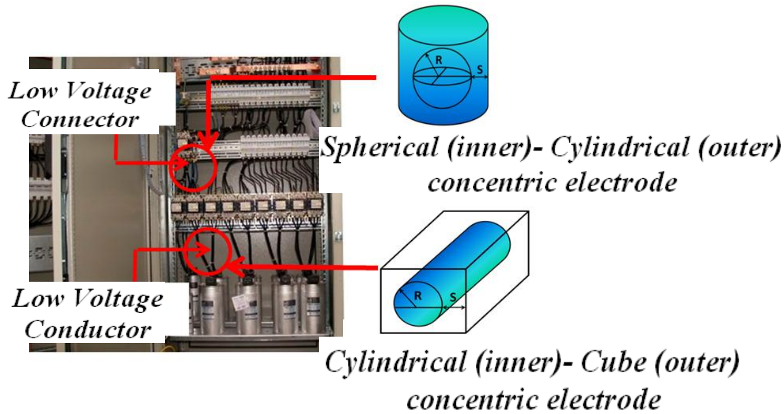

Figure 3. Comparison between practical equipments and asymmetrical concentric electrodes

2. THE RELATIONSHIP BETWEEN ELECTRIC FIELD AND ELECTRODE

It is known that the maximum electric field stress is a relative function of the shape and dimension of concentric electrode. Hence, the Finite Element technique that supports Numerical method was used to analyse the relative function between electric field and shape of concentric electrodes that usually defines by Partial Differential Equation (PDE). Three main parameters that use to analyse electric field are electric field intensity (*E* or $\overline{E}$; V/m), electric field density (*D*; C/m^2) and voltages (*V*; Volts) [1-6]. According to Gauss's Law theory, the density of electrically charged particles at that specification (ρ) can be determined by:

$$\nabla \bullet D = \rho \tag{1}$$

Where, electric field density (*D*) is:

$$D = \varepsilon E \tag{2}$$

When, ε = constant coefficient of material dielectric (F/m) type

From equations (1) and (2), the different potential voltages can be defined by using Laplace's Equation as shown in equation (3)

$$-\varepsilon \nabla^2 V = 0 \tag{3}$$

It can be noted that the electrically charged particles is usually distributed in the electric filed, and hence it can be presented by mathematical model in First order equation with Continuous function (Linear form). In order to analyse the potential voltages of the concentric electrode, the triangle nodes (shown in figure 4) is distributed on the surface the electrodes. Furthermore, the mathematic equation of distribution potential voltages; *Ve*(x,y) is explained as follows:

$$Ve(x, y) = a + bx + cy \tag{4}$$

Where, x and y are the condition parameters in linear equation. In the meantime, a, b and c are constant coefficient factor. Hence, the electric field intensity of electrode can be determined by using the relative function of potential voltages from equation (4).

$$-\nabla V = \overline{E} \tag{5}$$

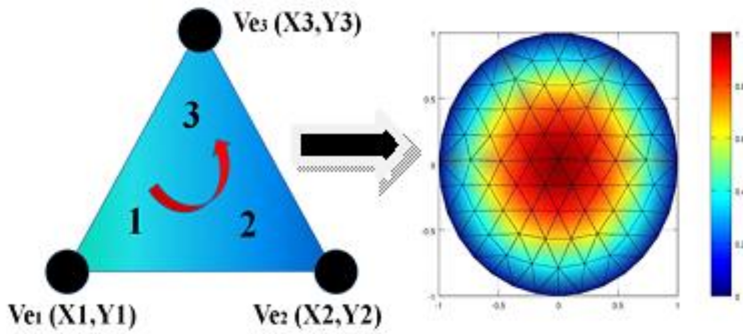

Figure 4. The distribution of triangle node with in spherical concentric electrode

As can be seen from equation (5), the Finite Element technique is used to apply and analyse the maximum electric filed stress (E_{max}) of the electrodes, and hence the follows conditions are needed to be concern in order to ensure the accurate results:

- All electrodes are copper material.
- The potential voltage of electrode sets to 1 in order to simplified the mathematic model with relatively fast computation.
- In order to ensure the accurate results, the radius of concentric electrodes (R) sets to relative increasing function of the distance between inner and outer concentric electrodes (S), which are 0.005, 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045, 0.05, 0.055, 0.06, 0.065, 0.07, 0.075, 0.08, 0.085, 0.09 and 0.095 mm., respectively.
- Error of calculation sets at 0.01% of each iterative calculation and uses Maxwell software version 9sv.

Figures 5 and 6 show the E_{max} of the symmetrical concentric electrodes, which are Spherical-Spherical and Cylindrical-Cylindrical, and asymmetrical concentric electrodes, which are Spherical (inner)-Cylindrical (outer) and Cylindrical (inner)-Cube (outer). It can be seen that the E_{max} of Spherical-Spherical concentric higher than Cylindrical-Cylindrical concentric electrodes. This result is similar to the E_{max} of asymmetric concentric electrodes, when the E_{max} of Spherical (inner)-Cylindrical (outer) concentric electrodes is more than the Cylindrical (inner)-Cube (outer) concentric electrodes. Thus, this can be explained the corona discharge (shown in figure 7) at the connection point between connector and conductor of LV Main Circuit Breaker (MCB). Moreover, this phenomenon can lead to insulation breakdown of the equipments [4-6].

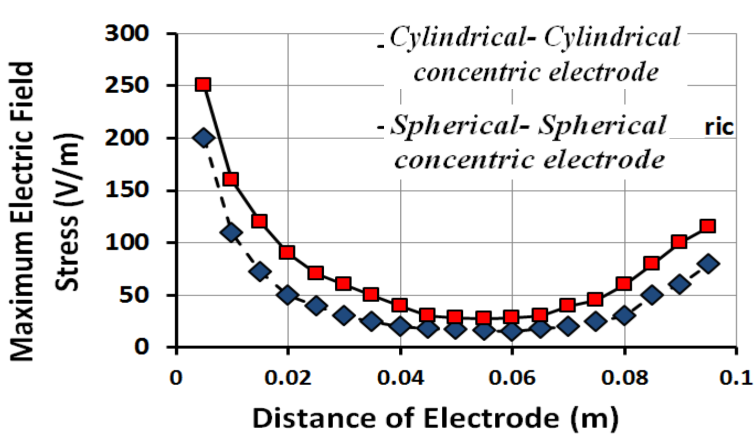

Figure 5. Comparison between E_{max} of Spherical-Spherical and E_{max} of Cylindrical-Cylindrical

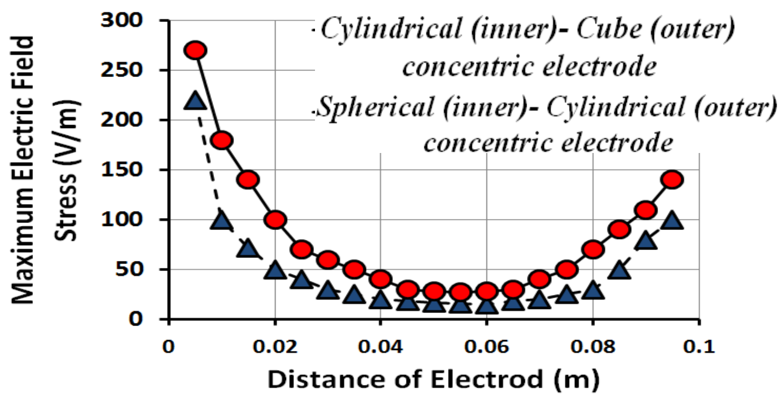

Figure 6. Comparison between E_{max} of Spherical (inner)-Cylindrical (outer) and E_{max} of Cylindrical (inner)-Cube (outer)

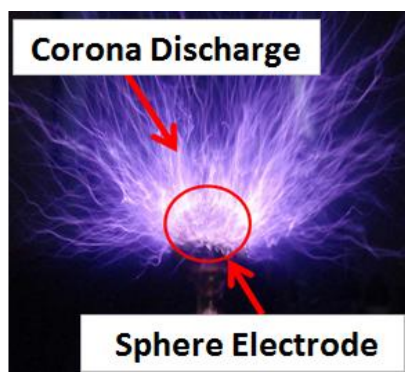

Figure 7. Corona discharge at spherical electrode with the maximum electric field stress

3. CONCLUSION

The results shown that the maximum electric field stress of the Spherical concentric electrode is higher than the Cylindrical concentric electrode. In the same way, the Spherical (inner)-Cylindrical (outer) concentric electrode has the maximum electric field stress more than Cylindrical (inner)-Cube (outer) concentric electrodes. This means that the maximum electric field stress of the inner spherical are higher than the cylindrical because the spherical electrode can be easily distributed the electrically charged particles. Thus, at connection point between connector and conductor (considers as Spherical-Spherical concentric electrodes) has the maximum electric field stress higher than the connection point with busbar (considers as Cylindrical-Cylindrical concentric electrodes). Therefore, the corona discharge can be occurred at the connection point between connector and conductor.

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