Electric Field Characteristics Inside Three-phase Gas Insulated Switchgear in the Presence of Foreign Metallic Particle

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Abstract

Three-phase equipment differs from single-phase equipment in two aspects: configuration and applied voltage. In this paper the effects of these differences on electric field in the presence of foreign metallic particle in three-phase GIS are reported. The electric field characteristic in three-phase GIS is different from that in single-phase one. There are periodic changes in the electric field magnitude and direction produced by three-phase voltage at any point. While the voltage phase varies, the electric field vector changes and rotates continuously. The rotating characteristics of the electric field vector in three-phase power apparatus depended on the position inside the insulation of the tank. The electric field vector locus is circular, elliptic, or linear. The elliptical nature of rotating electric field is expressed as electric field ratio. The presence of foreign metallic particle increases significantly the maximum electric field on the particle tip, but its effect on minimum electric field is not significant. The electric field ratio in the presence of particle is lower than one without particle.

Keywords: three-phase, rotating electric field, vector locus, metallic particle;

1. Introduction

Application of three-phase equipment (three-phase in one tank) such as three-phase gas insulated switchgear (GIS) and three-phase gas insulated bus (GIB), has been increasing due to its compactness and low cost [1-9]. A three-phase in one-tank design has also been developed for 550 kV GIS [7]. Three-phase equipment differs from single-phase equipment in two aspects: configuration and applied voltage. It has been reported that the electric field characteristic in three-phase GIS is different from that in single-phase one [10]. In this paper the effects of these differences on electric field in the presence of foreign metallic particle in three-phase GIS are reported. There are

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periodic changes in the electric field magnitude and direction produced by three-phase voltage at any point. While
the voltage phase varies, the electric field vector changes and rotates continuously. The rotating characteristics of the
electric field vector in three-phase power apparatus depended on the position inside the insulation of the tank. The
electric field vector locus is circular, elliptic, or linear. The elliptical nature of rotating electric field is expressed as
electric field ratio. The mathematic description of the rotating electric field is given considering the maximum and
the minimum electric field and the position inside the insulation. There is no zero electric field under three-phase
voltage. The areal velocity of the electric field vector locus is constant. The electric field vector moves slowly in a
high electric field area, but moves quickly in a low electric field area. However, the analysis so far is conducted in
the absence of foreign metallic particle. In this paper the effects of these differences on electric field in the presence
of foreign metallic particle in three-phase GIS are reported.

2. Mathematics Description of Rotating Electric Field Vector

The rotating electric field at a certain position (x,y) can be described by four parameters: the maximum Emax
(x,y) and minimum Emin (x,y) field strength, the phase angle of applied voltage $\theta_{\text{max}} (x,y)$ at maximum field
Emax (x,y), and field direction $\phi_{\text{max}} (x,y)$ at maximum field [10-12]. These parameters are illustrated in Fig. 1. $\delta_\gamma$
in the figure is defined as the angle that designates the intersection width of the electric field vector locus and critical
electric field circle Ec r.

The elliptical nature of rotating electric field is expressed as electric field ratio, $\eta$. It is defined as the ratio
between the magnitudes of the elliptical field along the main axes,

$$\eta = \frac{E_{\text{min}}}{E_{\text{max}}} (0 < \eta < 1)$$

where:

Emin: minimum electric field intensity at a certain point during a cycle of applied voltage
Emax: maximum electric field intensity at a certain point during a cycle of applied voltage

When the electric field ratio $\eta = 0$, the electric field vector locus is linear. When the electric field ratio $0 < \eta < 1$,
the electric field vector locus is elliptic. When the electric field ratio $\eta = 1$, the electric field vector locus is circular.
3. Model of Three-Phase GIS

A simplified model of three phase GIS was used in this research. It was composed of a tank model 150 mm in diameter, 300 mm in length, 2 mm in thickness, and three-phase conductors 25 mm in diameter. The electrode system was arranged to simulate three-phase electric field in three-phase equipment. The conductors were arranged in an isosceles triangle construction. The layout and dimensions of the model are shown in Fig. 2.

4. Electric Field Calculation

The electric fields inside the insulation of the construction were determined from a boundary element method simulation: along a circle among the phases and the tank, along vertical line starting from the bottom of the tank, along line connecting the centres of conductor phases, and around the conductor. The electric field calculation is two dimensional.
5. Electric Field Analysis and Discussion

5.1 Electric Field inside Three-phase GIS without Foreign Metallic Particle

The electric field vector locus at different points, those are at the distances 0 mm (A), 5 mm (B), 10 mm (C), 15 mm (D), 20mm (E), and 25 mm (F) away from S conductor in the absence of particle are shown in Fig. 3. The points are laid between S conductor and the center of three-phase GIS. The electric field ratio changes from $\eta = 0$ at S conductor surface (point A) to $\eta = 0.2$ at point B, $\eta = 0.4$ at point C, $\eta = 0.7$ at point D, $\eta = 1$ at point E.

Fig.3 The electric field vector locus at the distances 0 mm (A), 5 mm (B), 10 mm (C), 15 mm (D), 20mm (E), and 25 mm (F) away from S conductor in the absence of particle.

Fig.4 Minimum and maximum electric field from point B (5mm from S conductor) until point E(20mm from S conductor) without particle.
Here, while the vector locus is elliptic, its shape varies locally. On the electrode surface (at Point A) the locus is linear because the electric field lines are vertical to the conductor surface. At some regions, for example at point B, C, D, the locus is elliptic. Meanwhile, at point E, which is 5 mm below the center of the tank, the locus is truly circular.

If a point approaches the center of the cross section of the tank, the maximum electric field reduces; while the minimum electric field increases as shown in Fig. 4. The minimum and maximum electric fields are same at point E (20 mm from S conductor). The electric field vector locus changes from linear to circular when the points keep away from S conductor (point A) to the point 5 mm below the center of the three-phase construction (point E). The electric field ratio ($\eta$) changes from 0 until 1 from point A until E.

5.2 Electric Field inside Three-phase GIS in the Presence of Foreign Metallic Particle

The background electric fields on the calculation points with and without particle were calculated to observe the effects of the presence of a particle on the electric field ratio $\eta$ at the same points.

The diameter of a particle is 0.1 mm. The radius of the particle tip is 0.05 mm. Particles of 5 mm, 10 mm, 15 mm and 20 mm in length were laid at the S90 position to observe the effects of changes in electric field ratio $\eta$ on PD distribution pattern. The particle position is shown in Fig. 5.

Fig. 5 shows minimum and maximum electric field from point B (5mm from S conductor) until point E (20mm from S conductor) in the presence of particle. The presence of particle increases significantly the maximum electric field on the particle tip, but its effect on minimum electric field is not significant. Therefore, the electric field ratio in the presence of particle is lower than one without particle as shown in Fig. 7.
Fig. 6 Minimum and maximum electric field from point B (5mm from S conductor) until point E (20mm from S conductor) in the presence of particle

Fig. 7 Electric field ratio $\eta$ from point B (5mm from S conductor) until point E (20mm from S conductor)
6. Conclusions

Three-phase equipment differs from single-phase equipment in two aspects: configuration and applied voltage. In this paper, effects of these differences on the electric field in three-phase gas insulated system (GIS) are reported. The electric field in a three-phase construction of a simplified GIS model in the presence of foreign metallic particle was analysed. The following conclusions were drawn:

1. The presence of foreign metallic particle increases significantly the maximum electric field on the particle tip, but
2. The effect of the presence of foreign metallic particle on minimum electric field is not significant.
3. The electric field ratio in the presence of particle is lower than one without particle

References