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Developed optimization technique used for the distribution of U-shaped permittivity for cone type spacer in GIS

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ABSTRACT

The solid/gas interface formed by solid spacer and insulating gas represents the weakest point in gas insulated systems (GIS) which is due to field intensification on spacer surface especially near triple junctions (Solid insulator – Gas – Electrodes) at HV and ground electrodes. Functionally Graded Material (FGM) is applied to the spacer design instead of uniform distribution to improve the electric field distribution across the spacer surface without changing its simple profile. Cone spacer model with uniform and FGM permittivity distribution has been introduced to study the effect of FGM in improving the electric field characteristics along spacer surface and near triple junctions. The verification of the proposed model has been investigated by comparing the obtained simulation results of the field to these given by others. Developed computerized optimization technique for automatic U-shape permittivity distribution is presented. U-shape permittivity distribution is used to mitigate the electric field strength not only near HV triple junction (Solid insulator – Gas – HV electrode) but also near ground triple junction (Solid insulator – Gas – Ground electrode). The simulation of the electric field is presented by the concept of Finite Element Method (FEM) using Comsol Multiphysics software. The optimization algorithm is programmed using Comsol LiveLink™ for MATLAB.

1. Introduction

Gas insulated systems (GIS) are mainly and widely used for transmission and distribution of electrical energy [1,2]. The present and future trend in electric power equipment tends to be compact, small size, reliable and operated under higher voltage [3–5]. The solid insulators known as spacers play the most important and critical role in electrical insulation and supporting high voltage electrode [6]. Gas tight and gas permeable spacers are used to separate or join adjacent gas compartments of GIS. So, spacers in GIS are subjected to electrical and mechanical stresses. Electrical stresses are due to electric field intensification at interface surface with gas medium and mechanical stresses are due to HV voltage electrode supporting and differential gas pressure at gas tight spacers. The aim of the design of GIS at high voltage (HV) substations and switchgears is to optimize space requirement with higher operating voltage [7–9]. Working at higher operating voltages in these electrical equipment is constrained by the insulation properties at solid/gas interface surface especially near triple junctions (Solid insulator – Gas – Electrodes), at HV and ground electrodes due to field intensification with uniform permittivity distribution of the spacer [10]. This field intensification near triple junctions reduces the break down voltage across the spacer interface surface. To improve the insulation performance of the solid insulators, the electric field characteristics along solid/gas interface must be controlled especially near triple junctions as it is considered the weakest point in high voltage electrical equipment especially during switching and under impulse over voltage. The conventional techniques for the control of the electric field lead to the complicated structure of the insulators and increase the manufacturing cost [11]. Therefore, it is necessary to propose a new concept for the solid insulators with keeping their simple structure and configurations. When using a functionally graded material application, the electric field intensifications will be improved without changing the shape of the insulator [12–16]. The proposed developed optimization technique is used to make the optimum distribution of the relative permittivity inside the solid insulator.

The simulation of the electric field characteristics along the spacer and at triple junctions needs an accurate computation, so some numerical methods such as; Monte–Carlo method [17], Charge Simulation Method (CSM) [18] and Finite Element Method (FEM) [16] had been used to simulate the non-uniform electric field

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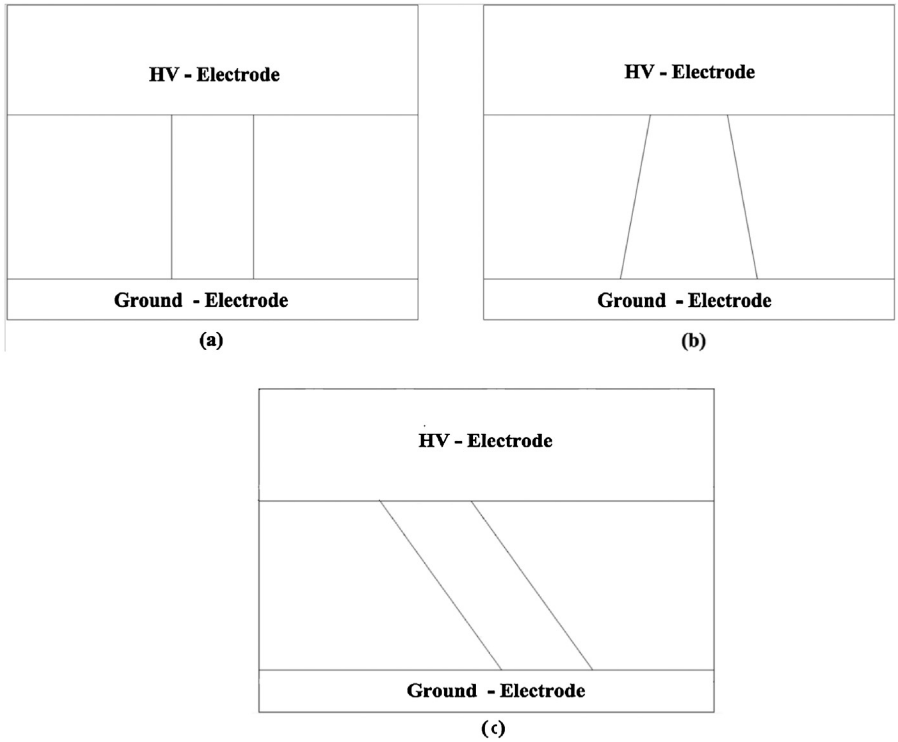

Fig. 1. Different types of spacer; (a) disc type spacer, (b) ordinary cone type spacer and (c) basin cone type spacer.

along the dielectric medium according to the field geometry problem. Till now most of the research work related to electric field computation has been done using CSM, with acceptable obtained results. However, the choice of the number and the type of charges; point, ring and line charges need tedious trial and error methodology which is time consuming [19]. FEM with the concept of partial differential equations is used for finding a solution which satisfies the boundary conditions of the field problem [20]. The advantages of FEM over other methods are that; this method can consider of complex shapes like the construction of the electrodes and the different configurations of the GIS. So, FEM is one of the efficient techniques for solving field problems which is used to determine the electric field over the spacer's surface [12–16].

In this paper, the electric field characteristics along uniform and FGM cone spacers have been presented and the effect of the FGM on mitigating the electric field strength along the spacer surface especially near triple junctions without changing the shape of the insulator has been introduced. Basin type cone spacer model [21] is used in this study as it has the largest leakage path. However, it has two triple junctions, one at HV electrode and another at ground electrode. Relating to the presence of free conducting particles, it is worth mentioning that test results revealed that the dielectric characteristics of conical-type spacer are better than those of the disc type [16]. The ordinary FGM is to gradually distribute the relative permittivity values from maximum ones at HV electrode to minimum ones at ground electrode. It is found that the ordinary FGM decreases the electric field intensification near HV triple junction however, it increases the electric field intensification near the ground triple junction. U-shaped distribution of relative permittivity across basin type cone spacer showed a good performance in mitigating field intensification at both triple junctions [22,23]. The electric field characteristics have been simulated by using Comsol Multiphysics program with the concept of FEM [24]. The obtained results from optimized FGM cone spacer and uniform spacer type have been compared. The calculation results, showed that the proposed developed optimization method could improve the electric field characteristics along the spacer surface without changing the shape of the spacer.

2. The proposed model

2.1. Spacer shape

AS mentioned before, spacers are the solid insulators in GIS that used for mechanical supporting and electrical insulating of HV voltage electrodes from ground electrodes. There are several types of spacers that are used in GIS [25]. The most common spacers types used in GIS are shown in Fig. 1. Disc type spacer is shown in Fig. 1a with square shape (90° angle) at both HV and GND triple junctions. This has the most uniform electric field distribution however, it has the smallest leakage path of other types of the spacers. Fig. 1b shows the ordinary cone type spacer that has a larger leakage path than disc type and make obtuse angle (larger than 90°) at both ground triple junctions. However, it makes acute angle (less than 90°) causing sharp edges at both HV triple junctions which leads to make intensification of the field in these regions. Basin type cone spacer shown in Fig. 1c has a large leakage path and a one acute angle only at HV triple junction however, it has another one at ground triple junction.

2.2. Studying model

Cone spacer type in insulating gas with relative permittivity ($\varepsilon_r = 1$) is selected as the studying model with two different calculations as follows:

1- Uniform material cone spacer type.

2- Applicability of the FGM to the cone type spacer.

Calculations were carried out in a rotationally and axially symmetric system, see Fig. 2. The spacer was laid between the HV and grounded (GND) electrodes in a coaxial arrangement. The applied voltage to HV electrode is 100 kV. The radiuses of the inner and the outer electrodes were set to 40 and 100 mm, respectively [26].