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Full Length Article

Mitigation of field stress with metal inserts for cone type spacer in a gas insulated busduct under delamination

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ABSTRACT

Increased power demand and energy density in cities resulted in the establishment of Gas insulated systems (GIS) as a substitute for the conventional air-insulated substations. Reliable and efficient design of the modules in GIS has been a major concern for the power engineers. Major dielectric strength breakdown and surface flashover causes were reported due to insulator failures like excessive field enhancements at the triple point junction formed by the electrode-gas-insulator interface. The insight of reducing the field along the surface of the spacer exhaustive field study was carried out on a conical spacer. Initially, a field study was carried out with a normal type spacer then extended to a molded spacer done with various shapes to obtain an optimal field spread. This Shape control may sometimes lead to very uneven shapes. Further, a functional graded material (FGM) is designed for the standard cone type spacer to obtain uniform field stress along the surface of a spacer to overcome the above problem. The grading of the spacer is done with different permittivities. Electric field is computed for different cases of graded spacers and Tuned Metal inserts and recessed electrodes were also imbibed in the spacer geometry for a better field distribution. The work was validated by comparing the optimal mold spacer field distribution with that of the FGM cone type spacer. Inspite of proper care taken during the manufacture, working, and maintenance of the spacers several flaws do occur. The delamination effect is considered and similar analysis is carried out and the results are presented and analyzed.

1. Introduction

Gas insulated systems are in wide usage since late 1960s due to the rapid growth in energy consumption under the constraint of urbanization. The major components in the system are SF_6 gas, spacers, conductor and outer enclosure. Solid insulators in GIS are employed to give mechanical support to the conductor in Gas insulated busduct. Apart from mechanical support they do the job of providing the clearance between the high voltage electrode and outer enclosure. Precise modeling of the spacers is an important factor for power engineers as major flashovers report the failure of these supporting structures called spacers. Excessive field intensity at the gas –electrode –spacer interface called the triple junction is the problem that needed to be answered. On the other hand inspite of the care taken during the manufacture, running and maintenance of the spacers there is every possibility of existence of certain latent defects like delamination, protrusion, voids, etc. These defects have a wide impact on the insulation strength of the system during its operation reflecting its life.

Maren Istad et al. [1] has studied proper insulation enhancement and coordination among the various components in a Gas Insulated system is of great concern in the power industry. Cookson et al. [2] identified that Spacer failures were one of the causes in the dielectric strength breakdown and surface flashover in the system. Partial discharge phenomena, Electric field distribution along the surface was considered as measures in determining the possibility of dielectric strength breakdown. On the other hand reports reveal the presence of certain latent defects like delamination (loss of adhesive), voids, cracks, etc on the surface of the spacers, though the spacers had undergone various tests during manufacture and maintenance process. These defects do influence the field distribution in turn leading to the failure of the spacer. Effective means of controlling the field spread along the surface of the spacer and reducing the field at the triple point junction is a way in which the insulation strength and coordination can be increased.

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M. S. Mashikian et al. [3] optimized post-type spacers for three-phase, sulfur hexafluoride gas insulated cables was designed based on method of dynamic Programming by Freeman. Marquardt method was used by author to improve the profile of the post type spacer so as to minimize the maximal electric field on the spacer surface. Elliptical cross-section spacers, optimization yielded reduction in the maximal value of the total field strength. C.M. Cooke et al. [4] investigated the flashover performance of post-type support spacers for concentric compressed gas-insulated transmission lines with metal inserts along the solid-gas interface. The flashover voltage is controlled by the electric field distribution and is inversely proportional to the stress enhancement in the gas. Spark over of the radial gas-gap has been the limiting factor in the design of spacers rather than surface flashover. Sudarshan, T. S et al. [5] reviewed the influence of system parameters such as insulator size, shape, surface condition, triple junction geometry, voltage waveform, gas formulation and particle contamination on the flashover characteristics.

Delamination has been a one of the major defects in spacer manufacture. Owing to the thermal or mechanical stresses, delamination would be initiated at electrode/epoxy interface leading to partial discharge (PD) activity. Delamination leads to the change in electric field along the gap G. Ueta, J [6]. Studies carried out by many researchers clearly indicate the need for precise geometry control of the spacer to have a quasi uniform field distribution so that the overall system performance can be increased. T. Takuma et al. [7] studied that controlling the geometry of the spacer could be effective in obtaining a quasi uniform field distribution along its surface. Field intensification at triple point junction could be reduced with the insertion of controlled metal inserts and shielded electrodes, however leading to increase in field strengths at other regions along the spacer. Spacer defects like delamination, voids, cracks, etc do influence the field distribution and needs to be controlled. Further the influence of various shapes and sizes of these defects on the field distribution is very much required to improve the reliability of the system [8–22].

Numerical field computation methods are divided basically into two main groups. The first one is based on domain subdivision methods such as the Finite Difference Method (FDM) and the Finite Element Method (FEM), and the second one is the boundary subdivision methods such as the Charge Simulation Method (CSM) and the Boundary Element Method (BEM). Each method has its own advantages and disadvantages, FDM is difficult to apply for problems with complicated or curved boundaries, CSM needs experience and intuition to adopt proper positions of simulation charges, BEM is often troublesome in numerical integration when a computation point coincides with a source and FEM involves more complicated programming. Despite of its drawback FEM is proven to be more suitable for solving complex and intricate problems.

Shape control to obtain uniform field stress along the surface of the spacer and incorporating metal inserts and recessed electrodes for minimizing the electric field stress at TJ's have been effective. Further metal inserts have been found to provide effective shielding of the triple junction, provided that the mid gap field remains below the inception level. But these methods increase the complexity of spacer design and sometimes may also not be economically feasible. FGM is a technique by which the permittivity of the support insulator is modulated to obtain uniforms field stresses along the surface of the spacer for standard shapes. FGM supporting insulators are practically synthesized by controlling the diffused fillers in the epoxy by applying centrifuge forces. Efforts have been made to obtain uniform field stresses along the surface of the spacer but the minimization of electric field stress at both ends of HV and ground electrodes TJs needs further study.

In this paper, precise spacer geometry control is carried out on a cone type spacer and field studies were done. Further modified cone type spacer is obtained in account of lower fields at the triple point junction and a reasonably uniform field distribution along the surface. The electric field distribution computation was done by Finite Element method, which is the most suitable for calculating stresses associated over a non-linear surface. This is accompanied by proper shaping along the spacer. Further the impact of controlled metal inserts and recessed electrodes on the field distribution especially at triple point junction to reduce the stress is evaluated. Three types of permittivity graded support insulators are used to analyse the electric field stress on the surface of the spacer and also at the triple junction at either ends of the spacer and the results are presented and analysed.

2. Shape control of cone spacers

In a GIS the two main insulating media used are the SF_6 gas and the solid insulating supports called spacers. The commonly used materials for GIS and its related applications are alumina or silica-filled epoxy matrix. The preferred shapes in GIS are Disc, cone and post type of insulators. For present work, a normal cone type spacer is taken with clearance between the outer electrode to that of the inner electrode as 100 mm. For inner electrode an voltage of 1.0 p.u is applied while the outer electrode is grounded. The bustube is filled with SF_6 gas and relative permittivity is taken to be 1.005. The spacer is made of epoxy material with a relative permittivity of 4.5. Electric field estimation is done by using FEM technique which is detailed in the next section. In view of the field spread obtained along the spacer surface the geometry of the cone type spacer is modified by having a reasonably smooth profile avoiding rigid curves as they could enhance the field distribution. The profile of the optimized spacer is shown in Fig. 1. The radius of curvature is altered to the spacer surface and the field plots were attained. While comparing, the better shape spacer field distribution was compared to the normal cone type spacer for further confirmation.

The use of metal inserts and lower-level electrodes at the spacer were effective in field reduction at the triple point junction [17]. This method was applicable to the optimal mold spacer by considering an elliptical shaped metal inserts with different sizes. The stress distribution on the surface of the spacer for different elliptical shaped metal inserts were plotted. The obtained optimal mold spacer model with finely tuned metal inserts and lower-level electrodes is required and is shown in Fig. 2. Metal inserts had good impact on reducing the field stress particularly at the triple point junction.

3. Functionally graded material cone type spacer

Due to low permittivity of gas insulation region compared to that of solid insulator the electric field stress under AC and impulse voltage application usually gets intensified in the gas region. In order to minimize this field intensification the FGM spacer is made effective by modulating the permittivity within the solid insulator. By means of permittivity graded-FGM electric field stress intensification at the region of interest can be minimized. The important aspect is to select the permittivity distribution so as to increase the field utilization factor of the electric field stress distribution as much as possible.

FGM supporting insulators have created a new arena for designing support insulators with standard shapes and with distributed permittivity. Modulating the permittivity distribution along the length of the spacer the field stress can be controlled to obtain as per the requirement. Fig. 3 shows FGM type coaxial disc type support insulator. Permittivity-graded materials are processed by