AN ANALYTICAL STUDY ON THE EFFECT OF MULTIPLE DIELECTRICS IN THE DESIGN OF INSULATION SYSTEMS

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Abstract - Insulation is the heart of any electrical equipment. It arrests the flow of current from the live conductor to earth and also provides physical support. In a configuration with more than one dielectric the ratio of permittivity of the dielectrics and their respective thicknesses determine the voltage distribution among them. Based on this principle multi dielectric insulation systems are being developed to enhance the electric strength of the equipment like impregnated power cables. A detailed study of various factors which determine the affect of insulation coating on electric stress distribution for a particular electrode configuration are discussed in this paper. Case studies depicting the influence of dielectric coating in designing the insulation system for circuit breaker and live tank current transformer (CT) are presented. The electrostatic field analysis for different configurations of electrodes, coated with different dielectrics was carried out and verified experimentally. The simulation and experimental results were in good agreement. The important aspects to be considered while designing multiple dielectric insulation systems, especially for equipment with limited clearance are discussed in this paper.

I. INTRODUCTION

In all electrical equipments insulation is inherently used to isolate high voltage terminal (HT) from low voltage terminal (LT) and to provide mechanical support and electrical strength. The design of insulation for a particular configuration is based on test voltage levels, dielectric strength of insulation, clearance between HT and LT and shape of the electrodes. The electric stress for a particular configuration can be minimized either by shaping the electrodes to achieve uniform field or by insertion of higher dielectric strength insulating material with appropriate permittivity and thickness at high stress regions.

Electrode configurations with extremely non-uniform fields are more common in practice than with uniform and weakly non-uniform fields, for the reason that design of equipment to achieve uniform field is very difficult. In order to achieve the required dielectric strength, many HV insulation systems like transformer insulation are designed with various insulating materials of different permittivities. The application of multi-dielectric insulation systems is high in configurations where there is acute need to control electrical stresses within the given boundary conditions. The requirements of having multiple dielectric insulations systems, their applications and the design of such systems are presented in this paper.

II. ELECTRIC FIELD ANALYSIS AND DESIGN OPTIMIZATION

It is very important to study the configurations of the HT and LT electrodes in the system, evaluate the maximum stress and ascertain the design adequacy of insulation to withstand these stresses, Ref.[1]. A multiple dielectric insulation model consisting of HT and LT electrodes, separated by SF6 insulation medium of relative permittivity 1, and a dielectric of higher permittivity and thickness of few millimetres is introduced near the HT edge as shown in Fig. 1.

![Fig. 1: Multiple dielectric insulation model](image)

The distribution of equipotential lines in the models without dielectric (model-1) and with dielectric layer near HT edge (model-2) is shown in Fig. 2a & 2b respectively. In model-2 the voltage drop in the high permittivity region is lower due to better distribution of the field as depicted in inset of Fig. 2b and hence the electric field stress has come down by 65% at electrode edge as shown in Fig. 3. The electric stress from HT edge to the LT edge through the SF6 insulation for both the models is plotted in Fig. 4a & 4b. Though there is reduction in stress at the HT edge in model-2, there is increase in stress on the dielectric surface from by 80%. If we consider the breakdown stress in low

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permittivity dielectric to be 10kV/mm then model-2 can prove to be an optimal solution.

The insulation layer of higher permittivity value and appropriate thickness, around a HT or LT edge tries to shift the equipotential lines beyond the insulation surface, and the stress at the outer edge is determined by the shape of insulation surface which screens the HT or LT edge. The worst scenario occurs in a system where the thickness of lower permittivity material is lesser than its counterpart, which results in higher stress concentration in that region causing the breakdown. In the design of multi-dielectric insulation systems the thickness of each dielectric should be chosen such that the electric stresses are within their respective breakdown limits, Ref.[2]. In configurations where the field in uniform multi-dielectric insulation systems would have a negative impact as the maximum stress is likely to increase. Two case studies reflecting all the above aspects are discussed below.

![Fig. 2a: Voltage distribution in the model-1](image1)

![Fig. 2b: Voltage distribution in the model-2](image2)

![Fig. 3: Electric stress distribution](image3)

![Fig. 4a: Electric stress distribution in the model-1](image4)

![Fig. 4b: Electric stress distribution in the model-2](image5)

III. EXPERIMENTAL RESULTS

Case 1: The first case study presents a situation, where use of high permittivity insulation layer has lead to reduction in the breakdown voltage. A SF6 filled circuit breaker of medium voltage level was developed in-house and the preliminary design model-1 is shown in Fig.5, consisting of T-section HT and a moving electrode hanging from the top bushing to the middle portion of side bushing,
with bottom electrode and screens near side bushing being earthed. The equipment could clear upto 75% of the required impulse voltage and internally flashed from HT to side shield beyond this voltage, while the required test voltage was 75 kV. The epoxy casting in the region where maximum stress is occurring was designed with a view to increase the creepage distance between HT and LT. The electric field studies were carried out and the maximum stress in the region between epoxy casting and side wall was evaluated as 10kV/mm as shown in Fig. 6a, and it was inferred that the reduction in the width of low permittivity dielectric has resulted in increase of electric stress beyond the breakdown limit. The model-1 was modified to model-2 by completely removing the epoxy casting and the part of metal portion along with the epoxy layer as shown in Fig. 6b. The increase in gap between HT and LT with uniform insulation reduced the stress in the annular region by 32% and finally clearing the required BIL test level.

It can be inferred from the above electric field analysis and experimental results that the use of partial insulation layer between HT and LT, which reduces the width of lower permittivity dielectric, was detrimental and resulted in lower breakdown voltages.

Case 2: The development of high voltage (HV) live tank SF6 current transformer (CT) presents a situation, where use of high permittivity insulation layer has resulted in reduction of stresses and thus in successful design of the equipment. The CT model along with translucent view of tank portion is shown in Fig. 7. The technology of a live tank SF6 filled CT is very challenging due to non-linear geometry and position of the HV / ground electrodes. The primary is a bare copper pipe in physical contact with the tank to ensure live tank configuration. The coils are encapsulated in epoxy and supported by centre pipe which is at the ground potential. The inner area of an SF6 CT is filled with SF6 gas at a pre-determined pressure. The coil and tank of the CT are raised to a height in order to provide sufficient clearances externally.

The preliminary design of the CT model-1 had LT coil without any epoxy casting. The stress between insulated copper strands of the coil and live tank was very high due to sharp edges of copper conductors, and also due to non-symmetry between LT coil and tank as shown in Fig. 8a. The CT displayed internal breakdown at voltages well below the required impulse test level level. The design was modified to model-2, with an epoxy casting embracing the coil to provide smooth surface on the coil, and also reduce non-symmetry between LT coil and tank as shown in Fig. 8b. The coil is embraced in epoxy coating of appropriate thickness to withstand the internal stress, and also provide a smooth profile with improved symmetry to tank, thus reducing the electric stress by 50% and thus clearing the required test voltage.
From the above two case studies it can be observed that the application of Insulation coating on a conductor, in order to reduce or minimize the stress concentration at the electrode edge depends on type of configuration and can prove to be detrimental if applied for unsuitable configurations.

The greatest advantage of introducing a high permittivity dielectric into an insulation system occurs in highly non-uniform field configurations. In uniform field conditions there is limited advantage of using multi-dielectrics of large permittivity ratios. Usage of low permittivity dielectrics of high breakdown strength can be of greatest advantage in designing equipment with frozen dimensions. The ratio of the permittivities and width of both the dielectrics should be such that the maximum stress is with in tolerable limits. The above inferences can be very helpful, especially in designing HV electrical equipment having more than one dielectric and also for modifying the existing designs, by which the breakdown strength of insulation system can be considerably improved.

IV. CONCLUSION

With the advent of new insulating materials the electrical apparatus are being designed with multiple dielectrics to garner the advantages of such insulation systems. The effects of using dielectric coating for different electrode configurations are discussed with reference to electric field simulations carried out using electro and coulomb software and verified experimentally. The important aspects to be considered in designing insulation systems, especially for equipment with stringent boundary conditions are discussed in this paper.

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VI. REFERENCES