The Design of Dielectric Barriers for HVDC Bushings

ABSTRACT

High voltage bushings employ capacitive grading foils to control the electric field distribution under AC conditions. However, under DC conditions, the foils are unable to prevent a concentration of electric field within the bushing due to its high resistivity relative to that of the surrounding oil. A method of controlling the electric field is therefore required for DC conditions, and this is usually achieved through the use of dielectric barriers which surround the oil-immersed end of the bushing. This paper describes analytical techniques used to assess the performance of a particular barrier configuration in order to optimise its design.

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1 INTRODUCTION

A bushing is a means of passing a high voltage conductor through an earthed wall such as the metal tank that encloses an oil insulated transformer. The bushing insulates the high voltage conductor from earth and also provides a means of mechanically supporting the conductor. Epoxy resin impregnated paper (ERIP) bushings are manufactured by winding layers of crepe paper onto a high voltage conductor and then impregnating the paper with epoxy resin to form solid insulation when the resin has cured. Metallic foils are inserted during the winding process and they form a series of capacitors between the HV conductor and earth. The foils are designed to grade the electric field throughout the bushing in order to optimise the insulation performance (1).

A cross-section through an arbitrary bushing is shown in the schematic diagram of Figure 1. This section is rotationally symmetric about the centre line and shows the cylindrical conductor, the concentric grading foils, the tapered ERIP profile and the mounting flange. Figure 1 only shows the oil end of the bushing; this end is approximately 2m in length and is mechanically secured to the turret of a transformer tank using the flange. The other end of the bushing is considerably longer and is used to make a connection to an external overhead line.

Figure 1 shows the equipotential distribution when the bushing was analysed at a potential of 400kV rms; the dotted lines represent the equipotential lines at 10% intervals (40kV rms). The electric field analysis was performed using Electro (2), which is a boundary element software package. Figure 1 shows that the equipotential lines appear to be evenly spaced along the bushing surface and the change in potential from 40kV rms (10%) to 360kV rms (90%) occurs over the entire length of the bushing. The equipotential lines experience a moderate deviation at the ERIP-oil interface as the permittivity of ERIP is approximately twice that of oil.

The above example shows that the equipotentials are evenly distributed along the bushing surface under AC conditions due to the grading effect of the foils. However, bushings may also be required to deliver DC voltages, in a DC-DC converter station for example, and it can be shown that there may be an uneven equipotential distribution under DC conditions.

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Figure 2 shows the resulting equipotential distribution when the bushing was subjected to a DC voltage of 400kV. Under DC conditions, the equipotentials experience a deviation at the ERIP-oil interface due to the difference in resistivity between the two materials. As the resistivity of ERIP may be 100 times greater than that of oil, the deviation under DC conditions is considerably greater than that under AC conditions, and as a result the equipotentials tend to concentrate within the ERIP material.

Figure 2 shows that the equipotentials are confined to the lower third of the bushing, near the high voltage conductor in particular, and the electric stress is therefore enhanced around this region. It is desirable to re-distribute the equipotentials along the bushing surface in order to reduce the electric stress at the high voltage conductor.

2 DIELECTRIC BARRIERS

A set of dielectric barriers can be used to re-distribute the electric field under DC conditions in order to use a greater proportion of the bushing. Dielectric barriers are made from a material with a similar resistivity to that of ERIP, such as transformerboard (3), and they form a series of concentric cylinders around the oil end of the bushing. The number of dielectric barriers is determined by the operating voltage of the bushing, and typically 5 barriers are required for a 400kV DC bushing.

Figure 3 shows five barriers positioned around the bushing with an equal radial separation between each barrier. The inner barrier is formed around a curved electrode that is electrically connected to the HV conductor and it acts as a shield. The second barrier is often called a 'tulip' as it is contoured to follow the ERIP profile. The length of each barrier is approximately proportional to its diameter.

As the barriers have a similar resistivity to that of the ERIP, they re-distribute the stress along the bushing surface. Figure 3 shows that the potential distribution along the bushing surface has been improved by the presence of the barriers. As a result, there is a significant reduction in the stress near the HV conductor, and the change in potential from 40kV (10%) to 360kV (90%) occurs over ~40% of the bushing surface.

2.1 Effect of barrier configuration

The above barrier configuration was modified in an attempt to further improve the equipotential distribution along the bushing surface. The length of each barrier was doubled while the radial separation remained unchanged, and the modified barrier configuration is shown in Figure 4.

Figure 4 also shows the improved equipotential distribution due to the modified barrier configuration. In this case, the change in potential from 40kV (10%) to 360kV (90%) occurs over ~50% the bushing surface. However, this figure demonstrates that it is difficult to quantify the performance of the two barrier configurations using the equipotential distribution alone, and another technique is required.

2.2 Assessing the barrier performance

Two techniques are available to assess the performance of the barrier configurations. The first technique involves quantifying the maximum electric stress at the bushing surface in order to identify the weakest point. Partial discharge activity may occur at this point if the electric stress exceeds the dielectric strength of either the ERIP or the oil. The second technique involves determining the cumulative stress along the bushing surface in order to assess the integrity of the entire bushing surface.

The maximum electric stress on the bushing surface was calculated using Electro for each barrier configuration, and the results are listed in Table 1. In the absence of a barrier (Figure 2), the electric stress at the bushing surface reaches 40kV/cm. This stress is reduced to 24kV/cm with the original barrier (Figure 3) and 20kV/cm with the modified barrier configuration (Figure 4). Table 1 also shows the maximum stress under AC conditions (14kV/cm rms) for comparison. From this data, it is clear that both barrier configurations have a significant effect on the electric stress. In addition, the modified barrier configuration offers a 20% reduction in stress over the original barrier configuration.

voltage	barrier	stress
400kV DC	no barrier	40kV/cm
400kV DC	original	24kV/cm
400kV DC	modified	20kV/cm
400kV rms AC	no barrier	14kV/cm rms

Table 1

The above technique identifies the stress at the weakest point on the bushing surface whereas cumulative stress analysis is used to assess the integrity of the entire bushing surface. The cumulative stress, as defined by Nelson (4), is a measure of the average electric stress as a function of path distance along the bushing surface.

Figure 5 shows the cumulative stress curves for both barrier configurations. It can be seen that the modified barrier configuration results in a cumulative stress that is 10% lower than that measured with the original barrier configuration over most of the bushing surface.

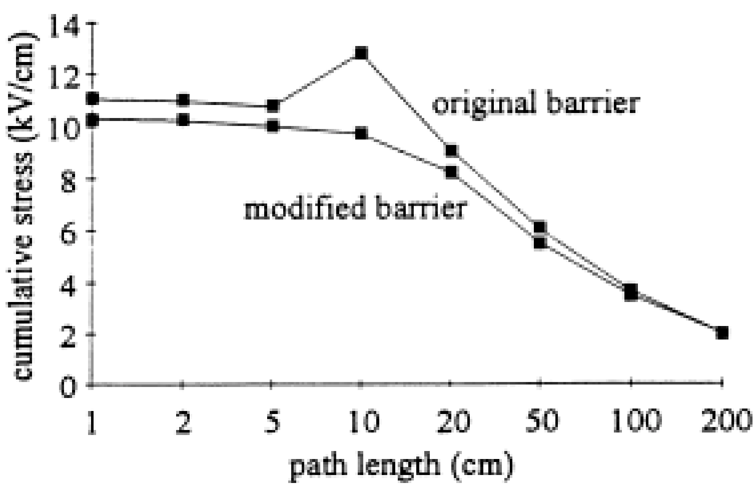

Figure 5

3 DISCUSSION

Dielectric barriers may be used to control the electric field distribution along the surface of an HVDC bushing, and their performance may be assessed using electric field analysis. The peak electric stress and the cumulative stress distribution provide a quantitative assessment of the barrier design. These techniques may be used at the design stage in order to investigate the optimum barrier configuration for a particular bushing.

ACKNOWLEDGEMENT

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REFERENCES

(1) W J John and M M Sakr, "Capacitor bushing theory", Proc. IEE, part IV, 1953

(2) Integrated Engineering Software, "Electro", Version 3.8, 1995

(3) H P Moser, "Transformerboard", Scientia Electrica, 1979

(4) J K Nelson, "Some steps toward the automation of the design of composite dielectric structures", IEEE Trans. Dielec. and Elec. Ins., Vol.1, No.4, 1994, pp.663-671

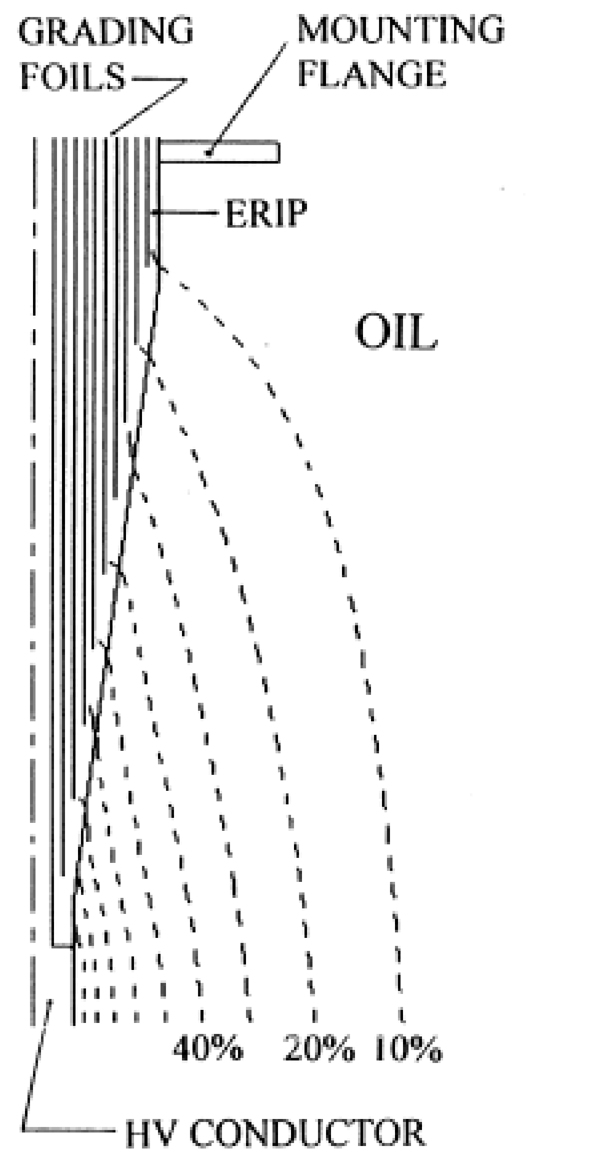

Figure 1
Equipotential distribution under AC conditions

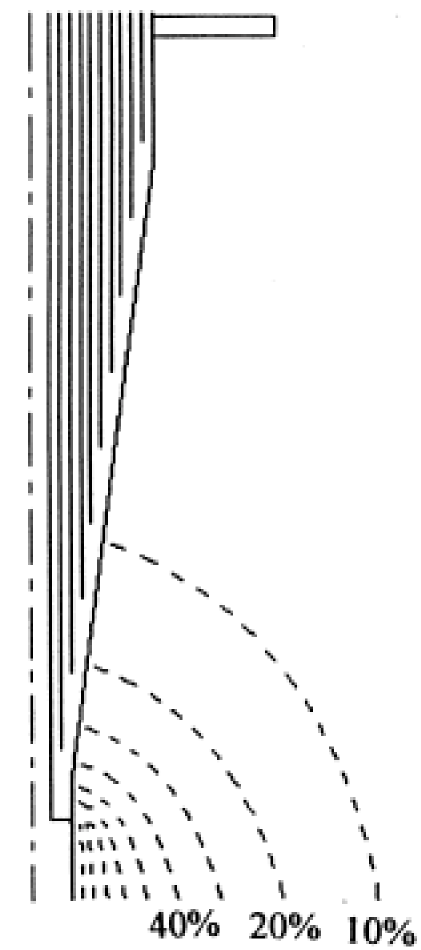

Figure 2
Equipotential distribution under DC conditions

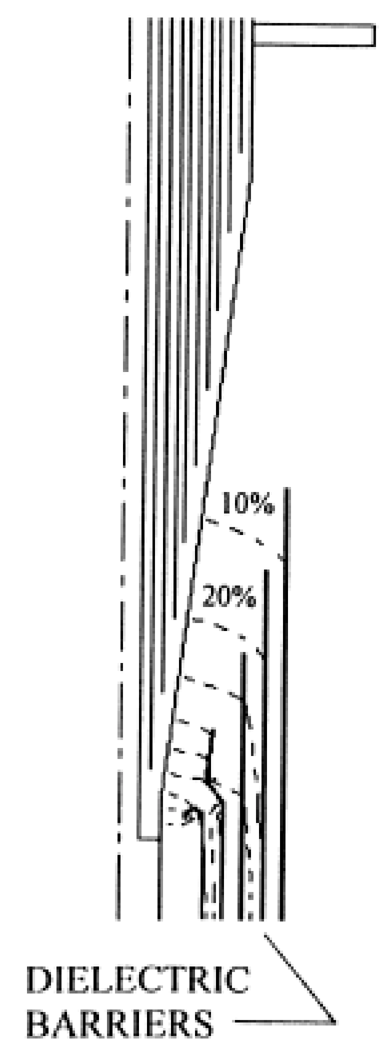

Figure 3 Dielectric barriers used to control the DC equipotential distribution

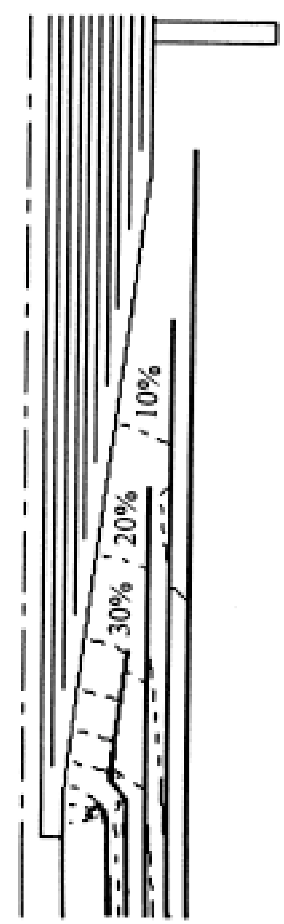

Figure 4
Modified barrier configuration