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BUBBLE EFFECT IN BUSHING INSULATORS WITH INSULATION MANUFACTURED FROM DIFFERENT MATERIALS

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Abstract: The article presents research results of bushing insulator models in terms of the possibility of bubble effect occurrence. There were three kinds of insulating systems subjected to the research: paper – mineral oil, resin bounded paper – mineral oil, and paper – synthetic ester. The main effect of the work is to show the possibility of bubble effect occurrence in bushing insulators. It was found that replacing paper with resin bounded paper results in lowering the initiation temperature of the bubble effect. Replacing mineral oil with synthetic ester significantly improves the properties of the system and causes rising the initiation temperature of the bubble effect.

1 INTRODUCTION

The goal of the research was to obtain answers to the following three questions.

- Does the bubble effect occur in the bushing insulator of paper – mineral oil insulation?
- Can we expect this effect in the insulator of resin bounded paper – mineral oil insulation?
- Does replacing mineral oil with synthetic ester change quantitative relationships describing the bubble effect?

The insulation of paper and mineral oil in a bushing insulator is qualitatively identical to the main insulation of the transformer, therefore we should expect this effect. A different quantitative ratio of the cellulose mass to the oil mass can affect certain changes. We were, however, particularly interested in the role of metal screens controlling distribution of electric field intensity. Intuitively assessing the situation, it seemed that metal screens might strongly reduce water steam migration, and considerably influence bubble effect development.

Bushing insulators of the oldest concept have their insulation made of paper impregnated with mineral oil. Such an insulator, according to the international nomenclature, has a symbol OIP (Oil Impregnated Paper) [1].

One of the oldest and popular designs of a bushing insulator is based on the insulation of resin bounded paper and oil. The paper is covered on one side with thermohardening resin. The paper prepared in such a way is wound onto a metal bolt; screens controlling electric field intensity distribution are placed between paper layers. Next the insulator core is heated, which causes thermal hardening of the resin. To make moisture penetration more difficult, the space between the ceramic housing and the impregnated core is filled with a special mass of very high viscosity. In contemporary designs, the mass is replaced with mineral oil. Due to the applied cellulose material, such an insulator has a symbol RBP (Resin Bounded Paper) [1].

In the newest designs of bushing insulators, technological changes have been introduced. Instead of covering the paper with resin, it is impregnated with resin. The paper is wound onto a metal bolt placing properly aluminium screens. The core made in this way is next vacuum-dried and then it undergoes pressure impregnation with resin, which must have sufficiently low viscosity. The housing can be ceramic or made of silicone elastomer. The space between the insulator core and the shield insulator is filled with oil. Such an insulator, because of the applied technology, has a symbol RIP (Resin Impregnated Paper) [1].

Properly scheduled investigations on models will let us answer a few detailed questions. Do the metal screens controlling the distribution of electric field intensity change conditions of water migration in paper and reduce bubble effect development? Does covering the paper with resin change water absorption and its release, and does it affect bubble effect development? Can replacing mineral oil with synthetic one influence initiation temperature of the bubble effect?

2 REASONS OF TEMPERATURE INCREASE IN PAPER-OIL INSULATION

It is crucial to understand reasons of temperature increase of the bushing until it is destroyed. In a new bushing of good dielectric properties of the insulation, the source of heat are power losses resulting from flowing current. In an old moistened bushing, another source of heat appears: dielectric losses. Figure 1 shows the relationship between loss factor *tgδ* and paper moisture at a few temperature values.

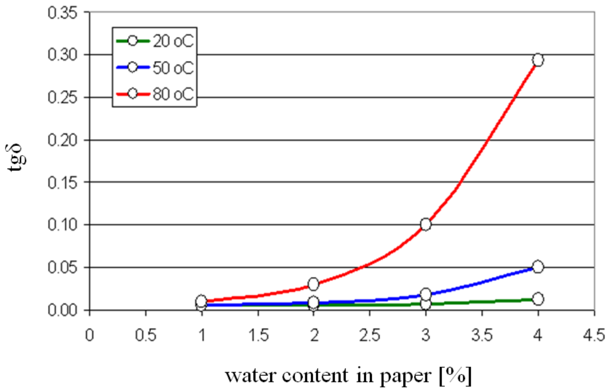

Figure 1: Dielectric loss factor as a function of water content in the paper for the temperatures of 20, 50, 80°C at 50Hz [2]

It results from Figure 1 that the influence of moisture on *tgδ* is considerable, particularly at higher temperatures. We did model research, from which it results that at a selected average paper moisture and at an electric field intensity of a few kV/mm, over a certain initial temperature, there is a self-reinforcing mechanism of temperature increase. The temperature increase in the insulation results in *tgδ* increase, and the increase of *tgδ* causes temperature increase. Thus, as a result of such a feedback, the temperature rises very quickly without restrictions, which leads either to the thermal breakdown or the bubble effect [3]. This experiment explains why, even in the case of a little loaded transformer, there can be an explosion and breaking the bushing. It should be noted that in the case of a heavily moistened bushing, the critical temperature, over which the temperature rise is unlimited, is relatively low and it is only 70-80°C.

According to the opinion of Polish grid operators, all transformer breakdowns that took place recently, started with bushing insulators if the insulators were of the same age as the transformer. Our suggestion is that the reason of the bushing explosions and breakdowns is the bubble effect. Up to now, this effect has been associated only with the main insulation of the transformer, which is unjustified.

3 RESEARCH OBEJTS

The research objects were laboratory models on a scale of 1 : 10. They imitated the insulating system of the bushing insulator quite well. In order to demonstrate differences in the development of the bubble effect mechanism, three situations were modelled:

- paper – mineral oil,
- paper – synthetic ester MIDEL 7131,
- resin bounded paper – mineral-oil.

All the three models differed only with applied insulating materials, whereas the dimensions and geometry of the models were the same.

Twelve layers of paper were wound onto a copper pipe of 10 mm diameter and 150 mm long. Every three layers of the paper, a sheet of aluminium foil was placed, which imitated the screen controlling the distribution of electric field intensity. The aluminium foil was of a graded width, as it is in a bushing insulator. Inside the pipe, a heater of a precisely adjusted temperature was placed. A thermocouple was fitted between the surface of the copper pipe and the first paper layer. In this way, the highest temperature in the model was measured. It is a correct assumption because in a real transformer, the bubble effect takes place always in the hot-spot region.

In the model of resin bounded paper and mineral oil, we used insulating materials acquired from a company which is the manufacturer of bushing insulators of that sort. We received a semi-product in the form of paper coated with phenol-formaldehyde resin. After completing, the model was vacuum-dried at the environment temperature and next the resin was hardened at the temperature of 150°C for 15 minutes. At the first stage of heating, the resin melts, saturates the paper, glues the layers, and only then thermal hardening follows.

The cores with the wound paper or resin bounded paper were dried in the vacuum to equalize the conditions. Next all the models were placed in a chamber and they were moistened in a controlled way by means of the contact with humid air for 6 days.

The prepared models, properly moistened, were put in a glass vessel and immersed in mineral or synthetic oil. The model was being warmed up at a pace of about 6°C/min, recording the image all the time. The temperature displayed on the meter screen was also recorded with a camera.

4 RESEARCH RESULTS AND THEIR INTERPRETATION

Out of several recorded objects, a few frames were selected, which are a good illustration of the investigated effect and let us draw initial conclusions. Figures 2 to 5 show some selected images taken with a camera at the same temperature of the research objects. The moisture of the models was a little greater than a typical moisture of transformer insulation.

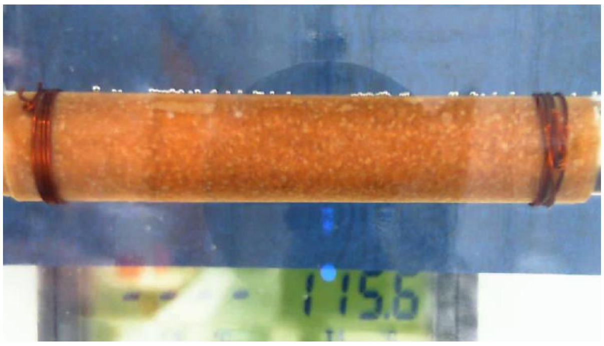

Figure 2: Paper - mineral oil, water content 5%, 115.6^{o}C, start 92.2^{o}C

We can see in Fig. 2 bubbles of water steam on the surface of the paper whose moisture is 5% at the temperature of 115.5^{o}C but the initiation temperature of the bubble effect was 92.2^{o}C. The initiation temperature is in agreement with the one presented by Oommen [4] and in our previous articles [5]. Thus we can conclude that the bubble effect in the bushing insulator model occurs and the presence of the metal screens does not restrict the effect. Additionally, the initiation temperature of the bubble effect was checked at paper moisture of 7% (Fig. 3). This temperature is 85^{o}C and is also in agreement with values presented in the literature.

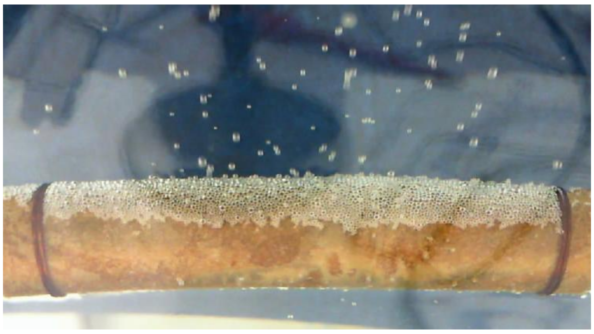

Figure 3: Paper - mineral oil, water content 7%, 115.6^{o}C, start 85^{o}C

Figure 4 shows a model made of resin bounded paper of 5% moisture at the temperature of 115.8^{o}C. The start of the bubble effect took place at the temperature of 88.4^{o}C, thus it is lower than for the paper without the resin (Fig. 2). The intensity of the effect in Figure 4 is much higher than in Figure 2, at the same temperature values. We can conclude that the presence of the resin lowers the initiation temperature of the bubble effect and increases its intensity.

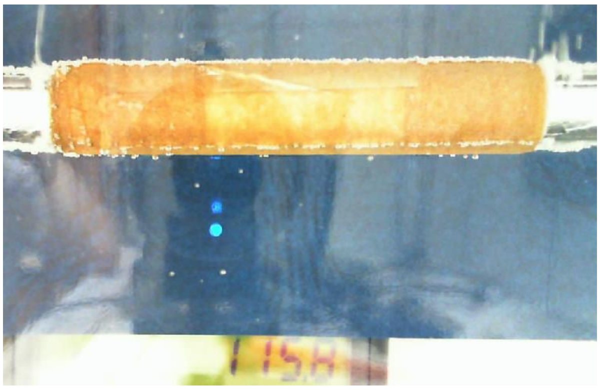

Figure 4: Resin bounded paper - mineral oil, water content 5%, 115.8^{o}C, start 88.4^{o}C

In the model made of paper - synthetic ester (Fig. 5), in this temperature range, the effect did not occur, which proves the advantage of such a model. It is probably related with high water solubility in MIDEL and favourable equilibrium conditions in the paper and the liquid.

Figure 5: Paper - synthetic ester MIDEL 7131, water content 5%, 115.3^{o}C, the effect was not initiated

5 CONCLUSIONS

The most important result of this article is showing that we should expect the bubble effect in bushing insulators. Most probably, this effect leads to so frequent breakdowns of bushings, operated for 20 – 25 years, thus moistened to a degree exceeding the critical value.

We can state on the basis of the experiments on the models that metal screens placed between paper layers do not affect bubble effect development. The dependence of the initiation temperature of the bubble effect on paper moisture is the same as in the literature.

Initiation of the bubble effect in the insulating model of resin bounded paper – mineral oil occurs at a lower temperature than for the model of paper – mineral oil.

Replacing mineral oil with synthetic ester MIDEL 7131 considerably improved the properties of the insulating system. In the temperature range of up to 115.3^{o}C, at paper moisture of 5%, the bubble effect did not take place, whereas in the setup with mineral oil at the same paper moisture, the initiation temperature of the bubble effect was 92.2^{o}C.

6 ACKNOWLEDGMENTS

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