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Comparative Study of Breakdown Voltage of Mineral, Synthetic and Natural Oils and Based Mineral Oil Mixtures under AC and DC Voltages

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Abstract: This paper deals with a comparative study of AC and DC breakdown voltages of based mineral oil mixtures with natural and synthetic esters mainly used in high voltage power transformers. The goal was to analyze the performances of oil mixtures from the dielectric withstand point of view and to predict the behavior of transformers originally filled with mineral oil and re-filled with synthetic or natural ester oils when emptied for maintenance. The study concerns mixtures based on 20%, 50%, and 80% of natural and synthetic ester oils. AC breakdown voltages were measured using a sphere-sphere electrode system according to IEC 60156 specifications; the same specification was adopted for DC measurements since there is no standard specifications for this voltage waveform. A statistical analysis of the mean values, standard deviations, and histograms of breakdown voltage data was carried out. The Normal and Weibull distribution functions were used to analyze the experimental data and the best function that the data followed was used to estimate the breakdown voltage with risk of 1%, 10%, and 50% probability. It was shown that whatever the applied voltage waveforms, ester oils always have a significantly higher breakdown voltage than mineral oil. The addition of only 20% of natural or synthetic ester oil was sufficient to considerably increase the breakdown voltage of mineral oil. The dielectric strength of such a mixture is much higher than that of mineral oil alone and can reach that of ester oils. From the point of view of dielectric strength, the mixtures constitute an option for improving the performance of mineral oil. Thus, re-filling of transformers containing up to 20% mineral oil residues with ester oils, does not present any problem; it is even advantageous when considering only the breakdown voltage. Under AC, the mixtures with natural ester always follow the behavior of vegetable oil alone. With the exception of the 20% mixture of natural ester in DC, the breakdown voltage values of all the tested mixtures were in accordance with the normal distribution, which made it possible to define the breakdown voltages for the risk levels of 1%, 10%, and 50% of probability.

Keywords: insulating oils; vegetable oil; synthetic oil; mineral oil; oil mixtures; AC breakdown voltage; DC breakdown voltage; re-filling of power transformers; statistical analysis; normal distribution; Weibull distribution

Figures 20 and 21 give the voltages U1%, U10%, and U50% determined using compliance with the Normal law. We observe that mineral oil has the least interesting dielectric strength compared to ester oils and mixtures; it has the smallest breakdown voltages with risks of 1%, 10%, and 50% probabilities. The mixtures giving the best BDV in DC are mixtures with 80% natural ester and 50% synthetic ester while in AC the best mixture is that with 50% synthetic ester oil.

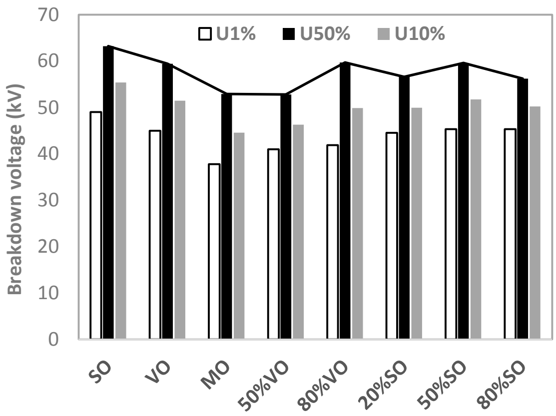

Figure 21. Probability of DC breakdown voltage of oil mixtures.

4. Conclusions

This work showed that:

Whatever the type of voltage (DC or AC), ester oils always have a significantly higher breakdown voltage than mineral oil. Thus vegetable oil can be used as a satisfactory alternative to mineral oil in power transformers.

The mixtures may be an option for improving the performance of mineral oil, from the point of view of dielectric strength. The addition of only 20% of natural or synthetic ester oil is sufficient to considerably increase the breakdown voltage of mineral oil. The dielectric strength of such a mixture is much higher than that of mineral oil alone and can reach that of ester oils.

The re-filling of transformers can be considered with mixtures composed of 20% of mineral oil and 80% of ester oil. In the case of vegetable oil, the breakdown voltage of the mixture remains equal to that of natural ester alone. In contrast, when the used replacement oil is synthetic ester, the dielectric strength of the mixture is decreased in comparison with that of synthetic oil.

Under AC, the mixtures with natural ester always follow the behavior of vegetable oil alone, unlike mixtures with synthetic ester, which have a breakdown voltage which varies considerably with added concentration up to exceeding that of synthetic oil alone.

Under DC, whatever the nature of ester (natural or synthetic), the dielectric strength of mixtures varies as a function of the concentration added to mineral oil and is between that of mineral oil alone and ester oils alone.

The breakdown voltage generally follows a normal distribution whatever the oil or mixture.

With the exception of the 20% mixture of natural ester in DC, all the tested mixtures were in accordance with the normal distribution, which made it possible to define the breakdown voltages for the risk levels of 1%, 10%, and 50% of probability.

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Conflicts of Interest: The authors declare no conflict of interest.

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