Improvement of the test method for insulating oils

W. LICK[1], G. J. PUKEL[1], H. M. MUHR[1], M. BAUR[2]

[1]Institute of High Voltage Engineering and System Management, Graz, University of Technology, Inffeldgasse 18, A-8010 Graz/Austria

[2]BAUR Test and Measuring Technique Ltd., Raiffeisenstrasse 8, A-6832 Sulz/Austria

***Abstract* — The dielectric breakdown voltage of an insulating liquid is of importance as a measure of the liquid's ability to withstand electric stress. The parameters of the standard test methods from different countries are not similar. In the different standards there are used five or six single breakdowns in a glass or a plastic vessel with about 0.5 litter test oil content. The voltage raising up velocities are between 0.5 and 3 kV/s. After filling the test oil in the test cell until the start of the first breakdown test there is a pause between 3 to 10 minutes and between each breakdown there are breaks of 1 or 2 minutes. Also the form of electrodes are different, sphere formed (according VDE) or flat formed (ASTM). With these single breakdown values the mean value, which height is a parameter for the oil quality, and the coefficient of variation were calculated. A weak point of the standard dielectric breakdown tests is that it is possible to reach values for the coefficient of variation up to 30 % and higher. In this paper it will be shown where the problems are and some ways are given how to minimize the coefficient of variation.**

***Index Terms* — Insulating oil, oil breakdown, dielectric oil tester.**

I. INTRODUCTION

The oil-board insulation system is still of big importance for the insulation of electrical power equipment such as high voltage transformers, current and voltage transformers, power circuit breakers and oil-filled cables. An important advantage of the oil-board insulation is the reliability over many years. The main tasks of the oil (in most cases mineral oil) are the separation of different electrical potential, the impregnation of the board components and the removal of the produced heat in the device. In combination with board the oil part is the electrical weaker component. Nevertheless, insulating oils has been a satisfactory insulating material for high-voltage insulation purposes for a century. One of the reasons for this is that insulating oil, as a viscous liquid, automatically adapts to all changes in the insulation volume and so it suppresses internal partial discharges that never be completely avoided in the case of solid insulation systems. But it is a demand of time to reduce costs, volume and weight so the amount of insulating oil in an electrical power equipment was steady reduced while the unit power was increased, figure 1.

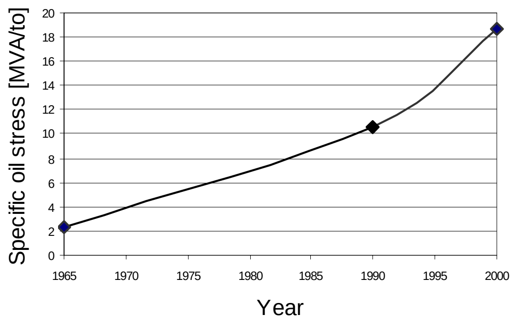

Figure 1: Specific oil stress (vertical scale in MVA/to) versus year of construction (horizontal scale) for high voltage transformers

This continuous higher specific oil stress was reached by improving the transformer design. Thanks to the high capacity of numerical field calculation methods performed with computers it is possible to achieve a great homogeneity of the internal voltage distribution. Also new and better cooling systems allow a higher mean oil temperature in the transformer while the temperature of hot spots was decreased. And last but not least new production processes and many diagnostics methods allow a higher stressing of the oil-board system.

One old but very popular diagnostic method for the oil component is the determination of the breakdown voltage. Because the electrical strength of the oil is the most important magnitude for a safety operation. Manufacturers and users of oil-insulated electrical power equipment perform oil breakdown test according to the relevant standards for checking the oil quality when filling new equipment and diagnosing in-service insulation contamination or aging. It is widely accepted that moisture and particles have a big influence on the dielectric strength of insulating oil. So dielectric tester of insulating oil should be sensitive to these parameters. The determination of the AC breakdown voltage of insulating oil is included in international and national standards on liquid dielectrics. Among them the most well-known are IEC 60156, ASTM D-1816 and

JIS C2101/78. All standard test methods have a bad reproducibility. The reason can be found in the usually high values for the coefficient of variation you can reach for the test series with the specified single breakdowns.

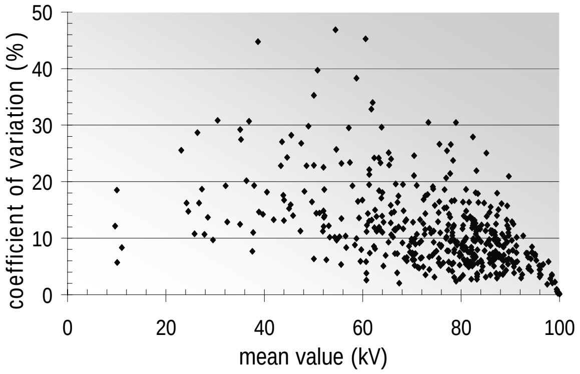

Figure 2: Coefficient of variation (vertical scale in %) versus mean value (horizontal scale in kV) for 459 single breakdown tests according IEC 60156

According figure 2 especially insulating oils with mean values between 40 and 60 kV can reach high values for the coefficient of variation. The reason is that for such "medium quality" oils the probability is not as low as for "good quality" oils that a weak point appears between the electrodes (for instance a particle) and produces a breakdown during the test voltage apply. And also the probability for this "medium quality" oils is not as high as for "bad quality" oils that for each single test a weak point appears between the electrodes. Therefore just for this "medium quality" oils a high coefficient of variation makes the decision what to do, processing or renewal the oil filling, more difficult. All standard dielectric oil tester only use a small oil volume, between the electrodes, which get tested compared to the whole oil volume which is filled in the test vessel. So these standard breakdown tester can not be enough sensitive for particles because of there statistical distribution in the test cell. According to Sinz [1] and Trinh [2] it is necessary to increase the electrode surface and the stressed oil volume for a good sensitivity both for clean oils and particles contaminated oils. An idea therefore is to use coaxial cylinder electrode arrangement. There are also considerations to replace the ramp voltage by a step-by-step test voltage [1, 3]. An result of such tests is presented in the following figures 3, 4 and 5. In figure 3 are standard test methods (ASTM and IEC) compared with modified test methods version by using a step-by-step voltage instead of the voltage ramp (ASTM mod. and IEC mod.) and a coaxial cylinder electrode arrangement with 2 mm gap distance (2-mm coax). As can be seen the ASTM and IEC standard test procedures are not sufficiently sensitive to particle contamination compared to a modified version with by using a step-by-step voltage or a coaxial cylinder electrode arrangement.

Also the comparison of figure 4 and 5 shows the advantage of using a coaxial cylinder arrangement instead of the standard IEC electrodes referring to particle sensitivity.

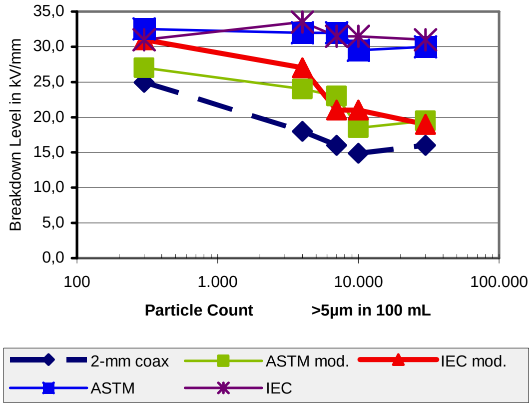

figure 3: Breakdown field strength (vertical scale) versus particles contamination of the oil (horizontal scale) for standard and modified oil breakdown test methods, according [3]

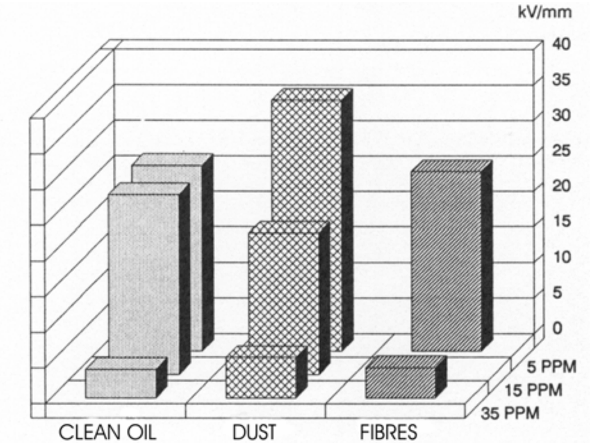

Figure 4: Breakdown field strength of standard IEC test in dependence of oil purity and humidity, according 1.

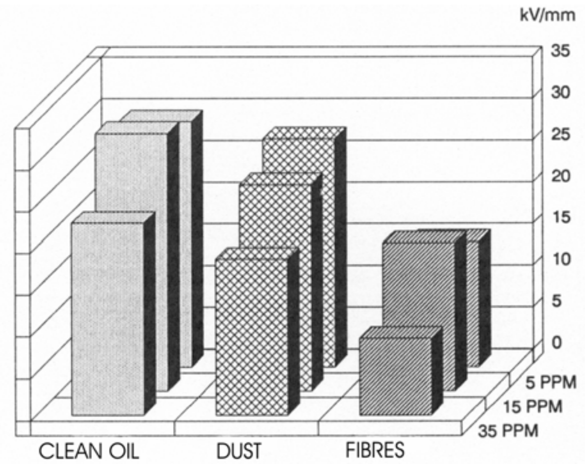

Figure 5: Breakdown field strength of a 2 mm coaxial cylinder arrangement in dependence of oil purity and humidity, according 1.

II. DEVELOPMENT

Our proposal for improving the standard oil breakdown test is the use of rogowski-formed electrodes, figure 6 in a glass vessel, figure 7 which is surrounding the electrodes, picture 8.

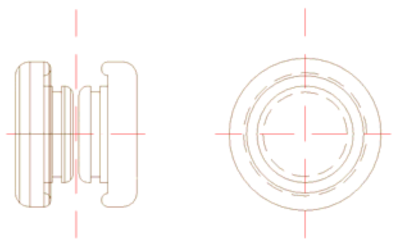

Figure 6: Rogowski-formed electrodes for 2 mm gap distance

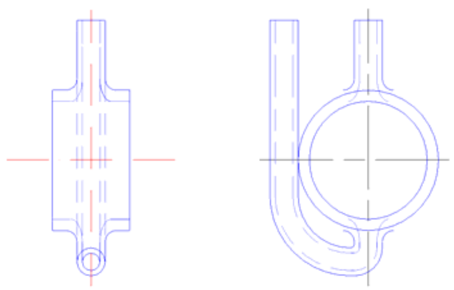

Figure 7: Glass vessel with inlet tube to the underside and the outlet tube on the upper side

The advantages of this arrangement for the oil breakdown determination are the smaller amount of test oil needed and the bigger electrical stressed oil volume compared to the standard test methods. Practically the whole oil volume in the glass vessel get electrical stressed because the border area where the electrical stress is decreasing is very small. So this arrangement is more sensitive to contamination. The advantages compared to a coaxial cylinder electrode arrangement can be found in a accurately adjustment of the electrode distance by using the width of the glass vessel and also in the trouble-free controlling the border area. Moreover it is possible to make a visual inspection by using a glass vessel. Picture 8 shows our proposal for a new oil test cell in the assembled condition without seal rings at the border area.

Picture 8: Proposal of a new oil test cell

To avoid discharges on the outside, above the glass surface, during the test we propose to put the whole new oil test cell in an oil bath. It is obvious to use therefore the standard oil breakdown test devices, picture 9.

Picture 9: Integration of the new oil test cell in a standard oil breakdown test device

The filling of the glass vessel with the testing oil can be performed with the help of a pump from the sample container. Attention should be given to a bubble free infill of the testing oil. A possibility to check the whole arrangement before performing the test of an oil sample is the use of a reference oil with well known breakdown strength before filling in the next test oil sample. Another way for a bubble free infill can be done by using a hydrostatic pressure difference between the sample container and the glass vessel.
Another important aspect for a sensitive and reliable determination of the test oil condition is a good homogenization of the oil in the sample container. As performed test showed, figure 10, particles deposit to the bottom of the sample container and have to be washed up and homogenized before testing. Figure 10 shows a repeated particle count test of an oil in a oil sample container according ISO 4406 (1999). After 10 repeated measurements (between 16:11h to 16:33 h) the oil in the sample container was stirred and 9 additional particle count tests were performed. It is clear recognizable the increase of the particle amount.

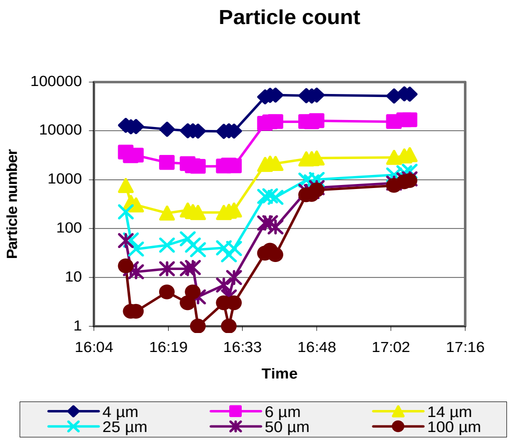

figure 10:Particle number (horizontal scale, logarithmic) versus time of the performed test without (before 16:33h and with stirring (after 16:33h)

Therefore a stirrer in the sample container or a vibrating plate should be used. Also for that, not only for the infill, attention should be given in preventing of bubble generation.
Another new technical innovation is the introduction of a cleaning process after each single breakdown. In a previous thesis [4] it could be shown that with a so called "charging voltage" after each breakdown contaminations on the electrodes from the breakdown can be detached and removed with a oil streaming between the electrodes. An oil streaming alone is not sufficient to remove all breakdown contamination from the oil gap especially from the electrodes. With a moderate voltage (about the half of the achieved breakdown voltage) for a time duration up to 60 seconds and a subsequent spoiling of the oil gap after each single breakdown a satisfactory cleaning can be reached and a possible interference of the following breakdown value can be avoided.

III. CONCLUSION

The proposed new oil breakdown test shows the following advantages compared to the standard methods:

- Smaller total quantity of test oil needed
- 7 to 10 times higher electrical stressed oil volume
- More sensitive referring particles in oil
- Automation possible
- Cycle test possible
- Better independence of single test with the cleaning procedure
- Integration in common standard oil test devices possible
- Simple and quick check of the whole test arrangement by using of a reference liquid

IV. ACKNOWLEDGMENT

Many thanks are given to Company BAUR Test and Measuring Technique Ltd. A-6832 Sulz/Austria, for the support of this investigations.

V. REFERENCES

[1] P. Sinz: "Influence of moisture and particles on the electrical strength of insulating oils", Doctoral Thesis, Graz, University of Technology, 1990
[2] Trinh, N. G., Vincent, C., Regis, J. " Statistical Dielectric Degradation of Large-Volume Oil Insulation" IEEE Transaction, PAS-101, No. 10, 1982, pp. 3712-3721
[3] C. Vincent, C. Benoit, R. Olivier: "Comparative Evaluation of parameters of the Dielectric Breakdown Test on transformer Oil" International Conference on Dielectric Liquids, Rom, July 1996
[4] W. Lick: "Electrical strength of long breakdown distances in oil-board-dielectric" Doctoral Thesis, Graz, University of Technology, 2002