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New test method for dielectric breakdown voltage of insulating oils

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ABSTRACT

Standard dielectric breakdown tests for insulating oils consist of five or six single breakdowns in a glass or a plastic vessel with about 0.5 litter test oil content. For each breakdown the voltage gets raised up linear from zero to the breakdown value usually with 0.5 ... 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. Between each breakdown there are breaks about 1 ... 2 minutes. Optional a stirrer produces an oil circulation in the test oil. The form of electrodes are different, according VDE (sphere formed) or ASTM (flat formed). 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 that it is possible to influence the coefficient of variation by changing of different test parameters and also the test procedure.

INTRODUCTION

It is widely accepted that moisture and particles have a big influence on the dielectric strength of insulating oil. So dielectric tester of mineral 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. For manufacturers and users of liquid-insulated power equipment, these standards are used for checking the oil quality when filling new equipment and diagnosing in-service insulation contamination or aging.

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.

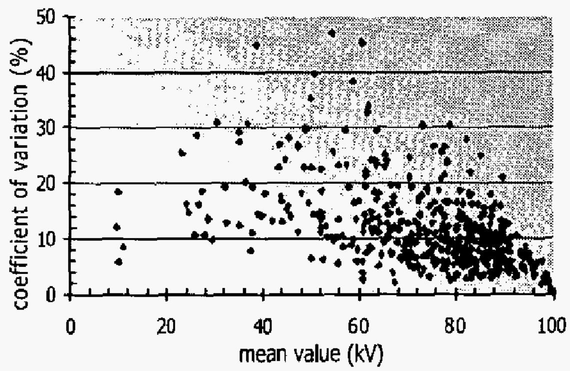

figure 1: Coefficient of variation (vertical scale in %) versus mean value (horizontal scale in kV) for 459 single breakdown tests according IEC 60156 [1]

According figure 1 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. And so 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.

The AC breakdown voltage test is a commonly used diagnostic tool. Every changing of the test procedure which would lower the coefficient of variation is desirable. For investigation which parameters of the test procedure influence the coefficient of variation breakdown test with mineral oil have been performed.

MEASUREMENTS

A standard dielectric oil tester (BAUR DTA 100E) was used for performing breakdown tests with mineral oils of different qualities according IEC 60156. For the tests there were available a new oil qualified as good oil a used oil qualified as medium oil and a oil contaminated with board particles qualified as bad oil.

With the used oil tester it was possible to adjust many parameter of the test procedure. In a first step we have investigated how much a simple variation of the test procedure parameters only influence the coefficient of variation.

So the voltage raising up velocity was changed between 0.5 kV/s to 5 kV/s. This was performed both for the good oil and the medium oil.

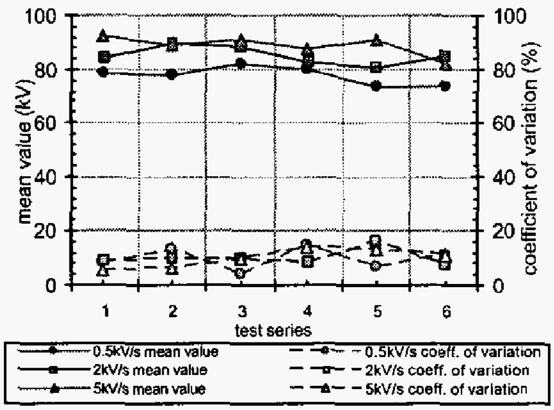

figure 2: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the good oil and different voltage raising up velocities

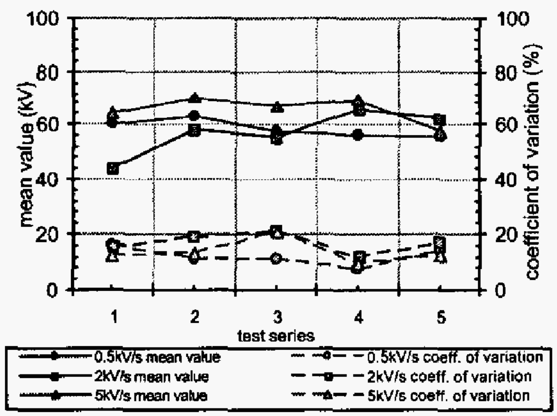

figure 3: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the medium oil and different voltage raising up velocities

Figures 2 and 3 show no significant difference for the coefficient of variation for the different voltage raising up velocities. As expected the breakdown values for the higher voltage slew rate are in most cases higher than for the lower. And also the coefficient of variation for the good oil, figure 2 are lower than for the medium oil (in accordance with figure 1).

Another aspect is the question of stirring the test oil during test procedure. According to the standard IEC 60156 both stirring and not stirring is allowed.

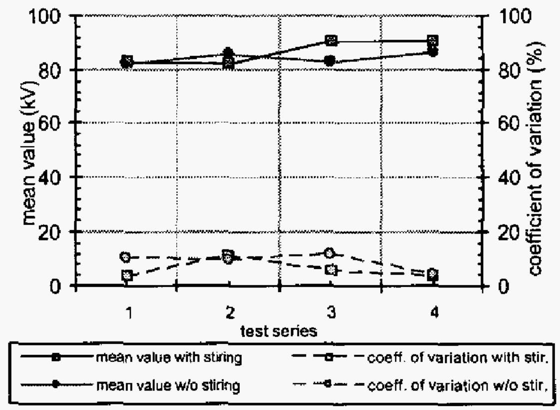

figure 4: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the good oil and with and without stirring

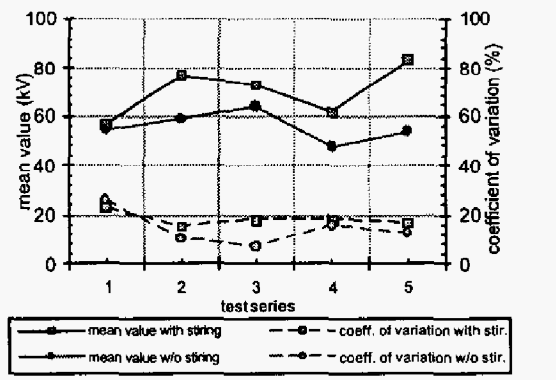

figure 5: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the medium oil and with and without stirring

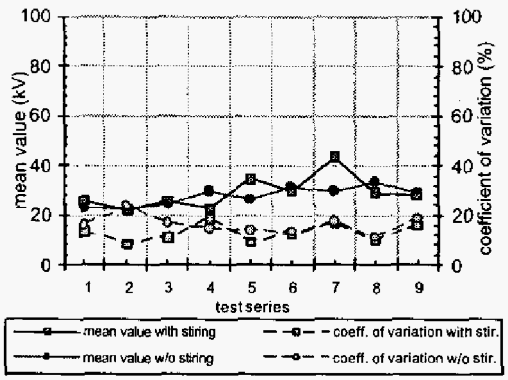

figure 6: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the bad oil and with and without stirring

As can be seen by figures 4 to 6 there is also no significant difference for the coefficient of variation for both cases with and without stirring for all three tested oil qualities. But for the medium oil there is a clear difference for the mean values. In case of stirring the mean values are higher. The reason may be that the stirrer produces a streaming which transport the particles to the edges of the test cell where they deposit. And just for the medium oil this effect has a big impact to the breakdown voltage. For the good oil with its few particles and the bad oil with its many particles the stirring seems to have no great influence on the breakdown voltage.

The next investigated parameter was the pause time between the single breakdowns of a test series. Usually a pause time of two minutes is applied. Considering that the pause time may have a great influence to the deposition of particles the biggest impact is expected for the medium quality oil.

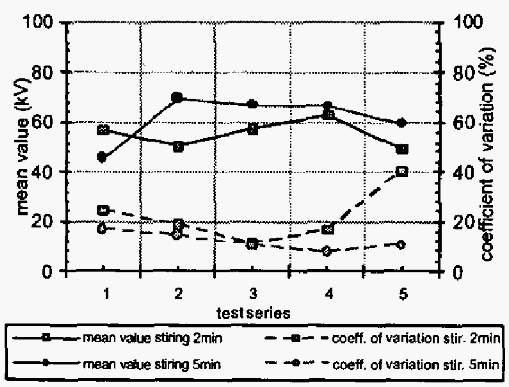

figure 7: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the medium oil and with 2 and 5 minutes pause time between the single breakdowns

Figure 7 shows slight better values for the coefficient of variation in case of five minutes pause time between the single breakdowns.

Comprising the results a changing of test procedure parameters has a more or less influence to the coefficient of variation but it does not seem to show promise for a great improvement for the coefficient of variation and for the reproducibility.

Another aspect which should be clarified is the question how the successive breakdowns of a test series interact. Each breakdown produces impurities. Part of these impurities disappear (e.g. bubbles) but part of them will remain in the test oil or on the electrodes. In a previous thesis [2] it could be shown that with a so called "cleaning voltage" after each breakdown contaminations on the electrodes from the breakdown can be detached and with a oil streaming removed between the electrodes. This technique was performed with a rogowski-formed electrode arrangement with 30 mm gap distance in a big steel vessel ($12m^3$). After each breakdown a "cleaning voltage" half the breakdown value was applied for 30 seconds and then with a oil streaming between the electrodes the contaminations were removed between the electrodes. The result was a better mean value (up to 17 percent compared without this technique) and a lower coefficient of variation.

So it was tried to apply this technique also with the standard dielectric oil tester. After each breakdown a "cleaning voltage" about half the breakdown value was applied for one minute.

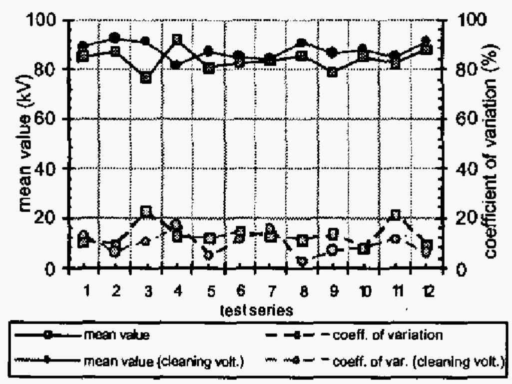

figure 8: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the good oil and with and without cleaning voltage after each breakdown, test procedure according IEC 60156

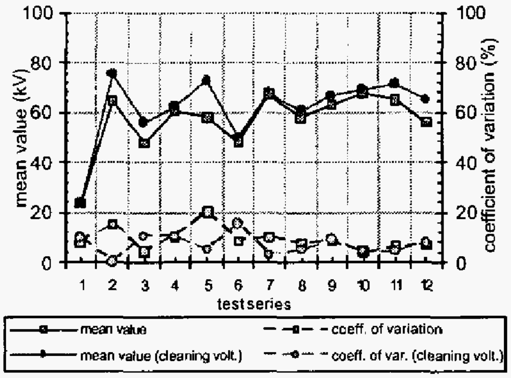

figure 9: Mean value and coefficient of variation (vertical scales) versus number of test series (horizontal scale) for the good oil and with and without cleaning voltage after each breakdown, test procedure according ASTM D1816

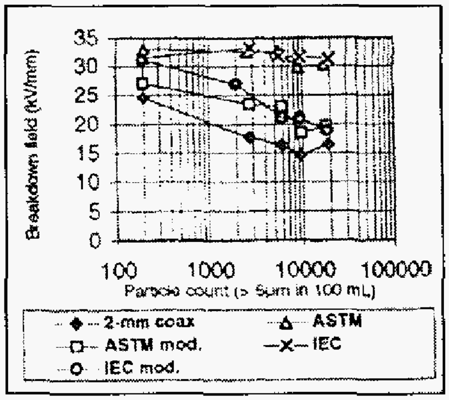

figure 10: Breakdown field (vertical scale) versus particles contamination of the oil (horizontal scale) for different breakdown test methods, according [5]

As can be seen from figure 8 and 9, both for IEC 60156 and ASTM D1816 standard the implementation of a "cleaning voltage" may reduce the coefficient of variation but only slightly. The reason therefore is that usually dielectric oil tester (like BAUR DTA 100) have a very small energy conversion between the electrodes in case of a breakdown. So only a small amount of contamination will be produced by each breakdown and a additional cleaning of the electrodes surfaces with the "cleaning voltage" is not necessary. This helps only in cases with a great energy conversion during the breakdown between the electrodes to reduce the interaction of successive breakdowns.

As can be seen from the performed tests a clearly reduction of the coefficient of variation by changing of a test procedure parameter or by introduction of a cleaning voltage does not occur. According to Sinz [3] mainly particles and moisture influence the breakdown behaviour of insulating liquids. All standard dielectric oil tester have a small oil volume between the electrodes which is tested. So these standard breakdown tester can not be enough sensitive for particles because of there statistical distribution in the test cell. According to Trinh [4] 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 electrode arrangement. There are also considerations to replace the ramp voltage by a step-by-step test voltage [3, 5]. An result of such tests is presented in the following figure 10. In this figure are standard test methods (ASTM and IEC) compared with step-by-step voltage (ASTM modified and IEC modified) and a coaxial electrode arrangement (2-mm coax). As can be seen the ASTM and IEC standard test procedures are not sufficiently sensitive to oil particle contamination.

CONCLUSION

A promising way to reduce the coefficient of variation for the oil breakdown testing is the changing of the test cell in such a way to reach bigger electrode surfaces and stressed oil volume. At the moment we are testing different arrangements with rogowski-formed electrodes. Such an arrangement meets the condition mentioned above (bigger electrode surface and stressed oil volume compared with the standard test cells) and it is also possible to reduce the amount of the testing oil needed. A second step is to raise up the test voltage application time with a step-by-step voltage. And a slightly improvement can be reached by using a cleaning voltage after each single breakdown and optimize the parameters of the test procedure.

REFERENCES

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