High-Voltage, High-Frequency dielectric properties of mineral transformer oil

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Abstract

In close proximity of voltage-source-converters and by transformer switching over longer lines, frequencies well above 50/60Hz are occurring. Their impact upon the transformer insulation system is yet unknown. For a frequency dependent analysis, a power source was built to generate signals from 10kHz up to 250kHz with a constant maximum amplitude of 100kV.
In a first step, mineral transformer-oil (Shell Diala D) as a basic insulation of most power transformers was investigated. The frequency influence on the dielectric strength and area effect was measured and compared with standard values.

1. Introduction

By intensifying the use of modern power electronics, other than the standard 50/60Hz frequency voltages are occurring. Not only in the network itself, where most of the high frequency noise is filtered and therefore not present any more, is impacted, but more intensively the switching components and directly connected equipment are more directly and gravely influenced.
The progressively extended use of power electronic components is due to the need for long range transmission capability and decentralized generation of electrical energy. In the first case, the compensation of existing lines, for example with Flexible AC Transmission Systems (FACTS) is a crucial. Especially STATCOMS (Static Synchronous Compensators) and UPFCs (Unified Power Flow Converters) are promising there. Both of them can best be built with static inverters, using turn-on and –off valves with IGBT technology. The thereby used voltage pulses are the source for the high frequent noise.
While the just mentioned compensation is needed for decentralized generations as well, the transmission of power is needed in this case as well. For example, connecting a more distant offshore wind-farm to the grid, can best be done with DC transmission in underwater cables for low losses. Static inverters are good utilized there, posing the same problems as when used in FACTS.
Filtering the high frequent noise is a viable possibility, yet producing losses there. The higher cut-off frequency can be, the fewer the losses will be.
The major problem in that quest is the lack of knowledge about what the insulation system of a power transformer will do when subjected with this continuing frequency stress. For investigations in that field, a proper power source is needed to generate discrete frequencies. As well as the frequency, the source needs to be able to reach an amplitude of up to 100kV for proper breakdown testing, taking standard test methods for oil as an example. The thereby built source, as well as results of breakdown strength for mineral transformer oil at higher frequencies will be described here.

2. High frequency, high-voltage source

For the building of a suitable power source, different basic setups can be used. In older investigations, mainly for polymeric foils, resonance transformer principles were used for test signal generation [1,2]. Derived by those sources, a series resonant circuit was built, that is capable of producing much higher amplitudes. By applying current with a frequency variable inverter, the voltage over the inductor is rising accordingly [3]. The frequency under test is directly given by the resonance frequency of the series circuit, where the sample is part of the capacitive part, despite measurement and control devices for frequency tuning.
A problem is occurring directly with the need for a fixed inductance for a desired tuning for resonance. Yet the more power is lost, the lower the reachable amplitude and with it the frequency will become mostly due to the quality factor of the inductance. Building a good reactor with low losses is therefore of central interest and considerations on the quality factor itself needs to be done.
When all of those influences are properly considered, investigations of transformer oil with a standard test setup, as suggested in IEC 156, can be done. Therefore in use is a vessel with two electrodes, radius 25mm and a gap distance of 2.5mm by “Bauer”.
For concerning other influences, like the area effect, another vessel is built and used. Since sharp edges of the electrodes are producing numerous problems with the high frequencies, test setups like ASTM can not be applied completely. Electrodes with 57mm diameter and Rogowski-profiles at the edges are used instead to account for area effects [4]. Bisections of the IEC-values to the plane electrode ones should be explainable [5] and are expected.

3. Breakdown strength of mineral transformer oil (Shell Diala D)

Numerous testing of mineral transformer oil for standard power frequencies was done over the years and is still be done for assessing the ability for use and quality testing. In depth investigations in that matter will therefore not be done again here. Main focus of material

properties and dielectric breakdown testing are higher frequencies in the kHz range. Standard tests are performed only for comparison and verification of the fundamental properties of the used oil samples.
In a first step, different gap and therefore flashover distances were tested with diverse setups. 50Hz values of oil were taken with a standard test, varying the gap, while the high frequency measurements around 130kHz were done with the plane electrodes. In all observations it has to be kept in mind, that the high frequency tests are not as easily performed than the power frequency ones. A certain capacitive load in the series resonance circuit needs to be applied, getting problematic with the standard VDE test vessel.
The expected differences in measurement because of the area effect are not matched. The bisection of values is exceeded, leaving only 1/3 of the breakdown strength in those tests. A more detailed observation about the influence of frequency and area effect is therefore crucial.
During this testing, the standard test vessel needs to be inserted in the resonance circuit. For increasing the capacity, additional ceramic capacitors were inserted in series with enough overhead, keeping in mind that the dielectric breakdown properties for high frequencies are there unknown as well.
A stabile resonance of 115kHz can be produced, yet the reachable amplitude is a little more limited, only permitting around 50kV before loosing to much energy. Thinking about the standard tests, flashover strengths for the 2.5mm gaps should be well above 50kV as it was proven, when looking at Fig.1.

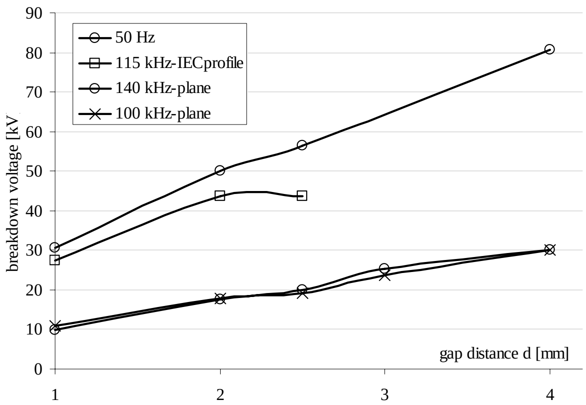

Fig.1: Comparison of the breakdown voltage of Shell Diala D with different electrode shapes and frequencies

With the plane electrodes, testing with and without the additional capacitive load was done, to see the influence of the frequency variations. When looking at the curves in Fig.1, only little variations in that matter can be seen. Yet it has to be noted, that the frequency variation of only 40kHz is not so high to expect major variations well above statistical spreading of breakdown.
More visible is the difference with a wider change of frequency. A decrease up to 10kV with the 115kHz IEC-profile tests can be seen.
With the tests done there, a clear influence of the frequency can be proven, while the area effect is nearly behaving as it should.
The gradient of the curves is another matter. Between 2 ad 3mm distance, a change is happening, which is most visible for the 115kHz IEH-profile curve. Only explanation can be the Schwaiger utilization factor for the profiles, being at 0.97 [4]. That is only for the 2.5mm gap distance. Any other will result in more inhomogeneous fields leading to changes in breakdown strength. Therefore the 2.5mm distance should be the preferred and must be investigated in more detail.
Investigating this gap distance with the calotte profile is though posing several problems and limitations to the circuit. To generate high frequencies, the capacitive load needs to be small, as well as the resistive dampening to get a high amplitude, but still a higher capacitive load produces a better resonance and is hence reducing the losses. All in all two requirements, leading in opposite directions.

3. Outlook

As it can be clearly noted by the results of the taken measurements, a large improvement of the resistance of the circuit needs to be done. Problematic is thereby the influence on the reachable amplitude and frequency of the specimen itself. This is resulting in the major decrease to about 50kV for the tests of Shell Diala D with the VDE-profile electrodes. An advancement seems to be with the impedance, where further improvements on the losses and the quality factor need to be done. Adding to that, alterations on the excitation by the frequency variable inverter should improve the reliability to do long term testing.

4. References

[1] N. Hardt, D. Koenig, “Testing of insulating materi-als at high frequencies and high voltage based on the Tesla Transformer principle”, IEEE Intl. Sym-posium on Electrical Insulation, pp.517-520, 1998

[2] F. Scheuerer, “Investigation of the insulation characteristics of solid insulation at high periodic voltage stress (in German)”, TH Darmstadt, Institute for High-Voltage Technology and Electrical Measure-ments, PhD Thesis, 1993

[3] M. Nagel, C. Herold, T. Wenzel, T. Leibfried, “Combined high frequency and high voltage insulation system investigation”, IEEE Intl. Symposium on Electrical Insulation, 2006

[4] M. Beyer, W. Boeck, K. Möller, W. Zaengl, “High-Voltage Technology” – in German, Springer, 1986

[5] Y. Kawaguchi, H. Murata, M. Ikeda, “Breakdown of transformer oil”, IEEE Trans. on Power Apparatus and Systems, Vol.91 No.1, 1972, pp.9-23