Evaluation of the dissipation factor under different environmental conditions

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Abstract: For the extension of life time and under the aspect of reliability diagnostic measurements represent a fixed part in the choice of the maintenance strategy. The diagnostic measurement can be distinguished to electrical, mechanical, chemical and thermal methods. For electric power generation, transmission and distribution systems the dielectric diagnosis is applied. Often used measurements are: insulation resistance, capacitance, dissipation factor and dielectric response methods in time and frequency domain (IRC, PDC, RVM, FDS, …). The advantage is the destruction free application with the restriction that the measurement is only off-line possible.

The dissipation factor represents an imported parameter for the condition evaluation of high voltage power equipment. The classical method to determine the dissipation factor and the tan δ tip-up is the Schering Bridge. New computer-based measuring systems operate according to the principle of a vectorial impedance measurement in the frequency range by analysing the fundamental current harmonic. Earlier investigations have shown a very good correlation between the results of both methods.

In most cases at on-site measurements different environmental conditions (primary temperature and air humidity) were given. For a condition evaluation a direct comparison of test results is necessary, due to this fact the values have to be corrected. In this paper dissipation factor measurements under different environmental conditions were carried out. In special the behaviour at different temperatures and/or air humidities were simulated in a climate chamber under high voltage. The results were evaluated and a correction factor was investigated. As test object generator bars (resin rich / mica insulation system) were used.

1 INTRODUCTION

Dielectric diagnostics observe and evaluate the effect between the electromagnetic field and the material. Insulation resistance, Capacity and dissipation factor as material and device-specific parameters give significant information about changes in the insulation medium.

The dissipation factor and/or capacity measurement are important methods for the actual condition evaluation of insulating systems especially when the dielectric properties of high voltage insulation of electric energy equipment are to be assessed. A rise of tan δ is a sign for strong worsening of the insulation condition, mostly caused by internal partial discharges.

The classical circuit for the measurement of capacity and dissipation factor is a “C / tan δ” Schering Bridge, which is an AC-balanced bridge circuit. It is characterised by the fact that the object reality is stressed closed to high voltage, which can be measured (opposite usual alternating voltage bridges). A balancing process of the bridge is required.

Recently new electronic bridges were developed where no balancing of the bridge is necessary. This capacitance and dissipation factor bridges are computer-based measuring systems which work according to the principle of a vectorial impedance measurement in the frequency range by analysing the fundamental harmonic of the currents of the test object and the reference capacitance [1]. So these bridges measure the ratio of their input currents. Thereby the dissipation factor results from the measurement from the phase shift of the current signals of a measuring branch and the reference branch.

The comparison branch consists of a reference high voltage capacitance in series with the input (low voltage terminal) of the current sensor of the electronic bridge. The measuring branch consists of the test object in series with the input of a second current sensor. The measuring principle is schematically shown in Fig. 1.

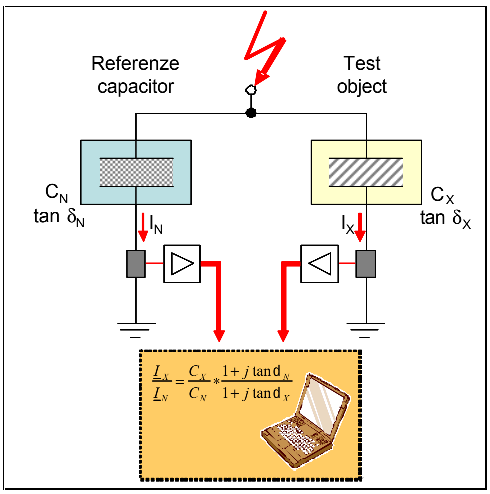

Fig. 1: Capacitance and dissipation factor measurement system at high voltage

The amplitude und phase of the currents were measured, amplified digitised and transmitted to the computer. The value of the capacitance and dissipation factor of the reference branch is necessary. With this data the dissipation factor tan δ_X and the capacitance C_X of the test object can be calculated by applying a Discrete Fourier Transformation.

2 THE DISSIPATION FACTOR AND ITS DEPENDANCE PARAMETERS

Doing measurements onsite the environmental conditions like temperature and air humidity were given and can not be influenced. The dissipation factor of electrical insulation systems is strongly dependant to these parameters and is varying with time (summer, winter or morning, afternoon) and with load (low load, full load). For this reason the following measurements should give a view how much the dissipation factor can shift due to temperature and air humidity.

3 TEST SETUP AND RESULTS

In the first test a generator bar of resin rich type was taken to measure the temperature dependence. In the second test series the behaviour of tan δ with air humidity variation was investigated. The measurements were done in a climate chamber where temperature and humidity could be defaulted, see Fig.2.

Fig. 2: Climate chamber

The preparation of the test objects can be seen in Fig. 3. All dissipation factor measurements were done with air gap and guard rings to prevent of leakage currents.

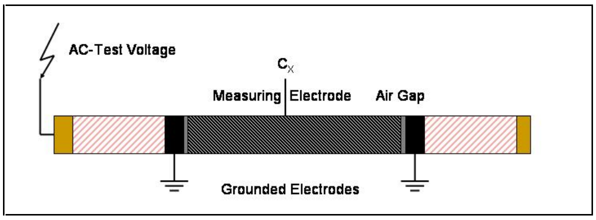

Fig. 3: Preparation of generator bars for tan δ measurements

3.1. Temperature

The permanent operating temperature was taken with an infra red measuring device. The temperature started at room temperature and was raised in steps up to the maximum rated operating temperature of 90 °C. The dissipation factor measurements were done with a LEMKE LDV6 between 20% and 120% of rated voltage at each temperature step. The results were given in Fig. 4.

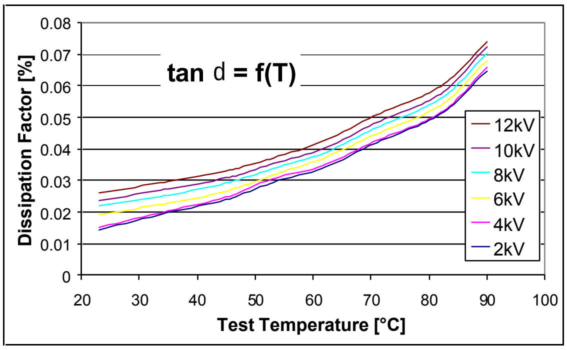

Fig. 4: Tan δ in dependence of temperature

In Fig. 4 it can be clearly seen that there is a strong temperature dependence which is not linear. Doing a mathematic approximation of the measured curves following polynomial functions are fitting very exactly the measured results:

2kV: $\tan\delta(T) = 0{,}0148 - 0{,}0001.T + 8.10^{-6}\,.\,T^2$ (1)

12kV: $\tan\delta(T) = 0{,}0307 - 0{,}0004.T + 9.10\text{-}6\,.\,T^2$ (2)

The dependence of test voltage in each temperature step was analysed and the result is shown in Fig. 5.

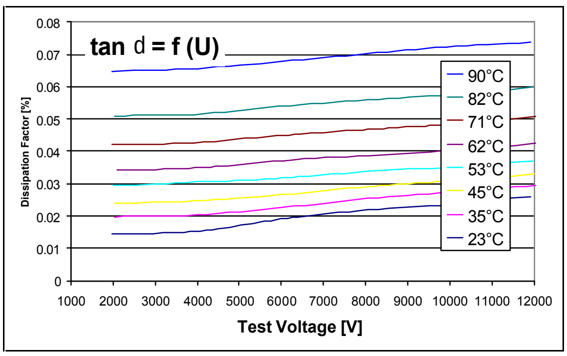

Fig. 5: Tan δ in dependence of test voltage

In Fig. 5 can be seen that the dissipation factor for each temperature corresponds to a linear function and the voltage dependence is low. For a mathematical description a linear equation can be used:

23°C: $\tan\delta(U) = 0{,}0115 + 1.10^{-6} \,.\, u$ (3)

90°C: $\tan\delta(U) = 0{,}0623 + 1.10^{-6} \,.\, u$ (4)

In literature the temperature relation of the dissipation factor is often given as an exponential function. In [2] a comprehensive literature review was done and following mathematical formulation was found:

$$\tan\delta(T_R) = \tan\delta(T_M) \,.\, (e^{-k\,(TM-TR)}) \qquad (5)$$

with T_M … temperature during measurement
T_R … reference temperature with known $\tan\delta$
k … system factor

This formula requires one known value of $\tan\delta$ and the k-factor. With a k-factor of 0,017 [2] equation 6 results. This equation is plotted in a diagram, shown in Fig. 6.

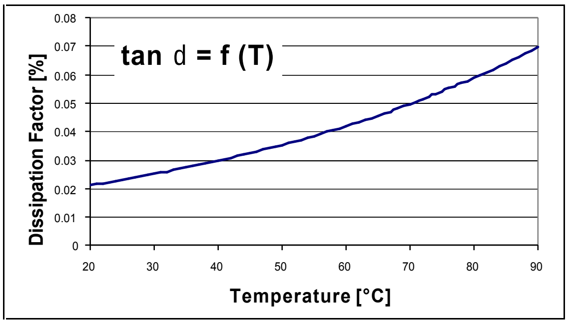

Fig. 6: Calculated $\tan\delta$ in dependence of temperature

Comparing the calculated $\tan\delta$ from equation 6 with the measured curve of Fig. 4 the best correspondence can be found for a test voltage of 6kV. The polynomial function (equations 1, 2) was transformed to an exponential function as equation 5, the result can be found in equation 7. The divergence of both equations was within very close borders and test results meet the specification from [2] exactly.

$$\tan\delta\,(\text{measured}) = 0{,}0139 \,.\, e^{0{,}0172T} \qquad (6)$$

$$\tan\delta\,(\text{calculated}) = 0{,}0151 \,.\, e^{0{,}017T} \qquad (7)$$

For condition evaluation the dissipation factor should always be taken at a reference temperature, mostly at room temperature. With this equation the dissipation factor at different temperatures can be calculated. This means that it is not necessary to wait until the machine cooled down to the reference temperature, a long period of time can be saved.

3.2. Air humidity

The second parameter of high interest is the air humidity. Air humidity can vary in dependence form air temperature very wide. Normally relative air humidity between 30 and 80 % is given, in extreme climates (desert, tropical) lower or higher values can be existent.

For this test series different types of generator bars were tested in a climate chamber, where the temperature was constant and the air humidity could be chosen between 20 % and 98 %. The measurements were only done when the state of equilibrium was reached, the climate conditions were measured with a TESTO 400 system.

The test objects were of resin rich (RR) and vacuum pressure impregnation (VPI) type, also different glass fibre tapes were used. Four test objects could be observed parallel, so for these four bars identically conditions were given. As example of evaluation some representative diagrams should be shown. In Fig. 7 the dissipation factor for a VPI system with a standard glass fibre tape was tested. The diagram shows the $\tan\delta$ for different test voltages, the results were within very close divergence.

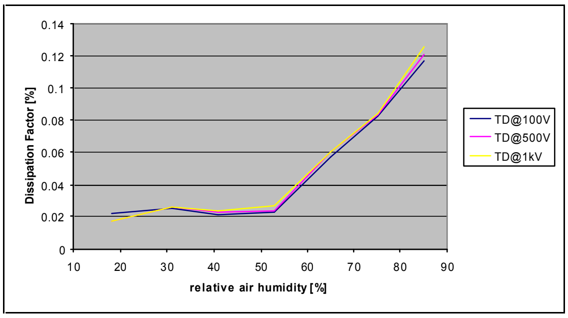

Fig. 7: Tan δ in dependence of air humidity for a VPI System

At lower air humidity the $\tan\delta$ is constant at 2%, from 53% relative humidity a sharp bend can be observed. The curve increases linear up to a $\tan\delta$ of 12% at 85% r.h. Same observations were done at the other VPI bars.

The resin rich bars showed a similar behaviour, starting with a constant value of 2% the $\tan\delta$ raises almost linear from a humidity of 59% r.h. up to 16%.

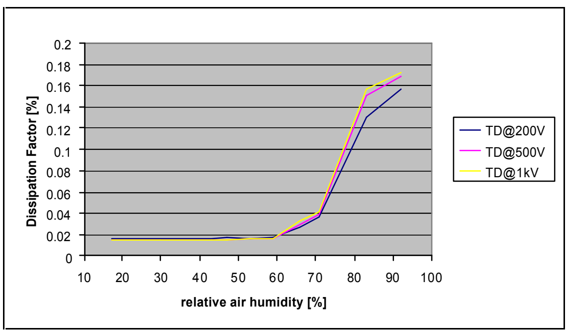

Fig. 8: Tan δ in dependence of air humidity for a RR System

To explain the bend in the curve further investigations were done. The sudden raise of the dissipation factor could be caused by a change of the insulation resistance. For this reason the surface and the volume resistance at same environmental conditions were m easured with a Megohmmeter. Surface and volume resistance can not be measured separately, the cross section and equivalent circuit can be found in Fig. 9.

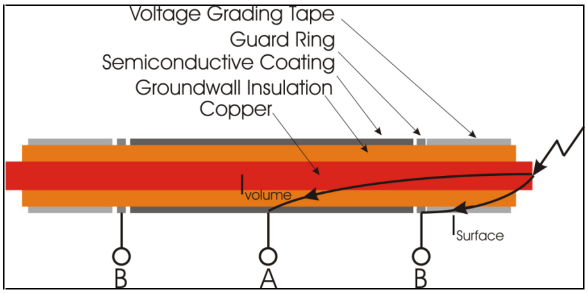

Fig. 9: Cross section of a generator bar and equivalent circuit for insulation resistance measurement

The measurements were done in two steps: first the insulation current on the semiconductive coating (A) was measured for the approximation of the volume resistance, guard rings should prevent surface currents (B grounded). And second the insulation currents between copper and guard rings (B) were measured for the approximation of surface resistance. The high voltage (5kV DC) was applied to the conductor.

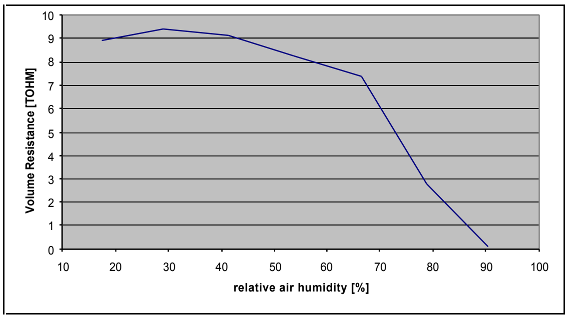

Fig. 10: Volume resistance of RR System

The volume resistance is relatively constant until 70% r.h. at 9 TOhm and then strong falling. It has to be assumed that the volume resistance does not break down, because the bars were tested up to a voltage of 10 kV AC withstand voltage. For this reason this behaviour can be reduced to following observation of the surface resistance.

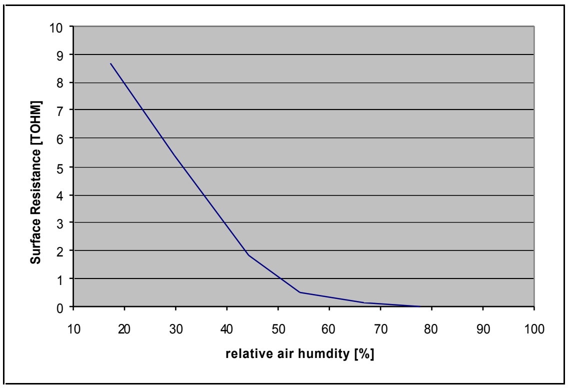

Fig. 11: Surface resistance of RR System

The surface resistance is linear decreasing until a humidity of approximately 50% is reached. Resuming the results of the insulation resistance measurement it can be pointed out that between 50 and 70 % a change in the behaviour of the insulation medium can be observed. The characteristic of the dissipation factor also changes in the same range.

4 CONCLUSIONS

Electrical insulation systems show a strong dependence to temperature and air humidity. For the behaviour of each parameter several measurements were done and mathematical models were developed.

The temperature dependence was reduced to an exponential function. With the described function it is possible to calculate the dissipation factor at any temperature if the system parameters were known.

The dependence of the dissipation factor from air humidity is more complicated and it has been shown that the surface currents over the voltage grading tape has important influence. From a relatively air humidity of 50% the surface resistance drops rapidly and influences the measurement results. As recommendation for dissipation factor measurements the influence of the air humidity should be observed carefully.

5 REFERENCES

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