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COMPARISON OF METHODS FOR THE DISSIPATION FACTOR MEASUREMENT AT PRACTICAL EXAMPLES

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Abstract: Due to the changes at the liberalized electrical energy market, the cost optimization at utilities and industries is of great company interest. The infrastructure gets increasingly aged and therefore a change in the maintenance strategies could be observed. From the former time-based strategies nowadays condition-based management strategies are more and more used. As one knows the equipment condition, optimal maintenance strategies could be developed and used. For the evaluation of the equipment condition factors like the insulation integrity or thermal aging, various monitoring-, analysis- and diagnostic methods are available. Defects in the electrical insulation material lead to a change of the physical, chemical and electrical properties of insulation materials, which causes a change of dielectric parameters, like the dissipation factor (tan delta).
For condition estimation of electrical equipment the tan delta measurement plays a big role. With the knowledge of this value a good integral estimation of the insulation condition is feasible. As this value has already been measured in the past, major empiric experiences regarding the behavior of this value and the corresponding effect in the insulation are available.
The classical method for determining the tan delta is the measurement by usage of the Schering Bridge, which is an AC-balanced bridge circuit. This balancing could be done manual or fully automatic by using a micro controller. Nowadays more and more fully unbalanced digital dissipation factor measurement instruments are used. With these instruments the vectorial current of the reference and the test branch is measured and the dissipation factor will be calculated in different ways.
In this paper the basics of these two methods (Schering Bridge and unbalanced bridge) are shortly described and possible applications are shown. For a comparison of these systems different test measurements and results are presented and discussed.

1. INTRODUCTION

Additional to high voltage tests as the withstand voltage also diagnostic tests are necessary for the evaluation of the electrical insulation quality. With these diagnostic tests closer condition estimation of equipment or of its insulation is possible. These measurements are for type, routine or end tests as well as time based condition monitoring. Furthermore for aged equipment the knowledge of the condition of the insulation is important, because the equipment should be replaced by a new one before an outage take place. Also defects could only be evaluated and analyzed by using suitable diagnostic instruments.

The proper procedures are dielectric measurement, partial discharge measurement, determination of system behavior, chemical analysis, optical and acoustic procedures and insulation material tests [3]. The dielectric measurement consists of the dissipation factor, capacitance, insulation resistance and the dielectric diagnostics (measurement of current and voltage in the time and frequency domain). In this paper the methods of dissipation factor and capacitance measurement will be described and compared in practical test measurements.

2. DISSIPATION FACTOR AND CAPACITANCE MEASUREMENT

Dissipation factor and capacitance are material and equipment depending values. By measurements the limits of values will be proven and tested. Trends could give hints for changes in the equipment or insulation material. For example an increasing capacitance of bushings or capacitors could be a result of the discharge between partial capacitances inside the equipment. An increasing dissipation factor could come from increasing humidity or structural changes caused by aging. Also the inception of high partial discharge could recognize by an increasing dissipation factor. The determination of the inception of the partial discharge by evaluation of the knee in the trend of the dissipation factor is relatively inexact und was only used in the beginning of high voltage diagnostic measurement.

3. MEASUREMENT OF DISSIPATION FACTOR AND CAPACITANCE

3.1. Influences and dimensions of tan delta

The result of the measurement is influenced by some parameters, which can be listed as follows:

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- Stray capacitance between earth and measuring object as well as earth and standard capacitor (assembling condition, type of fitting). The stray capacitances present the most important source of troubles, for this reason doubled shielded measuring cables were used.

- Surface currents (condition of surface) and leakage currents: to prevent these problems guard rings were applied if possible.

- Environmental conditions: The dissipation factor is dependant from temperature and the moisture content of the test object and the humidity of air. It is almost a exponential connection and with a correction factor the measuring result can be rectified [4].

- Magnetic fields could influence an additional current in the circuit

- Influences of the power supply, filters and non linear elements could influence the null instrument.

The dissipation factor is a quantity of material properties, which is essentially dependant of polarization behavior respectively polarization losses as well as conductivity properties. For high voltage insulation systems a quantity of about 10^{-3} (1‰) and lower describes a good dissipation factor however it is strongly dependant on which materials were used. For example synthetic resin shows a lower tan δ as asphalt or shellac insulation systems for generators.

3.2. Schering Bridge

The classic base circuit for the determination of the capacity and the dissipation factor is the C- tan delta measuring bridge of Schering. The advantage of this bridge in comparison with standard AC measuring bridges is, that the test object is stressed with high voltage, whereby the balancing elements are situated at the low voltage side. C_N is a nearly loss free capacitor e.g. a gas insulated capacitor with exactly known capacitance and dissipation factor.

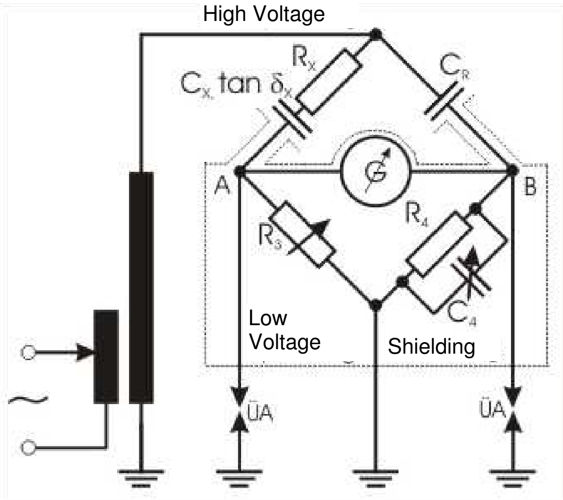

Figure 1. Principle circuit of the Schering Bridge

The test and reference object is situated to the bridge as shown in fig. 1. By using the balancing elements and the null indicator a the low voltage side the bridge is balanced. The null indicator will display the null value if the difference voltage between the two points is in value and phase null. In this case no current will flow through the null indicator. The accuracy and the sensitivity of this bridge depend mainly on the null indicator. The balancing condition can be described with following equation:

$$\frac{Z_X}{Z_3} = \frac{Z_R}{Z_4} \tag{1}$$

$$C_x = C_R \cdot \frac{R_4}{R_3} \tag{2}$$

$$\tan\delta = \omega \cdot C_X \cdot R_X = \omega \cdot C_4 \cdot R_4 \tag{3}$$

3.3. Direct Current Measurement

The principle of this method is to calculate the capacitance and the dissipation factor directly from the measured current. The current of both branches will be transformed and adapted by suitable measuring impedance. Afterwards it will digitalized by an ADC (Analog Digital Converter) and the necessary values will be calculated by a DSP (Digital Signal Processor). The results are transferred to a PC by an optical link for potential free measurement. Balancing tasks as like as at the Schering Bridge are not longer necessary. The phase shift and also the amplitude are directly computed from the digital signal. This computation is done in the DFT (Digital Fourier Transformation) area to get an higher accuracy of especially the phase angle between the two current vectors, which is equal to the tan delta (note: if the tan delta of the reference capacitor is zero).

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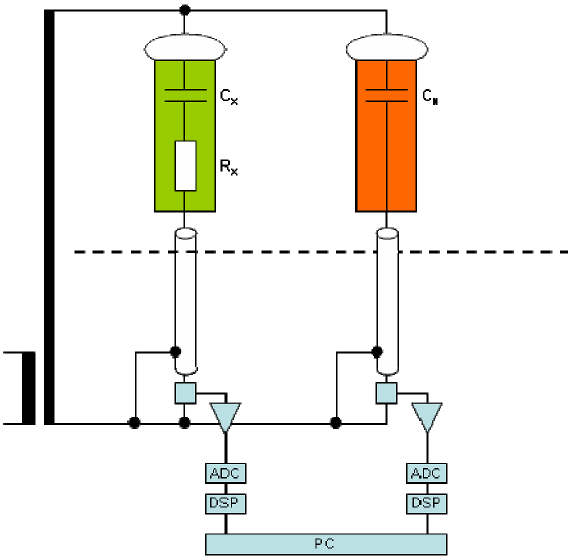

Figure 2. Principle schematic of a digital dissipation factor measurement instrument

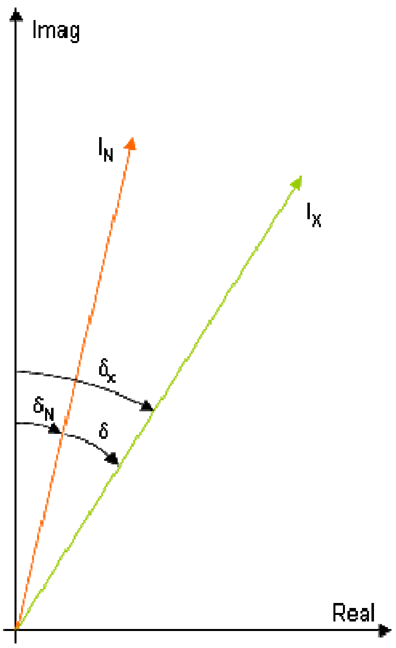

Figure 3. Vector diagram of the current components at the digital dissipation factor measuring system.

The calculation of the results at the digital dissipation factor measuring instrument is usually done in the frequency area. In fig. 3 the vector diagram of the fundamental component of the current is shown. By using the complex spectrum the absolute value and the absolute angle of each component could be computed. The difference of the absolute angle is the δ value. The dissipation factor of the reference capacitor will be noted by δ_N.

$$i_x \rightarrow I_x \quad (4)$$

$$i_N \rightarrow I_N \quad (5)$$

$$\tan\delta_X = \tan(\delta + \delta_N) \quad (6)$$

4. TEST OBJECTS AND TEST PROGRAM

For comparison the above discussed methods different machine bars are used to determine the dissipation factor and the capacitance in dependence of the voltage level. Three different types of Schering Bridges and three different digital dissipation factor measuring systems are used. The three Schering Bridges are chosen according to their null instrument. So at this comparison measurement a needle null instrument (SB1), a null instrument which shows separated the real and the imaginary part (SB2) and a oscilloscope as null instrument (SB3) are used. The digital systems had following distinguishing features: capacitive measuring impedance (MD1), resistive measuring impedance (MD2), resistive measuring impedance (MD3).

For the comparison measurements six machine bars, which are insulated with resin rich technology were tested. The terminal corona protection was guarded at the Schering bridges or directly grounded at the digital measuring systems.

4.1. Test results

With all six machine bars at all measuring systems the dissipation factor and the capacitance in dependence of the voltage was made. Due to the extensive test results only some examples of measuring analysis should be given.

1.1.1. First test object

The capacitance (Fig. 4) shows a very good accordance between the digital dissipation factor measuring systems and the Schering Bridge. The span between the capacitance results is approx. 3%.

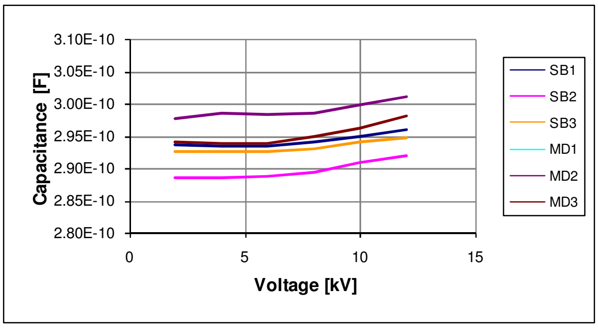

Figure 4. Capacitance results of the first measurement

The dissipation factor results (Fig. 5) shows a good accordance between SB1, SB2 and MD2, MD3. The results of SB3 differ from the other results. The envelope of the close measuring results is given by the two Schering bridges. This envelope has a difference of approx 0.3%. The measuring results of the digital dissipation factor measuring instruments are located between the results of the Schering Bridges and show a good accordance each other. During the measurement the adjustment of the Schering Bridge with the needle null instrument at voltages above the partial discharge inception voltage was a little bit delicate, because the needle moving was mainly effected at spontaneous higher partial discharges.

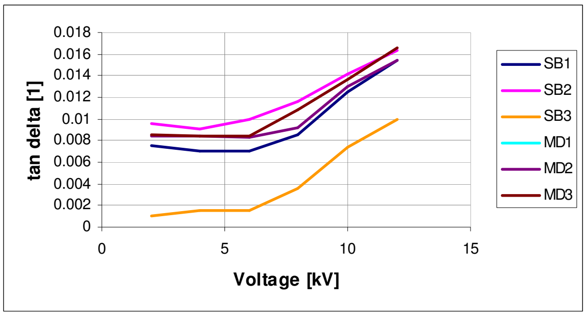

Figure 5. Dissipation factor results of the first measurement

1.1.2. Second test object

In comparison to the measurement at the first test object the capacitor results (fig. 7) don't show so a good accordance. The values of SB1 – SB3 and MD2, MD3 are really close with a maximum deviation of approx. 1.6 %. The results of the capacitance measurement of MD1 vary up to approx. 6 % in comparison to the other measuring results. This variation could occur from amplifier switching in the acquisition unit. The results of the dissipation factor show a nearly similar result as during the measurements at the first test object. The results of SB3 differ much more than the differences of the other results to each other. The maximum differences between the dissipation factor measurements are up to approx. 0.2%. Additional the dissipation factor results of SB2 are slightly different of the other measuring results. Again the bridge balancing of the Schering Bridge with the needle null instrument was a little bit delicate over the partial discharge inception voltage.

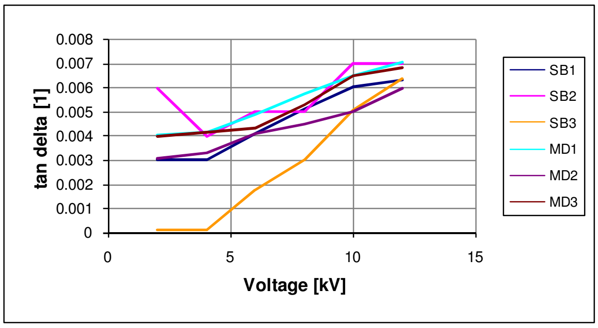

Figure 6. Dissipation factor results of the second measurement

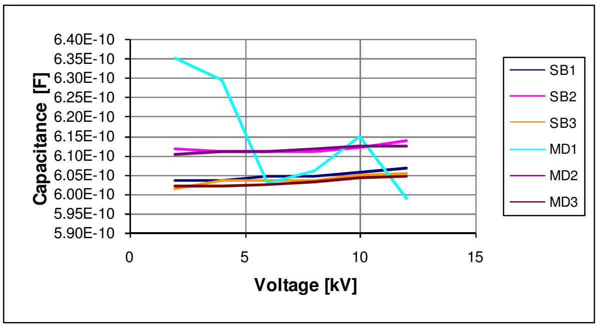

Figure 7. Capacitance results of the first measurement

5. SUMMARY

In this paper the theoretical principles of the Schering Bridge and the digital measuring instruments are in principle shown and discussed. For comparing various Schering Bridges with different null instruments and digital measuring systems were used for a test program testing various machine bars. At all measuring devices a SF_6 gas insulated capacitor was used as standard capacitor.

The results of the capacitance measurements show that there is a good correspondence between the Schering Bridge and the digital measuring instruments. The dissipation factor shows a bigger deviation between the different measuring instruments and also if the same measurement principle is used.

The accuracy of the Schering Bridge depends on their component in the bridge balancing box at the low voltage side and of the functionality of the null instrument. As discussed at the measuring examples if the null instruments are much more affected by the partial discharges a bridge balancing is more difficult and could lead to a rough estimation of the optimal justification. Modern digital Schering Bridge does the bridge balancing automatically. This could be also a problem if the null instrument is affected at high partial discharges.

The digital dissipation factor measuring systems are measuring the current of both branches directly and compute the value of the dissipation factor and the capacitance directly of the measured current. So therefore a balancing of the bridge isn't necessary and the measurement could be done in high speed (one result per current period is possible). Furthermore the current range could be increase by using current shunts. Usually the measuring results are stored at the PC.

6. AKNOWLEDGEMENT

In this paper measuring results of measurements at the Institute of High Voltage Engineering of Dresden University of Technology, Germany, and at the Federal Secondary College of Engineering Linz, Austria, are used.

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