Testing bushings with IDAX

Bushing design and failure mechanisms

Bushings are devices intended to safely transmit electrical energy through a grounded barrier. A well-known bushing application is carrying high voltage in a conductor into the grounded tank of a power transformer.

To achieve this, a design is used in which thin layers of an insulator (typically paper) together with strategically placed conductive layers are wrapped around the conductor in a manner that evenly distributes the electrical field. This assures that no flashover to the grounded parts, nor any puncture to the core conductor, occur (see Figure 1). To further increase the dielectric strength, the wrapped insulator is impregnated either with oil or resin. The most common designs are oil-impregnated paper (OIP) and resin-impregnated paper (RIP); to a lesser degree, resin-bonded paper (RBP) may be used. Recently, designs where synthetic insulation is used instead of paper, resin-impregnated synthetic (RIS) and resin-impregnated fiberglass (RIF®) have been introduced.

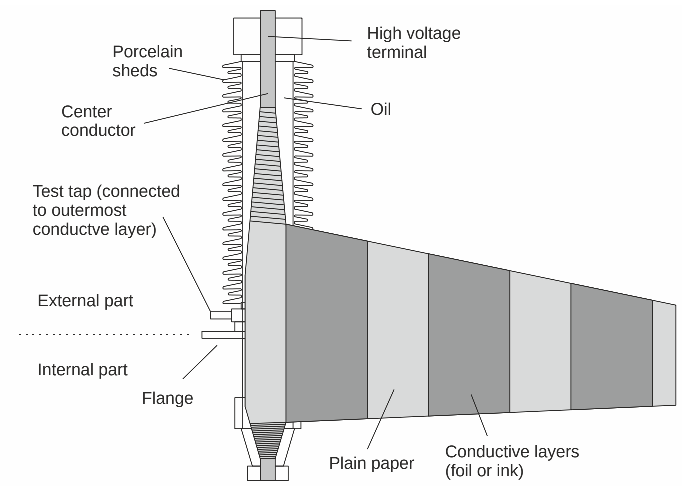


Figure 1: Principle design of a condenser bushing cut open and unwound

When put in use, the insulator of a bushing is homogenous and moisture-free but due to aging and environmental influence, the insulating properties will change. Increased moisture is caused both by ingress from the outside through leaking seals but may also result from degradation of paper due to heat or aging, processes from which water is a by-product. Furthermore, partial discharge in the bushing can result in increased levels of gas and voids in the insulation materials and can cause carbon deposits, both of which have a detrimental impact on the effectiveness of the insulation system.

If left to deteriorate, the bushing may explode with considerable violence and cause extensive damage to adjacent equipment, power outages, soil contamination, and injuries to personnel working in the proximity. It has been shown that 17 % of transformer breakdowns are caused by bushing failure, often followed by explosion, tank rupture, fire and potentially human harm. Some 30 % of all transformer fires can be attributed to bushing failure; in some markets, this figure is even as high as 70 - 80 %. It is, therefore, of utmost importance to assess the condition of bushings.

Traditional assessment of bushing condition

Dissolved gas analysis

OIP bushings can be analysed using dissolved gas analysis (DGA) which detects the gaseous by-products of partial discharge, such as methane and hydrogen. This, however, involves considerable risk of damaging the bushing, either through mechanical disruption to gaskets or by changing the internal oil level/pressure. Bushing types other than OIP cannot be analysed using DGA as there is no oil present.

Electrical tests

A common electrical test method for bushings is the measurement of capacitance and tan delta/dissipation factor at line frequency. Both parameters are listed on the nameplate of the bushing and with a relatively simple standard test, the condition of the bushing seemingly can be assessed. A C1 power factor/dissipation factor test checks the health of the bushing's main core insulation, while the C2 measurement is used to assess the bushing tap compartment's insulation plus the outermost main core insulating wraps and surrounding filler material. C1 capacitance of a bushing is generally in the 300-pF range and an increase of 1.5 to 10 % indicates a likely short-circuiting between two internal conductive layers; the resulting change in capacitance depends on the bushing design and voltage level.

For new, unused, and therefore typically moisture-free bushings, the tan delta is quite low. Bushings that have been commissioned and exposed to real world conditions may display an increase to the tan delta value, and for heavily deteriorated bushings, the tan delta value can be quite high. The exact ranges depend on the type of bushing and are described in the CIGRE technical brochure TB 445.

The temperature of a bushing affects the tan delta reading; a bushing in good condition generally has the same tan delta reading over the operating temperature range (and above), whereas for a deteriorated bushing, moisture causes the tan delta reading to rise with increasing temperature, as indicated in Figure 2.

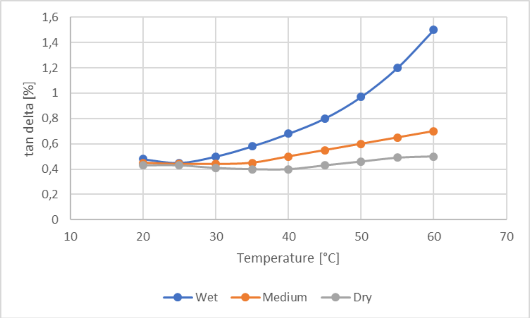


Figure 2: Illustrative temperature dependence of tan delta reading

At line frequency and 20 °C, which is the temperature all test measurements are referenced to, it is very hard to discern a deteriorated bushing from a good one. There is a noticeable increase in the tan delta value when the bushing is first commissioned but in the transition from good to bad, the tan delta value at line frequency and 20 °C may change only very little. The manufacturers of bushings supply temperature correction tables but, as they generally don't account for aging effects (mostly individual and unknown), not even the referenced values are of much use.

Testing at line frequency and normal temperatures isn't efficient in finding deteriorated bushings. In fact, testing bushings only at line frequency can mask serious errors and fail to identify bushings that need replacement, thereby possibly leading to serious and costly disruptions to service.

If it were possible to increase the temperature of a bushing and measure tan delta at many different temperatures, the test results would be more trustworthy but unfortunately that is not practicably possible.

DFR by Megger

Dielectric frequency response (DFR) is a technology pioneered for field use by Megger that assesses insulation condition by measuring tan delta at multiple frequencies.

The basis for the analysis is that the tan delta value is a function of frequency, temperature, and geometry (among others). As the geometry of a bushing under test generally remains constant, test results from the frequency domain can be transposed into the temperature domain: Measurements at reference temperature and frequencies lower than line frequency translate to line frequency and a temperature higher than reference and vice versa (see Figure 3).

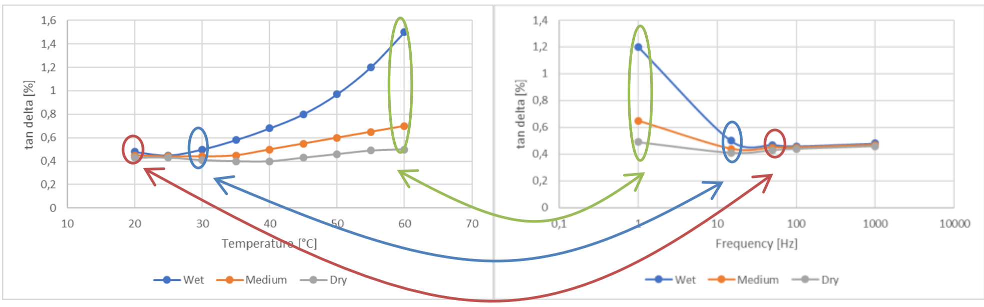


Figure 3: Illustrative relationship between temperature and frequency dependence of tan delta reading

At line frequency the following applies for the tan delta reading:

50 Hz: 15 Hz and 20 °C translates to 50 Hz and 30 °C
1 Hz and 20 °C translates to 50 Hz and 56 °C
60 Hz: 15 Hz and 20 °C translates to 60 Hz and 32 °C
1 Hz and 20 °C translates to 60 Hz and 58 °C

The tan delta frequency sweep used in DFR thus can be said to simulate a temperature sweep, and a bushing can then more easily be assessed by using information from a domain (frequency) that is easier and faster to manipulate.

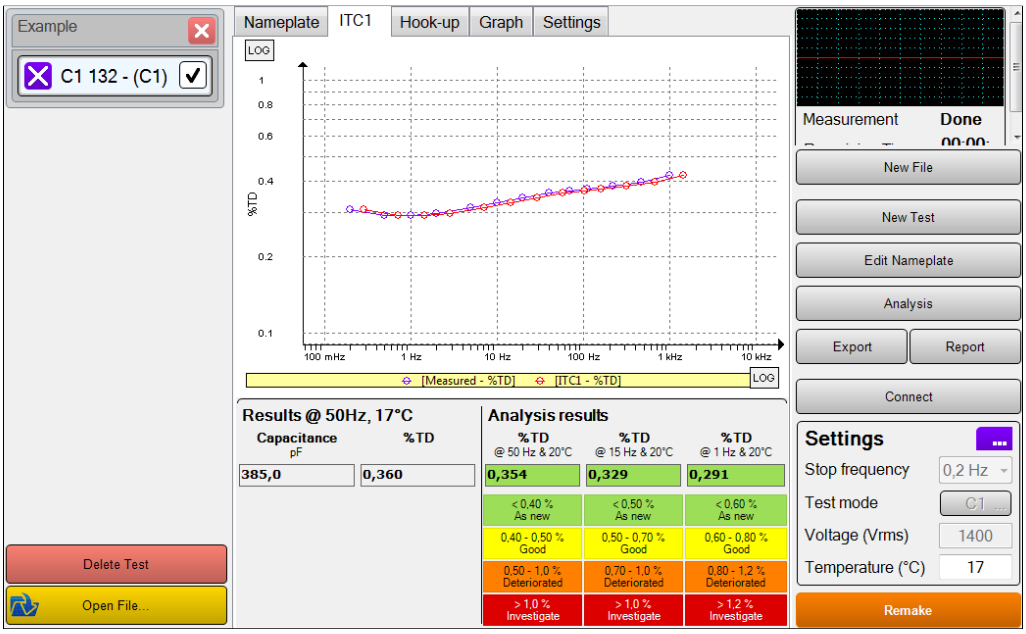
DFR by IDAX300

The IDAX300 uses the DFR technology described above for the analysis of insulation in power transformers, cables, bushings, and current transformers.

For bushings, a frequency sweep from 1 kHz to 1 Hz and assessment criteria tailored for the different types of bushings available (OIP, RIP, and RBP) are utilised. The information from the frequency sweep is temperature corrected using Megger’s proprietary Individual Temperature Correction (ITC) technology; for bushings, this method has been adapted to use only one homogenous insulation material, and this is named ITC1.

The DFR sweep stops at 1 Hz partly to save time (measurements at lower frequencies require increasingly more time) but also because all information necessary to detect aging in terms of moisture and the effects of partial discharges are detected already at and above 1 Hz. Further, frequent DFR measurements on bushings at the lowest frequencies are affected by creep currents that make interpretation more complicated.

The IDAX300 can test at voltages up to 200 V peak (140 VRMS) but for HV bushings, it is generally recommended that the VAX020 high voltage amplifiers (providing 2.0 kV peak 1.4 kV RMS) are used for improved signal-to-noise ratio.



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From the ITC corrected frequency sweep, assessment points at 1, 15, and 50 (or 60 Hz) are taken and a ‘traffic light’ colour system is used to indicate the status, which comes under the categories: “as new”, “good”, “deteriorated”, and “investigate”. For the frequencies 15 and 50 (60) Hz, the approval limits recommended in the CIGRE technical brochure TB 445 are used, and the 1 Hz approval limit is the Megger recommendation based on extensive experience with DFR. As bushing technology evolves, new types and approval criteria can be added for continuous improvement of the measurement technology.

It is important to note that DFR can not only detect increased moisture in a bushing, but it can also detect by-products from PD or even voids, carbon residues, and other inconsistencies. Any change to the homogenous insulation of a bushing is possible to detect and quantify with DFR and therefore, with the IDAX, Megger offers asset owners a great tool to assess the condition of bushings and secure the reliable and continuous operation of the electrical network.