Bushing diagnostics and conditioning
Product information
Original instruction
The information provided in this document is intended to be general and does not cover all possible applications. Any specific application not covered should be referred directly to ABB, or its authorized representative.

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Safety information

Keep this instruction available for those responsible for the installation, maintenance and operation of the bushing.

Installation, operation and maintenance of a bushing present numerous potentially unsafe conditions, including but not limited to the following:

- High pressures
- Lethal voltages
- Moving machinery
- Heavy components
- Slipping, stumbling or falling

Specialized procedures and instructions are required and must be adhered to when working on such apparatus. Failure to follow the instructions could result in severe personal injury, death and/or product or property damage.

Additionally, all applicable safety procedures – such as regional or local safety rules and regulations, safe working practices and good judgment – must be observed by personnel when installing, operating, maintaining and/or disposing of such equipment.

Safety as defined in this instruction involves two conditions:

1. Personal injury or death.
2. Product or property damage (includes damage to the bushing or other property, as well as reduced bushing life).

Safety notifications are intended to alert personnel of possible risk of personal injury, death or property damage. They have been inserted in the instructional text prior to the step in which the condition is cited.

The safety conditions are headed by one of the three hazard intensity levels that are defined as follows:

<<<WARNING>>> WARNING indicates an imminently hazardous situation, which if not avoided will result in death or serious injury. This level is to be limited to the most extreme situations.

WARNING also indicates a potentially hazardous situation, which if not avoided could result in death or serious injury.

<<<CAUTION>>> CAUTION indicates a potentially hazardous situation, which if not avoided may result in minor or moderate injury. It may also be used to alert of unsafe practices.

CAUTION may also indicate hazards solely related to property damage.

<<<INFO>>> INFO provides additional information to assist in carrying out the tasks described and to provide trouble-free operation.
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1. General guide to diagnostics and conditioning of bushings

In the following document, guidelines for diagnostics and conditioning of bushings are presented. The document is mainly based on experience from diagnostics and conditioning at ABB. Utilities and the test-equipment producers have considerable practical knowledge of the tasks described in this document. Combining the extensive knowledge possessed by utilities and test equipment producers with the product knowledge at ABB provided in this document, will result in the best possible interpretation of bushing condition.
2. Diagnostics

Several methods are available for diagnostics of high voltage bushings. In general, bushings from ABB can be considered maintenance-free. Inspection and service however, will sometime lead to bushing diagnostics.

In the following sections a guide is provided for various test methods and interpretations. Some methods for site diagnostics are not widely available on the market. They are therefore briefly described in this document.

2.1 Capacitance and tan δ measurement

**CAUTION**

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

**CAUTION**

The test tap must not be left open during service. Check that the grounding spring and the protective cap are in position after testing. The test tap design is shown in the installation and maintenance guides.

**CAUTION**

The testing equipment must not be connected to the test object before the transformer is de-energized and removed from service. All windings must be short-circuited, and windings not connected to bushings during testing must be grounded.

Prior to putting a condenser bushing in service, and when a fault is suspected, the capacitance and dissipation factor can be measured and compared with the values on the rating plate or in the routine test report. In conjunction with these tests, the electrical connection between the transformer tank and bushing flange must be checked with a continuity tester.

In this product information, the terms tangent delta, tan δ, power factor and dissipation factor can be used interchangeably.

### 2.1.1 Test equipment

**Measuring bridge:**
The measuring bridge shall be of the transformer-ratio arm type. Bridges of this type are available in several designs from various manufacturers. Examples of measuring bridges:

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doble Engineering Company</td>
<td>M2H</td>
</tr>
<tr>
<td>Tettex Instruments</td>
<td>2088</td>
</tr>
<tr>
<td>Tettex Instruments</td>
<td>2805</td>
</tr>
<tr>
<td>Multi-Amp Corporation</td>
<td>CB-100</td>
</tr>
</tbody>
</table>

Can be used under good interference conditions

For low voltage only (30 V)

Regarding the handling of the bridge, the manufacturer's manual must be consulted. For connecting the measuring lead to the test tap, a special adapter must be used for certain bushings. This device is described in the product information for each type of bushing.

**Power source:**
When measuring the dissipation factor, a power source must be available, either separate or integrated into the measuring equipment. The voltage should be adjustable up to at least 10 kV, and as much as possible, free from harmonics. To avoid problems when adjusting the null indicator, the voltage should be synchronous with the voltage in the plant.

**Measuring using digital instruments:**
If only the main capacitance C1, is to be measured, and an accuracy of ±3% is acceptable, a simpler method can be used. The method, described later in this document, only requires a power source of 400 V/2 A, two digital instruments and a 10 kW/10 W resistor.

### 2.1.2 Measuring procedure

When testing a bushing that has a capacitive test tap, i.e. practically all our bushings, it is not necessary to disconnect the top of the bushing. It is enough to open the disconnecting switch.

For the sake of safety and for reduction of the influence from winding inductance, all transformer windings must be short-circuited. Windings not connected to the tested bushing must be grounded. See Fig. 1.
The bridge must be placed on a vibration-free base. If the reference capacitor is separate, it must be placed on a dry, insulating base.

Depending on the insulation to be tested, the voltage source (test voltage) is connected via separate leads to the bushing top or the capacitive test tap. Leads for test voltage or grounding must not be common with leads for measuring. Measuring leads must be as short as possible and must not touch grounded objects. Bands or strings used for spacing must be clean and dry. This also applies to the test object. If the bushing is in its transport case, it must not be surrounded by wet filling material. The test tap must be clean and dry.

Under humid conditions, drying of the test tap may be required to obtain representative readings for tan δ over $C_2$. An air dryer may be used for drying. Cleaning of the air-side insulator housing is indispensable for correct measurement of tan δ over $C_1$.

2.1.2.1 Dissipation factor test

It is assumed that the bushing to be tested is equipped with a capacitive test tap. It is further assumed that the bridge in use can measure ungrounded, according to the UST method (Ungrounded Specimen Test). In this way, the influence from the transformer on the test results (tan δ) is minimized. The test shall be carried out at the highest possible temperature.

The ground terminal on the bridge must be connected to the ground terminal on the transformer. When measuring an unmounted bushing, the flange must be grounded. To make it possible to compare the test results with the value on the rating plate or with the routine test report supplied with each bushing, the dissipation factor must be measured at 10 kV.

The measurement procedure must begin with a low sensitivity on the bridge. The sensitivity is then gradually increased to the highest possible. In rare cases, external interference can make it difficult to set the detector to zero. If the interference cannot be eliminated, the sensitivity must be lowered. Table 1 shows the connections to be made when measuring the dissipation factor of the different insulations. Note that most bridges provide capacitance and dissipation factor in the same measuring operation.
Table 1. Connections for different measurements. Here with the nomenclature of Doble Engineering.

<table>
<thead>
<tr>
<th>Test sequence</th>
<th>Test Level</th>
<th>Voltage to HV test lead to LV test lead to Switch position</th>
<th>Measure tan δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 CL</td>
<td>CL Tap UST C1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Note A Tap</td>
<td>Tap CL Ground (GST) C1 + C2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Note A Tap</td>
<td>Tap CL Guard C2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Note A Tap</td>
<td>Tap CL UST C1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10 CL</td>
<td>CL Ground (flange) GST C1</td>
<td>The whole bushing</td>
</tr>
</tbody>
</table>

CL = Center conductor
Tap = Capacitive test tap
C1 = Main insulation
C2 = Tap insulation
UST = Ungrounded measurement (Ungrounded Specimen Test)
GST = Grounded measurement (Grounded Specimen Test)
Guard = In this position C1 is by-passed and only C2 is measured. This method is not available on all bridges.

Note A Tests 2, 3 and 4 must not be performed at a voltage higher than 500 V if the test tap insulation is delivery tested at 2 kV. If the test tap is tested at 20 kV, 2.5 kV or 5 kV may be used.

It is advisable to always perform Test 1. Test 2 should also be performed, especially if Test 1 produces a deviating result. The capacitance C2 can be calculated by subtracting C1. Tests 3 and 4 are investigative tests if the previous tests produce suspicion about a fault. The dissipation factor, measured in Test 4, should be compared with the values measured in Test 1. Test 5 together with Tests 1 and 2, are recommended for unmounted bushings.

Temperature correction:
The measured tan δ value must be temperature-corrected according to the correction factor in Table 2. GOx stands for all oil-impregnated paper condenser bushings (OIP), and GSx stands for resin-impregnated paper condenser bushings (RIP). For all bushings it must be assumed that the bushing has the same temperature as the top oil of the transformer. The test must be performed at a temperature as high as possible. Correction must be made to 20°C. The corrected dissipation factor (tan δ) is compared with the value on the rating plate or in the test report.

Table 2. Correction factors for tan δ.

<table>
<thead>
<tr>
<th>Range °C</th>
<th>OIP Correction to 20°C</th>
<th>RIP Correction to 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>0.80</td>
<td>0.76</td>
</tr>
<tr>
<td>3-7</td>
<td>0.85</td>
<td>0.81</td>
</tr>
<tr>
<td>8-12</td>
<td>0.90</td>
<td>0.87</td>
</tr>
<tr>
<td>13-17</td>
<td>0.95</td>
<td>0.93</td>
</tr>
<tr>
<td>18-22</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>23-27</td>
<td>1.05</td>
<td>1.07</td>
</tr>
<tr>
<td>28-32</td>
<td>1.10</td>
<td>1.14</td>
</tr>
<tr>
<td>33-37</td>
<td>1.15</td>
<td>1.21</td>
</tr>
<tr>
<td>38-42</td>
<td>1.20</td>
<td>1.27</td>
</tr>
<tr>
<td>43-47</td>
<td>1.25</td>
<td>1.33</td>
</tr>
<tr>
<td>48-52</td>
<td>1.30</td>
<td>1.37</td>
</tr>
<tr>
<td>53-57</td>
<td>1.34</td>
<td>1.41</td>
</tr>
<tr>
<td>58-62</td>
<td>1.35</td>
<td>1.43</td>
</tr>
<tr>
<td>63-67</td>
<td>1.35</td>
<td>1.43</td>
</tr>
<tr>
<td>68-72</td>
<td>1.30</td>
<td>1.42</td>
</tr>
<tr>
<td>73-77</td>
<td>1.25</td>
<td>1.39</td>
</tr>
<tr>
<td>78-82</td>
<td>1.20</td>
<td>1.35</td>
</tr>
<tr>
<td>83-87</td>
<td>1.10</td>
<td>1.29</td>
</tr>
</tbody>
</table>
2.1.2.2 Capacitance test

Capacitance testing using a bridge:
Fig. 2 shows the principle for capacitance measurement.

The measurement must be performed according to applicable parts of Table 1.

The transformer capacitance \( C_T \) to ground may have an influence on the measurement. In most cases this capacitance is small and normally produces only negligible error. However, a deviation between the individual bushings on all three phases may indicate influence from the transformer.

Capacitance testing using digital instruments:
This method may produce a relatively large measurement error (approx. \( \pm3\% \)) and can be used only for measuring main capacitance \( C_1 \). However, the disturbance sensitivity is less than for the bridge method, and possible influence from transformer capacitance is eliminated.

The test circuit is shown on the principal diagram in Fig. 3.

Electrical connection of the resistors \( R_2 \) must be good. The opposite terminal \( N \) of the transformer winding may be left open or grounded. If it is left open, it will take the same voltage as the top of the bushing. If grounded, the voltage source may be overloaded.

For measuring the voltage \( U_1 \) and \( U_2 \), digital instruments of the type Fluke 8020 or equivalent may be used. It should be noted that digital instruments do not work satisfactorily at temperatures below 0°C. At temperatures below 0°C, the instruments must be heated.

Increase the voltage \( U_1 \) of the voltage source until \( U_2 \) reaches at least 100 mV \( \text{rms} \). \( U_1 \) might then be between 200 and 400 V \( \text{rms} \). Read \( U_1 \) and \( U_2 \) and calculate the capacitance \( C_1 \) according to the formula below.

\[
C_1 = \frac{U_2}{U_1} \times \frac{1}{(R_2 \times 2pf)} \quad [\text{F}] \quad f = \text{frequency [Hz]}
\]

**At 50 Hz**
\[
C_1 = \frac{U_2}{U_1} \times 318 \quad [\text{pF}] \quad U_2 \quad [\text{mV}], \quad U_1 \quad [\text{V}], \quad R_2 = 10 \quad [\text{k} \Omega]
\]

**At 60 Hz**
\[
C_1 = \frac{U_2}{U_1} \times 265 \quad [\text{pF}] \quad U_2 \quad [\text{mV}], \quad U_1 \quad [\text{V}], \quad R_2 = 10 \quad [\text{k} \Omega]
\]
2.1.3 Interpretation of measurement

Comments on dissipation factor OIP bushings:
The dissipation factor is a critical property in an oil-filled condenser core bushing. It is mainly determined by the moisture level in the paper and the amount of contaminants in the insulation system. Besides this, the power factor is also very much dependent on the temperature. The principal behavior is shown in Fig. 4 for different temperatures and different moisture levels.

It is clear that the measurements at elevated temperatures are more sensitive. At 20°C, moisture levels between 0.1% to 1% show about the same dissipation factor. At an elevated temperature (90°C) they differ by a factor of 5 or more. The conclusion from this is that the important property is the dissipation factor at elevated temperatures and not the dissipation factor at 20°C. For bushings, the important factors regarding dissipation factor are:

1. A dissipation factor that is constant with regard to temperature during the entire bushing life.
2. A dissipation factor that remains constant during the entire bushing life.

For the manufacturer of a condenser core bushing, the objective is to achieve the right dissipation factor. The contribution to the dissipation factor from contaminants is avoided by proper material control as well as by stringent cleanliness requirements in the workshop. The moisture content in the bushing is determined by the winding technique and the drying process of the condenser core.

The standard procedure in making bushings is to wind the condenser core with the paper as such without drying. This produces a moisture content in the final condenser core of about 4-8%. The core is then dried in a separate heat and vacuum drying process until sufficient dryness is achieved. Since the water discharges axially, the core must be dried very carefully to ensure that no water is trapped at the center of the core. In the manufacturing of our bushings we dry the paper at the same time as we wind the condenser core. By doing this we attain a fully dry condenser core after winding and a separate drying process is no longer needed. The benefit is that no moisture is trapped at the center of the core. Together with this we also limit the drying time, which means minimum aging of the paper.

Both ANSI and IEC bushing standards require measurement of the dissipation factor at room temperature as a routine test on new bushings. This is done on all our bushings. During normal routine testing we have requirements for not only the level of the dissipation factor but also the change of voltage since this might be an important sign of contamination in the bushing. Besides this, we take a bushing from ordinary production every second month and place it in a 90°C oven. After 24 hours the dissipation factor is measured. Our internal instruction requires the value to meet the same requirements as at 20°C.

For the past 25 years, ABB has been using only pure cellulose together with aluminum foils and insulation oil in our condenser cores. Through experience, we have seen that the dissipation factor remains completely constant over the years. It is known from trade literature that different kinds of glues have caused problems with aging and with rising dissipation factor as a consequence. That we are using pure raw materials, a well controlled process and careful testing combined with our long service experience gives us the confidence to say that the tan δ level of our bushings will remain constant throughout the entire bushing life.
Comments on dissipation factor, RIP bushings:
When measuring tan δ on RIP bushings before the bushing is put into service, deviation of the tan δ value compared to the value on the marking plate might occur. The reason for this is most probably moisture penetration into the surface layer of the RIP. This can occur for instance, if the bushing is stored without its sealed protective bag, allowing air with high humidity to penetrate the outer surface layer of the bushing.

Normally the tan δ value will decrease to its initial, marking plate value if the bushing is stored indoors with controlled humidity for a week. If the transformer is energized with the bushing in service, the value will decrease within a couple of hours.

Please read and follow the suggested measures in the next section:

Measures for different temperature-corrected values, OIP and RIP bushings

0-25% increase:
The value is entered in the record. No further measures are to be taken.

25-40% increase:
The measuring circuit is checked regarding leakage and external interference. External interference can be for instance, influence from nearby current-carrying equipment and bus bars. If the difference remains, the oil level plug gasket will need to be replaced because of the moisture that has probably entered the bushing. The measured value is entered in the record, and the bushing can be put into service.

40-75% increase:
The measures as above, and the measurement itself, are repeated within one month.

More than 75% increase:
The bushing must be taken out of service. However, if the dissipation factor is less than 0.4%, the bushing may be put in service even if the increase in percentage from a low initial value is greater than 75%.

Comments on power factor measurements between the test tap and the mounting flange on OIP and RIP bushings:
Some of our customers also want to use the capacitance (C₂) and the dissipation factor over the tap insulation as a diagnostic tool. Based on our experience we strongly advise against this. There are several reasons for not using these values as diagnostic tools.

– Primarily this dissipation factor is specified to be less than 5% according to IEC 60137. This means that unless otherwise specified, no attention is given to decreasing that value to the same level as for the dissipation factor over the main insulation.

– The test tap is connected to the outer grounded layer on the condenser body. The solid layer outside the grounded layer contains an adhesive and cellulose to make the condenser body more stable. This means that the contribution to the dissipation factor from that part differs from the pure cellulose in the main insulation. It also means that this part cannot be used for diagnostic purposes because the adhesive affects the dissipation factor differently on different bushings.

It must be emphasized that under operational conditions, the outer layer must be grounded. Consequently, the insulation between the outer layer and the mounting flange is not subjected to an electrical field and thus does not cause any dielectric heat losses. It is likely that if the bushing is placed in a contaminated area, contaminants on the outside of the test tap will affect the results. Moisture around the test tap also affects the measurement.

It must be pointed out that if the test voltage (500 V if the test-tap insulation is delivery tested at 2 kV, and 2.5 kV to 5 kV if the test tap is delivery tested at 20 kV) is exceeded, partial discharge may occur in the region of the test tap, which also will affect the measurement.

– Taking all the variations above into account, tan delta over the test tap insulation varies between 0.4-3.0%.

Capacitance:
The measured capacitance C₁ is compared with the value specified on the rating plate of the bushing or with the 10 kV routine test report. If an increase of more than 3% is measured (which could indicate partial puncture) compared to the factory measured value, or an extremely low value (disruption), please contact ABB. A disruption (low C₁) may indicate transport damage, and the bushing must not be put into service. C₂ is influenced by the way the bushing is mounted on the transformer and should not be used for diagnostics.
2.2 Partial discharge measurement
Partial discharge measurement is primarily used in the routine testing method. Partial discharge may indicate external corona or internal insulation failures. Used for diagnostics on installed transformers or wall bushings, it will show the sum of the partial discharges in the bushing and transformer insulation. External discharges in switchyards may be suppressed by use of external connected measuring coils. With the use of newly developed acoustic sensors, partial discharges can be located. This method requires skilled personnel performing the measurements as well as knowledge of bushing and transformer design.

2.3 Dissolved gas analysis (DGA)

CAUTION
Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

This method of diagnostics can only be used on liquid filled bushings, e.g. GOx types. We do not normally recommend that our customers take oil samples from our bushings. The bushing is sealed and tightness-tested at the time of the manufacturing. Oil sampling entails opening of the bushing, and consequently introduces the risk of improper sealing after sampling is completed.

However, when a problem is known, such as a high power factor over C1, or high overpressure (GOEK), there might be a need for oil sampling and gas analysis. The indication of a problem could be found on bushings connected to GIS equipment (VTF) or installed on reactors that are not synchronized.

Fig. 5. Location of sampling plugs for GOA, GOB, GOC, GOE, GOH and GOG.
2.3.1 Oil sampling from bushings

Oil samples shall preferably be taken under dry weather conditions. If due to some urgent reason the sample is taken under any other condition, the following must be taken into account:

- Carefully dry and clean the area around the sampling plug before sampling.
- Protect the area around the sampling plug from rain.

When sampling, precautions should be taken to deal with any sudden release of oil.

The internal pressure of the bushing must not be altered before and after the sampling as the bushing is intended to work within a specified interval. This is satisfied if the sample is taken when the bushing’s mean temperature is between 0°C and 30°C.

The time during which the bushing is unsealed must be as short as possible. Flushing with dry air or nitrogen is normally unnecessary.

The oil sampling procedure is described in IEC 61464, Appendix A. Sampling of oil must be carried out using apparatus and methods complying with IEC 60567. It is recommended that samples be taken by qualified personnel, trained to carry out the task in accordance with IEC 60567.

Replenishment of oil is not required after a single sampling. However, after several samplings the volume can be reduced to such an extent that filling becomes necessary. It is especially important for bushing type GOEK with a small volume of oil. The new oil must comply with IEC 60296, Class II, degassed transformer oil, and be clean and dry.

The old gasket must always be replaced with a new one when the bushing is sealed after sampling.

---

Sampling procedure for GOB, GOH and old GOE without a sampling valve on the flange

**WARNING**

It can be high gas pressure inside of the bushing, so open the plug very carefully. Do not open it fully until the pressure is equalized as there is a risk that the plug can fly away if there is an over-pressure in the bushing. Precautions must also be taken as the gas in the bushing can be very flammable and explosive.

The sample is taken from a plug at the top of the bushing, preferably using a syringe with a rubber hose connected to the top of the syringe.

The location of the sampling plug is shown in Fig. 5. The dimension of the gasket is shown in Table 3. The gasket material must be nitrile rubber (resistant to transformer oil), with a hardness of 70 shore.

The tightening torque for the M8 sealing plug on GOB, GOE and GOH is 20 Nm. The tightening torque for the M16 sealing plug on GOE is 50 Nm.

Table 3. Dimensions of gaskets.

<table>
<thead>
<tr>
<th>Gasket</th>
<th>d (mm)</th>
<th>D (mm)</th>
<th>T (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M8</td>
<td>8</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>M16</td>
<td>14</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>5/8&quot;</td>
<td>14</td>
<td>35</td>
<td>4</td>
</tr>
</tbody>
</table>
Sampling procedure for GOEK, GOM, GOE and other bushings with sampling valve on flange

Connect the end of the hose to a suitable nipple and then connect the nipple to the valve on the flange. The valve thread is (R ¾") BSPT ¾" or R ½" (GOEK). Extract the oil. Depending on the temperature, the pressure inside the bushing might be above or below atmospheric pressure.

During the sampling process, it is very important to avoid any bubbles from entering the bushing. The bushing can be energized after one hour if it is ensured that no bubbles have entered the bushing during sample procedure. The bushing is otherwise energized after 12 hours.

Sampling procedure for GOA, GOC and GOG

On GOA, GOC and GOG bushings, the oil samples are taken from the hole for the oil level plug on the top housing according to Fig. 5. If the bushing is vertically mounted, the oil level is correct when even with the plug at 20°C. The sample is extracted with a syringe. If the oil temperature is slightly higher than 20°C, the oil level will be above the level of the plug. In such a case the hose on the syringe should be equipped with nipple according to Fig. 9. The oil plug is removed and the hose with the nipple is immediately attached. If the temperature is slightly below 20°C, the oil level will be below the plug and the sample is extracted according to Fig. 10. The tightening torque for the 5/8" sealing plug is 50 Nm.

2.3.2 Interpretation of analysis

Interpretation of the analysis is performed according to IEC 61464. If there are any questions, ABB can assist with the evaluation.
2.4 Moisture analysis

**CAUTION**

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

This method of diagnostics can only be used on liquid filled bushings, e.g., GOx types. We do not normally recommend that our customers take oil samples from our bushings. The bushing is sealed and tightness-tested at the time of the manufacturing. Oil sampling entails opening of the bushing, and consequently introduces the risk of improper sealing after sampling is completed.

However, when a problem is known, such as a high power factor over C, there might be a need for oil sampling and moisture analysis.

Attaining the proper moisture content in bushing oil is sometimes difficult. Compared to a transformer, a bushing has a much higher ratio of paper to oil. This means that regardless of the bushing manufacturing process, there will always be much more moisture in the paper than in the oil. (In paper the moisture is measured as a percentage, whereas in oil the moisture content is measured in ppm, "parts per million".)

Depending on the temperature of the bushing, the moisture will migrate either from the paper to the oil or from the oil to the paper in accordance with the equilibrium curves (piper diagrams) for oil-paper moisture. Due to this, a bushing will always show a much higher moisture content in the oil after a certain time in service at a high temperature. Consequently, to obtain a proper value, the oil sample should be taken at least 48 hours after the entire bushing has reached room temperature.

**2.4.1 Oil sampling from bushings**

Oil sampling is performed much the same as for DGA analysis.

**2.4.2 Interpretation of analysis**

The bushing is delivered from ABB with a moisture content in the insulating oil of maximum 3 ppm. If considerably higher concentrations are measured the sealing system on the bushing is damaged.

At a concentration of >10 ppm a tan δ measurement must be performed according to Section 2.1.2. Measures must be taken according to the recommendation in Section 2.1.3. At a concentration of > 20 ppm the bushing must be removed from service.

2.5 Oil leakage inspection

**CAUTION**

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

A visual inspection for leakage may be performed during normal station checks.

2.6 Insulator inspection

**2.6.1 Hydrophobicity classification**

**CAUTION**

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

The following information for hydrophobicity classification is provided with minor changes from STRI AB, Guide 1, 92/1 Hydrophobicity Classification Guide. STRI AB is an independent company for development and testing in the field of electrical power transmission and distribution. STRI is jointly owned by ABB, Svenska Kraftnät (the Swedish National Grid), Vattenfall AB and Statnett SF (the Norwegian National Grid).

**2.6.1.1 General information**

The superior electrical performance of composite insulators and coated insulators stems from the hydrophobicity (water-repellency) of their surfaces. The hydrophobicity will change with time due to exposure to the outdoor environment and partial discharges (corona).

Seven classes of the hydrophobicity (HC 1-7) have been defined. HC 1 corresponds to a completely hydrophobic (water-repellent) surface and HC 7 to a completely hydrophilic (easily wetted) surface.

These classes provide a coarse value of the wetting status and are particularly suitable for a fast and easy check of insulators in the field.

**2.6.1.2 Test equipment**

The only equipment needed is a common spray bottle that can produce a fine mist. Fill the spray bottle with tap water. The water must not contain any chemicals, such as detergents, tensides or solvents.

Complementary equipment that could facilitate the assessment are a magnification glass, a lamp and a measuring tape.
2.6.1.3 Test procedure
The test area should be 50-100 cm². If this requirement cannot be met this should be noted in the test report.

Spray 1-2 times per second from a distance of 25 ± 10 cm. Spraying shall continue for 20-30 seconds. The assessment of the hydrophobicity class must be performed within 10 seconds after completion of spraying.

Hydrophobicity classification can be difficult to perform in high winds. If this or other difficulties are present, this should be noted in the test report.

2.6.1.4 Classification of hydrophobicity
The actual wetting appearance on the insulator must be identified with one of the seven hydrophobicity classes (HC), which is a value between 1 and 7. The criteria for the different classes are shown in Table 4. Photos of typical surfaces with different wetting properties are shown in Fig. 12.

The contact angle ($\theta$) between the water droplets and the surface must also be taken into account. The contact angle is defined in Fig. 11. There are two different contact angles, the advancing contact angle ($\theta_a$) and the receding contact angle ($\theta_r$). A droplet exhibits these angles on an inclined surface.

The receding angle is the most important when the wetting properties of an insulator are to be evaluated. The inclination angle of the surface affects the $\theta_r$.

The contact angle is defined in Fig. 11. There are two different contact angles, the advancing contact angle ($\theta_a$) and the receding contact angle ($\theta_r$). A droplet exhibits these angles on an inclined surface.

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Table 4. Criteria for hydrophobicity classification (HC).

<table>
<thead>
<tr>
<th>HC</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Only discrete droplets are formed. $\theta_r &gt; 80^\circ$ or larger for the majority of droplets.</td>
</tr>
<tr>
<td>2</td>
<td>Only discrete droplets are formed. 50° &lt; $\theta_r$ &lt; 80° for the majority of droplets.</td>
</tr>
<tr>
<td>3</td>
<td>Only discrete droplets are formed. 20° &lt; $\theta_r$ &lt; 50° for the majority of droplets. They are usually no longer circular.</td>
</tr>
<tr>
<td>4</td>
<td>Both discrete droplets and wetted traces from the water runnels are observed (i.e. $\theta_r = 0^\circ$). Completely wetted areas &lt; 2 cm². Together they cover &lt; 90% of the tested area.</td>
</tr>
<tr>
<td>5</td>
<td>Some completely wetted areas &gt; 2 cm², which cover &lt; 90% of the tested area.</td>
</tr>
<tr>
<td>6</td>
<td>Wetted areas cover &gt; 90%, i.e. small unwetted areas (spots/traces) are still observed.</td>
</tr>
<tr>
<td>7</td>
<td>Continuous water film over the entire tested area.</td>
</tr>
</tbody>
</table>

Test report:
The test report shall include the following information:

General information
- Location, station, line
- Date and time of the assessment
- Weather conditions (temperature, wind, precipitation)
- Performed by

Test object
- Type of insulator
- Identity (item no., position)
- Voltage
- Date of installation or application of coating (type of coating)
- Mounting angle (vertical, horizontal, inclined x deg)

Hydrophobicity class
- HC for different positions: along the insulator (shed no.), along the surface within each shed sequence (top, bottom, core, large shed, small shed, etc.)
- Difference (if any) around the insulator circumference in comparison to values from previous measurements.

2.6.2 Sample collection and status determination of silicone grease on porcelain insulators

CAUTION
Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

This instruction describes the procedure for sample collection of silicone grease on insulators.
Fig. 12. Examples of typical surfaces with HC from 1 to 6 (natural size).
2.6.2.1 Test equipment

The following materials are required when sampling silicone:
- Three copper foils, measuring 15 x 70 x (0.2  0.3) mm
- Screwcapped glass jar, size sufficient to embrace the foils
- Disposable gloves

Use the gloves when handling the sampling equipment.

2.6.2.2 Sample collection

Procedure
- Use the disposable gloves and take a foil from the jar.
- The grease sample must be collected on the foil by scratching along the porcelain surface. This shall be performed in a way that leaves as little of the grease layer on the insulator as possible.
- The total sample collection area should not be less than 15 cm² and the total amount of collected grease should not be less than 1 g (~1 cm²). To meet these demands it may be necessary to use at least all three foils.
- Place the foil(s) with the grease in the jar and close the cap.
- Measure the sample collection area.
- Change gloves for the next sample collection.
- If possible, take photos of a typical sample collection area before and after the sample collection is performed.

Sample marking

Each glass jar with a grease sample should be marked with the sample collection date, type of insulator and designation, sample collection position and sample collection area. Sample marking can also be performed by giving the glass jars individual numbers and corresponding identification on a separate list.

The description of the position should be in the following order:

Position:
- Top     Corresponds to the position along the insulator
- 12 o’clock    Corresponds to the position along the insulator
- SW          Corresponds to the point on the compass (for transducers)
- Upper      Corresponds to the position on the shed

The positions for wall bushings are also shown in Fig. 13.

Packing

Securely place the glass jars in a box with the caps upwards. Mark the box “This side up”.

Send the sample for analysis to ABB.
2.6.3 Instruction for thickness measurement of silicone grease on porcelain insulators

CAUTION

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

This instruction describes the procedure for thickness measurements of silicone grease on insulators.

2.6.3.1 Test equipment

The equipment needed for measuring thickness consists of one squared copper strip measuring 15 x 200 x 2 mm and one measuring cup with a volume of 5 ml. (A tea spoon with a well defined volume.)

2.6.3.2 Measuring procedure

Use the 15 mm side of the copper strip as a scraper. Collect the grease by scraping from the outer tip of the large shed to the inner valley in a strict radial direction as described in Fig. 14.

No grease may be visible after the copper strip scraper has passed the surface.

Place the scraped grease in the measuring cup.

Repeat the scraping procedure until the cup is full (5 ml).

The coating thickness is calculated by using the number of times the scraping procedure is performed.

In Table 5 the coating thickness is listed in relation to the number of scrapings. This table is valid for a short long 95/95 profile only, which is used on ABB pole wall bushings at Radisson, Nicolet and Sandy Pond.

Table 5. Conversion, number of scrapings to coating thickness.

<table>
<thead>
<tr>
<th>Number of scrapings</th>
<th>Coating thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.1</td>
</tr>
<tr>
<td>4</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>0.68</td>
</tr>
<tr>
<td>6</td>
<td>0.57</td>
</tr>
<tr>
<td>7</td>
<td>0.49</td>
</tr>
<tr>
<td>8</td>
<td>0.42</td>
</tr>
<tr>
<td>9</td>
<td>0.38</td>
</tr>
<tr>
<td>11</td>
<td>0.31</td>
</tr>
</tbody>
</table>

For other shed profiles, please contact ABB for advice.

2.7 Thermovision

Using an IR-sensitive camera, see Fig. 15, hotspots on the bushing surface can be detected. At maximum rated current, the bushing’s outer terminal reaches a temperature of about 35-45°C higher than the ambient air. Significantly higher temperatures, especially with lower current loading, can indicate bad connections.

2.8 De-polymerization analysis

De-polymerization analysis is a method of determining aging of cellulose in OIP bushings. The method requires that the bushing be disassembled and a paper sample taken from the condenser body.

![Fig. 15. Measurement indicating poor current path between bushing inner and outer terminals.](image)
3. Conditioning

In general bushings delivered from ABB can be considered as maintenance-free. However, inspection and service experience will in some cases lead to conditioning of bushings.

In the following sections, cleaning of insulators and silicone grease treatment are described. There are several other possible conditioning methods for bushings, such as painting, RTV coating, preparation with shed extenders (booster sheds), etc., not covered in this document. For guidance, please contact ABB.

3.1 Cleaning of insulators

CAUTION

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

Avoid solvent coming in contact with the gasket and porcelain joints.

Under conditions with extreme pollution it may be necessary to clean the insulator surface.

3.1.1 Porcelain insulators
Clean the porcelain insulator with a water jet or wipe with a moist cloth. If necessary, ethyl alcohol or ethyl acetate may be used.

3.1.2 Silicone rubber insulators
Clean the silicone insulator with a water jet or wipe with a moist cloth. If necessary, ethyl alcohol or ethyl acetate may be used. 1,1,1,-Trichloroethane or methylchloride are not recommended due to their possibly harmful and environmentally detrimental properties.

3.2 Silicone grease treatment of wall bushings

The following method was primary developed for grease application on wall bushings in DC operation where uneven wetting may be problem for bushing operation. However, the treatment may also be useful at installations close to the sea where salty winds may cause external corona even if extreme arcing/creepage distances are specified.

CAUTION

Ensure that the transformer is de-energized and out of service before any work is performed on the bushing.

CAUTION

Care should be taken to avoid contact with the skin, face and eyes.

Contamination of the eyes should be treated by flushing with clean water.

Contamination of the skin should be treated by washing with soap and water.

If solvent is used, wear goggles, protective gloves, and if appropriate, a respiratory mask. Precautions must be taken in accordance with the manufacturer’s recommendations.

CAUTION

When a skylift is used, local safety recommendations must be followed. Move the skylift carefully when working close to the insulators to avoid damage to the porcelains.

Finally, care should be taken not to leave traces of grease on floor, ladders, scaffoldings or supporting structures, as the grease makes them slippery and dangerous for personnel.
**Assessment of hydrophobicity**

This check should be performed in accordance with the method described in the section Hydrophobicity classification.

Twelve test areas on each insulator must be selected as follows:

Three positions along the bushing, top (energized end), middle and the base end of the insulator. At each position the hydrophobicity is checked on the upper and under side of the larger shed for both the upper (12 o’clock) and under (6 o’clock) side of the bushing.

If the hydrophobicity is of Class 4 or higher, a check of hydrophobicity must also be performed on the adjacent shed. This provides an assessment as to whether the reduction in hydrophobicity is local or extends over the entire insulator.

Photo documentation of representative surfaces during the test is desirable and should always be performed for surfaces with the classification 4 or higher.

Renewal of silicone grease is recommended as soon as possible if the surface of Class 6 or 7 exceeds 50% of the total creepage length of the insulator.

**Visual inspection**

Visual inspection shall take into consideration changes in the form of cracks, blisters, peeling, sliding and erosion.

The inspection should be performed on all silicone-greased insulators once a year. The inspections should be recorded on a form. If any changes are observed, photo documentation is desirable.

**Additional requirements for recoating interval of more than two years**

After two years in service, the insulator shall have a surface less than Class 4 for 50% of the total creepage length of the insulator and less than Class 5 for 25% of the total creepage length of the insulator. No more than one of twelve isolated test areas from the test described above are of Class 6 or 7.

**Removability**

Remove the grease on a half turn on one shed sequence using the scraper 9779 023A. The time required to do this, and to fulfill the criteria under the heading Pretreatment before reapplication in the section Precautions upon application and reapplication, must not be more than 30 seconds.
Electrical activity
The bushing shall be observed using a pair of binoculars under rainy and foggy conditions regarding partial discharges. No activity is permitted.

Chemical analysis
A sample collection of silicone grease should be performed according to the section above, Sample collection and status determination of silicone grease on porcelain insulators.

One bushing is selected in each station. Three samples shall be taken. Two of the samples shall be taken in the area where the highest hydrophobicity class is measured. The third sample shall be taken in the area where the lowest hydrophobicity class is measured.

The samples may be sent to ABB for analysis regarding molecular weight distributions, contamination and silicone oil content. Changes in the chemical composition will provide further information about the aging status of the grease.

3.2.3 Precautions during application and reapplication
Pretreatment before the first application
Before the silicone grease is applied for the first time, the porcelain surface must be thoroughly cleaned by rinsing with plenty of water followed by hand wiping of the insulator with an alkaline detergent solution and finally rinsing the insulator with plenty of water. If the insulator is light polluted, cleaning with just water and rags is sufficient.

Pretreatment before reapplication
Before the application of a new layer of grease can begin, the old layer must be removed. Removal is accomplished using specially shaped handheld scrapers (provided by ABB, No. 9779 023A). Most of the visibly polluted grease must be removed. At least 90% of the insulator surface must be scraped. Traces of old grease left on the surface are acceptable as it helps to ensure good contact between the new layer and the insulator surface.

If hand wiping is employed, the following solvents are recommended in order to soften the polluted layer: Isopropanol and xylene.

3.2.4 Application
Ambient conditions
Because the insulator surface must be dry when the grease is applied, application must either be performed when the weather is dry or when there is protection against rain. For practical reasons application shall not be performed at a temperature below 10°C or with a wind speed higher than 10 meter/second.

Thickness
The target for average thickness is 0.30-0.90 mm. The function of the grease is not in any way sensitive to unevenness in the coating. After a certain time in service, bare spots on the insulators will be coated by self-spreading silicone oils migrating from more grease rich areas.

Isolated areas with grease thicknesses up to 4 mm are permitted, as well as isolated areas with coating thicknesses below 0.05 mm. The area of each such surface must be limited to 100 cm².

The thickness of the coating must be checked according to the section Instruction for thickness measurement of silicone grease on porcelain insulators.

Procedure
Apply the grease by hand using a painter’s glove.

To minimize the time for application, it is advisable to use two skylifts with two workers in each skylift.