DELTA 4000

12 kV Insulation Diagnostic System

Reference Manual
Applications Guide

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Reference Manual
Applications Guide

Megger Sweden AB is certified according to ISO 9001 and 14001.

SWEDEN

Megger Sweden AB
Eldarvägen 4
Box 2970
SE-187 29 TÄBY
Sweden

T +46 8 510 195 00
F +46 8 510 195 95
seinfo@megger.com
www.megger.comEDEN

UNITED STATES

Megger
2621 Van Buren Avenue
Norristown, PA 19403

USA

T +1 610 676 8500
F +1 610 676 8610
VFCustomerSupport@megger.com
www.megger.com

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Introduction

General

The intention of this reference-application manual is to guide the operator in the appropriate method of making capacitance and dissipation factor/power factor measurements on power apparatus and to assist in the interpretation of test results obtained. It is not a complete step-by-step procedure for performing tests.

Before performing any test with this apparatus, read the user manual and observe all safety precautions indicated.

Principle of operation

Most physical test objects can be accurately represented as a two or three-terminal network. An example of a two-terminal capacitor is an apparatus bushing without any test tap. The center conductor is one terminal and the mounting flange (ground) is the second terminal. An example of a three-terminal capacitor is an apparatus bushing which has a power factor or capacitance tap. The center conductor is one terminal, the tap is the second terminal, and the mounting flange (ground) is the third terminal.

It is possible to have a complex insulation system that has four or more terminals. A direct measurement of any capacitance component in a complex system can be made with this test set since it has the capability for measuring both ungrounded and grounded specimens.

Figure 1 shows a simplified measuring circuit diagram of the DELTA 4000 test set measuring a two-winding transformer in UST test mode. The test voltage is connected to the HV terminal and the current is measured at the LV terminal. Voltage and current are accurately measured in amplitude and phase and CHL capacitance, dissipation factor, power loss etc are calculated and displayed.

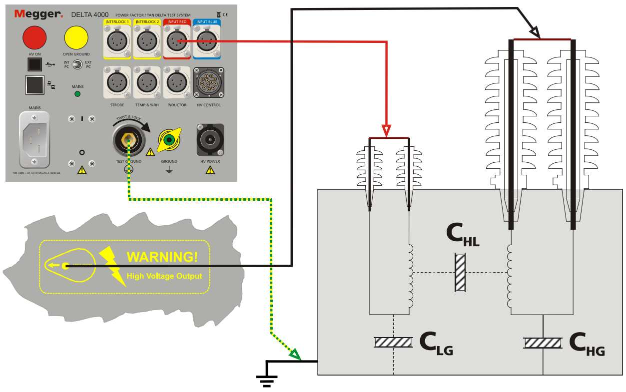


Figure 1: UST-R test setup for a 2-w transformer

Dissipation factor measurements can generally be performed with two different configurations, UST (Ungrounded Specimen Test) where the ground act as natural guard or GST (Grounded Specimen Test) with or without guard. Figure 2 shows a guarded UST measurement. The current flowing through CHL is measured but the current paths through CH and CL is guarded/grounded and not measured. Figure 3 shows a guarded GST measurement where the CH current to ground is measured but the current through CHL is guarded and measured.

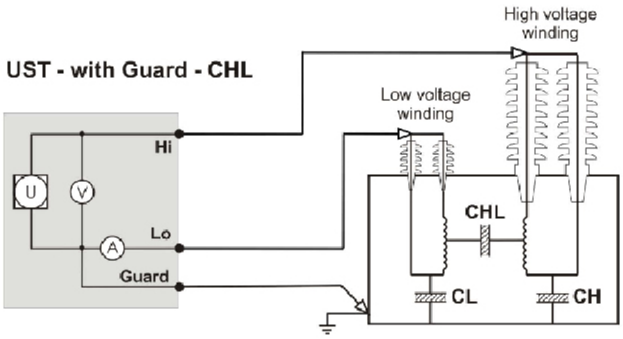


Figure 2: UST connection for measuring CHL in a two-winding transformer

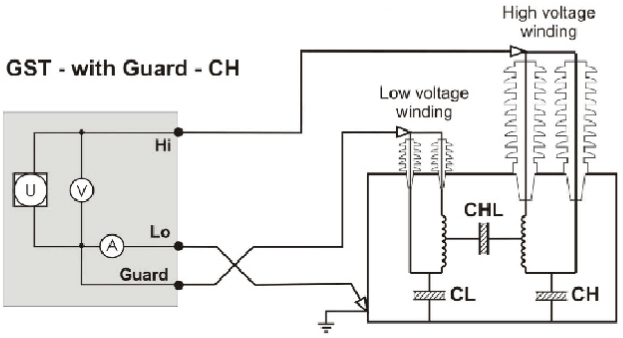


Figure 3: GST connection for measuring CH in a two-winding transformer

Current, capacitance and dissipation factor relationship

In an ideal insulation system connected to an alternating voltage source, the capacitance current I_c and the voltage are in perfect quadrature with the current leading. In addition to the capacitance current, there appears in practice a loss current I_r in phase with the voltage as shown in Figure 5.

The current taken by an ideal insulation (no losses, $I_r = 0$) is a pure capacitive current leading the voltage by 90° ($\theta = 90°$). In practice, no insulation is perfect but has a certain amount of loss and the total current I leads the voltage by a phase angle θ ($\theta < 90°$). It is more convenient to use the dielectric-loss angle δ, where $\delta = (90° - \theta)$. For low power factor insulation I_c and I are substantially of the same magnitude since the loss component I_r is very small.

The power factor is defined as:

$$\textbf{Power factor} = \cos\Theta = \sin\delta = \frac{Ir}{I}$$

and the dissipation factor is defined as:

$$\textbf{Dissipation factor} = \cot\Theta = \tan\delta = \frac{Ir}{Ic}$$

$$PF = \frac{DF}{\sqrt{1+DF^2}}$$

$$DF = \frac{PF}{\sqrt{1-PF^2}}$$

The DELTA 4000 is able to display either dissipation factor or power factor based on user's choice.

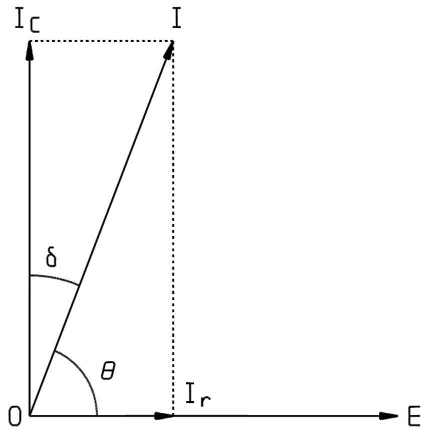


Figure 5: Vector diagram insulation system

In cases where angle δ is very small, sin δ practically equals tan δ. For example, at power factor values less than 10 percent the difference will be less than 0.5 percent of reading while for power factor values less than 20 percent the difference will be less than 2 percent of reading.

The value of I_c will be within 99.5 percent of the value I for power factor (sin δ) values up to 10 percent and within 98 percent for power factor values up to 20 percent.

Connections for UST/GST Configurations

DELTA 4000 supports two basic groups of operation, GST and UST mode. GST stands for grounded specimen test while UST stands for ungrounded specimen test. Within the two groups the test set can be operated in seven test modes as summarized in Table 1.1. Measurements are always made between the high-voltage lead and the lead/ connection in the measure column.

Table 1.1
DELTA 4000 test modes and internal measurement connections

UST: Ungrounded specimen testing			
Test mode	**Measure**	**Ground**	**Guard**
UST-R	Red	Blue	–
UST-B	Blue	Red	–
UST-RB	Red and Blue	–	–
GST: Grounded specimen testing			
Test mode	**Measure**	**Ground**	**Guard**
GST-GND	Ground	Red and Blue	–
GSTg-R	Ground	Blue	Red
GSTg-B	Ground	Red	Blue
GSTg-RB	Ground	–	Red and Blue

In UST test mode, Ground and Guard are internally connected. Internally the Red and Blue leads are either connected to be measured or connected to Ground (and Guard).

In GST test modes the current returning from Ground is measured. Internally the Red and Blue leads are either connected to Ground or Guard to be included in or excluded from the measurement.

2 Interpretation of measurements

Significance of capacitance and dissipation factor

A large percentage of electrical apparatus failures are due to a deteriorated condition of the insulation. Many of these failures can be anticipated by regular application of simple tests and with timely maintenance indicated by the tests. An insulation system or apparatus should not be condemned until it has been completely isolated, cleaned, or serviced and measurements compensated for temperature. The correct interpretation of capacitance and dissipation factor tests generally requires knowledge of the apparatus construction and the characteristics of the particular types of insulation used.

Changes in the normal capacitance of an insulation material indicate such abnormal conditions as the presence of a moisture layer, short circuits, or open circuits in the capacitance network. Dissipation factor measurements indicate the following conditions in the insulation of a wide range of electrical apparatus:

- Chemical deterioration due to time and temperature, including certain cases of acute deterioration caused by localized overheating.
- Contamination by water, carbon deposits, bad oil, dirt and other chemicals.
- Severe leakage through cracks and over surfaces.
- Ionization.

The interpretation of measurements is usually based on experience, recommendations of the manufacturer of the equipment being tested, and by observing these differences:

- Between measurements on the same unit after successive intervals of time.
- Between measurements on duplicate units or a similar part of one unit, tested under the same conditions around the same time, e.g., several identical transformers or one winding of a three-phase transformer tested separately.
- Between measurements made at different test voltages on one part of a unit; an increase in slope (tip-up) of a dissipation factor versus voltage curve at a given voltage is an indication of ionization commencing at that voltage.

An increase of dissipation factor above a typical value may indicate conditions such as those given in the previous paragraph, any of which may be general or localized in character. If the dissipation factor varies significantly with voltage down to some voltage below which it is substantially constant, then ionization is indicated. If this extinction voltage is below the operating level, then ionization may progress in operation with consequent deterioration. Some increase of capacitance (increase in charging current) may also be observed above the extinction voltage because of the short circuiting of numerous voids by the ionization process.

An increase of dissipation factor accompanied by in severe cases possible increase of capacitance usually indicates excessive moisture in the insulation. Increase of dissipation factor alone may be caused by thermal deterioration or by contamination other than water.

Unless bushing and pothead surfaces, terminal boards, etc., are clean and dry, measured quantities may not necessarily apply to the volume of the insulation under test. Any leakage over terminal surfaces may add to the losses of the insulation itself and may, if excessive, give a false indication of its condition.

Dissipation factor (Power factor) of typical apparatus insulation

Values of insulation dissipation factor for various apparatus are shown in Table 2.1. These values may be useful in roughly indicating the range to be found in practice. Please note that the higher values are not to be regarded as “OK” but instead examples of “to be investigated/at risk” data.

Table 2.1
DF (PF) of typical apparatus insulation

Type apparatus	% DF (PF) at 20°C
Oil-filled transformer: New, high-voltage (115 kV and up)	0.25 to 1.0
15 years old, high-voltage	0.25--
Low-voltage, distribution type	0.30--
Oil circuit breakers	0.5 to 2.0
Oil-paper cables, “solid” (up to 27.6 kV) new condition	0.5 to 1.5
Oil-paper cables, high-voltage oil-filled or pressurized	0.2 to 0.5
Rotating machine stator windings, 2.3 to 13.8 kV	2.0 to 8.0
Capacitors (discharge resistor out of circuit)	0.2 to 0.5
Bushings: Solid or dry	3.0 to 10.0
Compound-filled, up to 15 kV	5.0 to 10.0
Compound-filled, 15 to 46 kV	2.0 to 5.0
Oil-filled, below 110 kV	1.5 to 4.0
Oil-filled, above 110 kV and condenser type	0.25--

In IEEE 62-1995, typical values for dissipation/power factor are given as in Table 2.2.

Table 2.2
IEEE 62-1995 power factor values

	Typical power factor values @ 20°C		
	“New”	“Old”	Warning/alert limit
Power transformers, oil insulated	0.2-0.4%	0.3-0.5%	> 0.5%
Bushings	0.2-0.3%	0.3-0.5%	> 0.5%

IEEE 62-1995 states; “The power factors recorded for routine overall tests on older apparatus provide information regarding the general condition of the ground and inter-winding insulation of transformers and reactors. While the power factors for older transformers will also be <0.5% (20°C), power factors between 0.5% and 1.0% (20°C) may be acceptable; however, power factors >1.0% (20°C) should be investigated.”

Permittivity and % DF of typical insulating materials

Typical values of permittivity (dielectric constant) k and 50/60 Hz dissipation factor of a few kinds of insulating materials (also water and ice) are given in Table 2.3.

Table 2.3
Permittivity and dissipation factor of typical insulating materials

Material	k	% DF (PF) at 20°C
Acetal resin (Delrin*)	3.7	0.5
Air	1.0	0.0
Askarels	4.2	0.4
Kraft paper, dry	2.2	0.6
Oil, transformer	2.2	0.02
Polyamide (Nomex*)	2.5	1.0
Polyester film (Mylar*)	3.0	0.3
Polyethylene	2.3	0.02-0.05
Polyamide film (Kapton*)	3.5	0.3
Polypropylene	2.2	0.05
Porcelain	7.0	2.0
Rubber	3.6	4.0
Silicone liquid	2.7	0.01
Varnished cambric, dry	4.4	1.0
Water**	80	100
Ice**	88	1.0 (0°C)

* Dupont registered trademark.

** Tests for moisture should not be made at freezing temperatures because of the 100 to 1 ratio difference of % dissipation factor between water and ice.

Significance of temperature

Most insulation measurements have to be interpreted based on the temperature of the specimen. The dielectric losses of most insulation increase with temperature; however, e.g. dry oil-impregnated paper and polyethylene of good quality exhibit decrease of dielectric losses when temperature is raised moderately, e.g. from 20°C to 30°C. It is also known that the effect of temperature depends on the aging status of the insulation. In many cases, insulations have failed due to the cumulative effect of temperature, i.e., a rise in temperature causes a rise in dielectric loss which in turn causes a further rise in temperature, etc (thermal runaway).

It is important to determine the dissipation factor-temperature characteristics of the insulation under test. Otherwise, all tests of the same specimen should be made, as nearly as practicable, at the same temperature.

To compare the dissipation factor value of tests made on the same or similar type apparatus at different temperatures, it is necessary to convert the value to a reference temperature base, usually 20°C (68°F). Examples of standard tables of multipliers for use in converting dissipation factors at test temperatures to dissipation factors at 20°C are found in the Appendix A of this document.

In reality, temperature correction for a specific component is always individual and pending age/condition. DELTA 4000 has a unique and patented feature for estimating the individual temperature correction (ITC). By measuring dissipation factor over frequency and using mathematical formulas and models of insulation characteristics, the correct temperature correction can be determined from 5 to 50°C measurement temperature to 20°C reference temperature. The input data for the calculation is dissipation factor measured from 1 to 500 Hz and the method is principally based on Arrhenius' law, describing how the insulation properties are changing over temperature.

$$\boldsymbol{\varkappa = \varkappa_0 \cdot \exp(-W_a/kT)}$$

With activation energy W_a and Boltzmann constant k

The test temperature for apparatus such as spare bushings, insulators, air or gas filled circuit breakers, and lightning arresters is normally assumed to be the same as the ambient temperature. For oil-filled circuit breakers and transformers the test temperature is assumed to be the same as the top oil temperature or winding temperature. For installed bushings where the lower end is immersed in oil the test temperature lies somewhere between the oil and air temperature.

In practice, the test temperature is assumed to be the same as the ambient temperature for bushings installed in oil-filled circuit breakers and also for oil-filled transformers that have been out of service for approximately 12 hours. In transformers removed from service just prior to test, the temperature of the oil normally exceeds the ambient temperature. The bushing test temperature for this case can be assumed to be the midpoint between the oil and ambient temperatures.

Any sudden changes in ambient temperature will increase the measurement error since the temperature of the apparatus will lag the ambient temperature.

Dissipation factor-temperature characteristics, as well as dissipation factor measurements at a given temperature, may change with deterioration or damage of insulation. This suggests that any such change in temperature characteristics may be helpful in assessing deteriorated conditions. As an example, bushings have typically a rather flat temperature correction with only slightly elevated values at high temperatures. Generally a bushing showing highly increased dissipation factor at elevated temperature should be considered "at risk".

Be careful making measurements below the freezing point of water. A crack in an insulator, for example, is easily detected if it contains a conducting film of water. When the water freezes, it becomes non-conducting, and the defect may not be revealed by the measurement, because ice has a volumetric resistivity approximately 100 times higher than that of water. Moisture in oil, or in oil-impregnated solids, has been found to be detectable in dissipation factor measurements at temperatures far below freezing, with no discontinuity in the measurements at the freezing point.

Insulating surfaces exposed to ambient weather conditions may also be affected by temperature. The surface temperature of the insulation specimen should be above and never below the ambient temperature to avoid the effects of condensation on the exposed insulating surfaces.

Significance of humidity

The exposed surface of bushings may, under adverse relative humidity conditions, acquire a deposit of surface moisture which can have a significant effect on surface losses and consequently on the results of a dissipation factor test. This is particularly true if the porcelain surface of a bushing is at a temperature below ambient temperature (below dew point), because moisture will probably condense on the porcelain surface. Serious measurement errors may result even at a relative humidity below 50 percent when moisture condenses on a porcelain surface already contaminated with industrial chemical deposits.

It is important to note that an invisible thin surface film of moisture forms and dissipates rapidly on materials such as glazed porcelain which have negligible volume absorption. Equilibrium after a sudden wide change in relative humidity is usually attained within a matter of minutes. This, however, excludes thicker films which result from rain, fog, or dew point condensation.

Surface leakage errors can be minimized if dissipation factor measurements are made under conditions where the weather is clear and sunny and where the relative humidity does not exceed 80 percent. In general, best results are obtained if measurements are made during late morning through mid afternoon. Consideration should be given to the probability of moisture being deposited by rain or fog on equipment just prior to making any measurements.

Surface leakage

Any leakage over the insulation surfaces of the specimen will be added to the losses in the volume insulation and may give a false impression as to the condition of the specimen. Even a bushing with a voltage rating much greater than the test voltage may be contaminated enough to cause a significant error. Surfaces of potheads, bushings, and insulators should be clean and dry when making a measurement.

It should be noted that a straight line plot of surface resistivity against relative humidity for an uncontaminated porcelain bushing surface results in a decrease of one decade in resistivity for a nominal 15 percent increase in relative humidity and vice versa.

On bushings provided with a power factor or capacitance tap, the effect of leakage current over the surface of a porcelain bushing may be eliminated from the measurement by testing the bushing by the ungrounded specimen test (UST).

When testing bushings without a test tap under high humidity conditions, numerous companies have reported that the effects of surface leakage can be substantially minimized by cleaning and drying the porcelain surface and applying a very thin coat of Dow Corning #4 insulating grease (or equal) to the entire porcelain surface. When making a hot collar test, the grease is generally only applied to the porcelain surface on which the hot collar band is to be located and to that of one petticoat above and one below the hot collar band.

When testing potheads, bushings (without test tap), and insulators under unfavorable weather conditions, the dissipation factor reading may, at times, appear to be unstable and may vary slightly over a very short period of time. The variation is caused by such factors as the amount of surface exposure to sun or shade, variations in wind velocity, and gradual changes in ambient temperature and relative humidity. Similar bushings may have appreciably different dissipation factor values for the case where one bushing is located in the sun while the other is in the shade. A test made on the same bushing may have a different dissipation factor value between a morning and an afternoon reading. Due consideration must be given to variations in readings when tests are made under unfavorable weather conditions.

Electrostatic interference

When tests are conducted in energized substations, the readings may be influenced by electrostatic interference currents resulting from the capacitive coupling between energized lines and bus work to the test specimen. Other sources for interference may be corona discharges (especially at high humidity) and is some cases DC fluctuations in the grounding system. Trouble from magnetic fields encountered in high-voltage substations is very unlikely.

To counter the effects of severe electrostatic interference on the measurement, it may be necessary to disconnect the specimen from disconnect switches and bus work. Experience in making measurements will establish the particular equipment locations where it is necessary to break the connections. The related disconnect switches, leads and bus work, if not energized, should be solidly grounded to minimize electrostatic coupling to the test set.

The measurement difficulty which is encountered when testing in the presence of interference depends not only upon the severity of the interference field but also on the capacitance and dissipation factor of the specimen. Unfavorable weather conditions such as high relative humidity, fog, overcast sky, and high wind velocity will increase the severity and variability of the interference field. The lower the specimen capacitance and its dissipation factor, the greater the difficulty is to perform accurate measurements. It is also possible that a negative dissipation factor reading may be obtained so it is necessary to observe the polarity sign for each reading. Specifically, it has been found that some difficulty may be expected when measuring capacitance by the GST test method in high interference switchyards when the capacitance value is less than 100 pF. This difficulty may be minimized considerably by:

- Using the maximum voltage of the test set if possible.
- Disconnecting and grounding as much bus work as possible from the specimen terminals.
- Making measurements on a day when the weather is sunny and clear, the relative humidity is less than 80 percent, the wind velocity is low, and the surface temperature of exposed insulation is above the ambient temperature.

Tests made by the UST method are less susceptible to interference pickup than are tests made by the GST method. In the UST test method, the capacitive coupled pickup current in the high-voltage circuit flows directly to ground after having passed through the high-voltage winding of the power supply transformer. In the GST test method the same pickup current, after passing through the high-voltage transformer winding, must pass through one of the bridge transformer-ratio measuring arms before reaching ground.

Negative dissipation factor

Creep currents inside an insulation system or more commonly on surfaces; create change of potential distribution that may give increased or decreased dissipation factor, and in some cases also negative dissipation factor. This condition is most likely to arise when making UST and GST measurements on specimens who have a capacitance value of a few hundred picofarad or less. Equipment such as bushings, circuit breakers, and low loss surge arresters fall into this category.

The error is usually accentuated if tests are made under unfavorable weather conditions, especially a high relative humidity which increases surface leakage.

There appears to be no clear-cut way of knowing whether an error is significant or what remedies should be taken to overcome an error. A frequency sweep may give additional information. The best advice is to avoid making measurements on equipment in locations where negative dissipation factors are known to present a problem when unfavorable weather conditions exist, especially high relative humidity. Make sure the surface of porcelain bushings are clean and dry to minimize the effects of surface leakage. Make sure all items such as wooden ladders or nylon ropes are removed from the equipment to be tested and are brought out of any electrostatic interference fields that could influence a measurement.

Connected bus work, cables etc

A complete disconnected component is preferred when performing dissipation factor measurements. All connected bus work, cables, disconnect switches etc may add significant capacitance and losses in GST measurements where they are in parallel with the desired insulation measurement. For this reason, many test engineers will ask that the equipment under test be totally isolated from connected apparatus.

UST data is principally possible to measure without fully disconnecting the test object. The capacitance from the connected parts results only in a current to ground that is not measured in UST test mode.

3 Testing power system components

Transformers

Introduction

The transformer is probably one of the most useful electrical devices ever invented. It can raise or lower the voltage or current in an ac circuit, it can isolate circuits from each other, and it can increase or decrease the apparent value of a capacitor, an inductor, or a resistor. Furthermore, the transformer enables us to transmit electrical energy over great distances and to distribute it safely in factories and homes. Transformers are extensively used in electric power systems to transfer power by electromagnetic induction between circuits at the same frequency, usually with changed values of voltage and current.

Dissipation/Power factor testing is an effective method to detect and help isolate conditions such as moisture, carbonization, and contamination in bushings, windings and liquid insulation. In addition to power factor testing, transformer excitation current measurements will help detect winding and core problems.

The voltage rating of each winding under test must be considered and the test voltage selected accordingly. If neutral bushings are involved, their voltage rating must be considered in selecting the test voltage. Measurements should be made between each inter-winding combination (or set of three-phase windings in a three-phase transformer) with all other windings grounded to the tank (UST test). Measurements should also be made between each winding (or set of three-phase windings) and ground with all other windings guarded (GST test with guard).

In a two-winding transformer, a measurement should also be made between each winding and ground with the remaining winding grounded (GST-GND test). For a three-winding transformer, a measurement should also be made between each winding and ground with one remaining winding guarded and the second remaining winding grounded (GSTg test). This special test is used to isolate the inter-windings. A final measurement should be made between all windings connected together and the ground tank. It is also desirable to test samples of the liquid insulation.

Definitions

- Step-Down Transformer: A transformer in which the power transfer is from the higher voltage source circuit to a lower voltage circuit.
- Step-Up transformer: A transformer in which the power transfer is from the lower voltage source circuit to a higher voltage circuit.
- Autotransformer: A transformer in which at least two windings have a common section.
- Excitation Current (No-Load Current): The current which flows in any winding used to excite the transformer when all other windings are open-circuited.
- Tap (in a transformer): A connection brought out of a winding at some point between its extremities, to permit changing the voltage, or current, ratio.
- Delta Connection: So connected that the windings of a three-phase transformer (or the windings for the same rated voltage of single-phase transformers associated in a three- phase bank) are connected in series to form a closed circuit.
- Y (or Wye) Connection: So connected that one end of each of the windings of a polyphase transformer (or of each of the windings for the same rated voltage of single-phase transformers associated in a polyphase bank) is connected to a common point (the neutral point) and other end to its appropriate line terminal.
- Zigzag Connection: A polyphase transformer with Y-connected windings, each one of which is made up of parts in which phase-displaced voltages are induced.
- Tertiary Winding: The third winding of the transformer and often provides the substation service voltage, or in the case of a wye-wye connected transformer, it prevents severe distortion of the line-to-neutral voltages.

The following equipment and tests will be discussed in this guide:

- Two-Winding Transformers
- Three-Winding Transformers
- Autotransformer
- Transformer Excitation Current Tests
- Shunt Reactors
- Potential Transformers
- Current Transformers
- Voltage Regulators
- Dry-Type Transformers

Two-winding transformers

Two-winding transformer measurement is described in Figure 10.

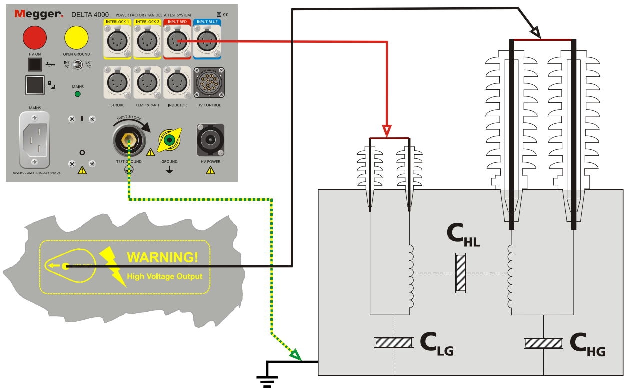


Figure 10: Two-Winding Transformer Test

Test connections

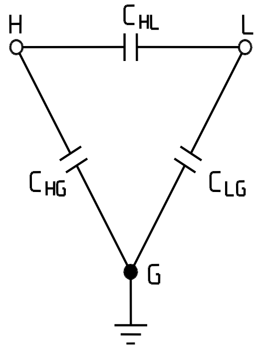
For all transformer testing, including spare transformers, ensure the following safety conditions are observed:

Test connections are defined in table 3.1.

Table 3.1
Two-winding transformer test connections

Test No.	Insulation tested	Low voltage lead configuration				Test lead connections to windings			Remarks
		Test mode	Measure	Ground	Guard	High voltage	Red	Blue	
1	CHG+ CHL	GST-GND		Red & Blue		H	L	–	L Grounded
2	CHG	GSTg-RB			Red & Blue	H	L	–	L Guarded
3	CHL	UST-R	Red	Blue		H	L	–	
4	CHL	–	Test 1 minus Test 2			–	–	–	Calculated interchecck
5	CLG + CHL	GST-GND		Red & Blue		L	H	–	H Grounded
6	CLG	GSTg-RB			Red & Blue	L	H	–	H Guarded
7	CLH	UST-RB	Red	Blue		L	H	–	
8	LH	–	Test 5 minus Test 6			–	–	–	Calculated interchecck

Equivalent circuit



Note: Short each winding on itself.	
Measurement Inter-checks (Calculated)	
Capacitance	**Watts**
$C_4 = C_1 - C_2$	$W_4 = W_1 - W_2$
$C_8 = C_5 - C_6$	$W_8 = W_5 - W_6$
Note: Subscripts are test numbers	

H	High-voltage winding
L	Low-voltage winding
G	Ground

1] The transformer must be taken out of service and isolated from the power system.

2] Ensure the transformer is properly grounded to the system ground.

3] Before applying any voltage on the transformer make sure that all bushing current transformers are shorted out.

4] Never perform electrical tests of any kind on a unit under vacuum. Flashovers can occur at voltages as low as 250 volts.

5] If the transformer is equipped with a load tap changer, set the unit to some step off of neutral. Some load tap changers are designed with arrester type elements that are not effectively shorted out in the neutral position even with all the bushings shorted.

6] Connect a ground wire from the test set to the transformer ground.

7] Short all bushings of each winding including the neutral of a wye-connected winding. The neutral ground must also be removed. The shorting wire must not be allowed to sag.

8] Connect the high voltage lead to the high side bushings for tests 1, 2, and 3. Ensure that the high voltage cable extends out away from the bushing.

9] Connect the red low voltage lead to the low voltage bushings.

10] For tests 5, 6 and 7, connect the high voltage lead from the test set to the low voltage bushings of the transformer and the red low voltage lead from the test set to the high voltage bushings.

11] Individual tests should be performed on each bushing. Bushings equipped with a potential/test tap should have the UST test performed and the GST on those without test taps.
Hot collar tests can if necessary be performed on both types.

12] Transformer windings must remain shorted for all bushing tests. Windings not energized must be grounded.

13] For transformers that have wye-wye configuration, and the neutrals internally cannot be separated, 1-3 and 5-7 cannot be measured. In this case short the high voltage bushings and the low voltage bushings together and perform a GST test. Test voltage should be suitable for the rating of the low voltage winding.

Test procedure

For all power factor testing, the more information you record at the time of testing will ensure the best comparison of results at the next routine test. Test data should be compared to the nameplate data. If nameplate or factory readings are not available, compare the results of prior tests on the same transformer or results of similar tests on similar transformers. If at all possible, power factor and capacitance readings should be taken on all new transformers for future benchmarking.

Field measurements of power-factor and capacitance can differ from measurements made under the controlled conditions in the factory. Therefore, the power-factor and capacitance should be measured at the time of installation and used as a base to compare future measurements. Power factor testing is extremely sensitive to weather conditions. Tests should be conducted in favorable conditions whenever possible. All tests are performed at 10kV. If these values exceed the rating of the winding, test at or slightly below the rating.

1] Follow the test sequence of the Two-Winding Transformers Test Connections. Tests 1, 2 and 3 can be completed without a lead change.

2] Test 4 is a calculation subtracting the capacitance and watts results in test 2 from test 1. The results should compare with the UST measurement for the C_{HL} insulation

3] Reverse the test leads for tests 5, 6 and 7. Test voltage should be at a level suitable for the secondary winding of the transformer.

4] Test 8 is a calculation by subtracting test 6 from test 5. Results should compare with the UST measurement in test 7 for the C_{HL} insulation.

5] Enter all the nameplate information of the transformer. Note any special or unusual test connections or conditions.

6] Enter ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

7] Enter the insulation temperature (top oil or winding temperature)

8] Correct the power factor readings of the transformer to 20°C using individual temperature correction or standard tables

9] Identify each set of readings of the transformer bushings with a serial number. Record manufacture, type or model and other nameplate ratings. Especially be aware to record nameplate C_1 capacitance and power factor values if available. Correct the power factor readings on the bushings to 20°C

Test results

Power factor results should always be compared to manufacturers' tests, or to prior test results if available. It is impossible to set maximum power factor limits within which all transformers are acceptable, but units with readings above 0.5% at 20°C should be investigated.

Oil-filled service-aged transformers may have slightly higher results and should be trended to identify significant changes.

Bushings, if in poor condition, may have their losses masked by normal losses in the winding insulation Therefore, separate tests should be applied to them.

Increased power factor values, in comparison with a previous test or tests on identical apparatus, may indicate some general condition such as contaminated oil. An increase in both power factor and capacitance indicates that contamination is likely to be water. When the insulating liquid is being filtered or otherwise treated, repeated measurements on windings and liquid will usually show whether good general conditions are being restored.

Oil oxidation and consequent sludging conditions have a marked effect on the power factors of transformer windings. After such a condition has been remedied, (flushing down or other treatment) power factor measurements are valuable in determining if the sludge removal has been effective.

Measurements on individual windings may vary due to differences in insulation materials and arrangements.

However, large differences may indicate localized deterioration or damage. Careful consideration of the measurements on different combinations of windings should show in which particular path the trouble lies; for example, if a measurement between two windings has a high power factor, and the measurements between each winding and ground, with the remaining winding guarded, gives a normal reading, then the trouble lies between the windings, perhaps in an insulating cylinder.

Three-winding transformers

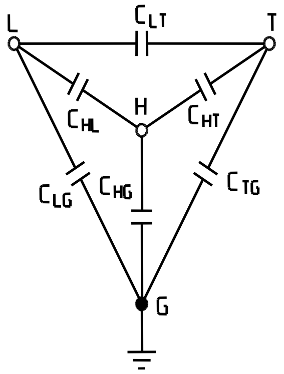
Testing of three-winding transformers is performed in the same manner as two-winding transformers with the additional tests of the tertiary winding. In some cases transformers are constructed so that the inter-windings are shielded by a grounded electrostatic shield or a concentric-winding arrangement. This could provide test results that capacitance is almost non-existent or even a negative power factor. The transformer manufacturer should be contacted to verify the existence of a shield or a concentric-winding arrangement.

Three-winding transformer test connections are described in Table 3.2.

Table 3.2
Three-winding transformer test connections

Test No.	Insulation tested	Low voltage lead configuration				Test lead connections to windings			Remarks
		Test mode	Measure	Ground	Guard	High voltage	Red	Blue	
1	CHG+ CHL	GSTg-B		Red	Blue	H	L	T	L Grounded T Guarded
2	CHG	GSTg-RB			Red & Blue	H	L	T	L & T Guarded
3	CHL	UST-R	Red	Blue		H	L	T	T Grounded
4	CHL	–	Test 1 minus Test 2			–	–	–	Calculated intercheck
5	CLG + CLT	GSTg-BR		Blue	Red	L	H	T	T Grounded H Guarded
6	CLG	GSTg-RB			Red & Blue	L	H	T	T & H Guarded
7	CLT	UST-RB	Blue	Red		L	H	T	H Grounded
8	CLT	–	Test 5 minus Test 6			–	–	–	Calculated intercheck
9	CTG + CHT	GSTg-B		Red	Blue	T	H	L	H Grounded L Guarded
10	CTG	GSTg-RB			Red & Blue	T	H	L	H & L Guarded
11	CHT	UST-R	Red	Blue		T	H	L	L Grounded
12	CHT	–	Test 9 minus Test 10			–	–	–	Calculated intercheck

Equivalent Circuit



H	High-voltage winding
L	Low-voltage winding
T	Tertiary winding
G	Ground

Note: Short each winding on itself.

Measurement Interchecks (Calculated)

Capacitance	Watts
$C_4 = C_1 - C_2$	$W_4 = W_1 - W_2$
$C_8 = C_5 - C_6$	$W_8 = W_5 - W_6$
$C_{12} = C_9 - C_{10}$	$W_{12} = W_9 - W_{10}$

Note: Subscripts are test numbers

Autotransformers

In the design of an autotransformer, the secondary winding is actually part of the primary winding. For a given power output, an autotransformer is smaller and cheaper than a conventional transformer. This is particularly true if the ratio of the incoming line voltage to outgoing line voltage lies between 0.5 and 2.

Autotransformers may have a tertiary winding. If so, both primary and secondary bushings are shorted together and the tertiary bushings are shorted to each other. The autotransformer is then tested as a two winding transformer. Individual tests should be performed on each bushing if they are equipped with a test tap.

If the autotransformer does not have a tertiary winding, short the high voltage bushings and the low voltage bushings together and perform a GST test. Test voltage should be suitable for the rating of the low voltage winding

Transformer excitation current tests

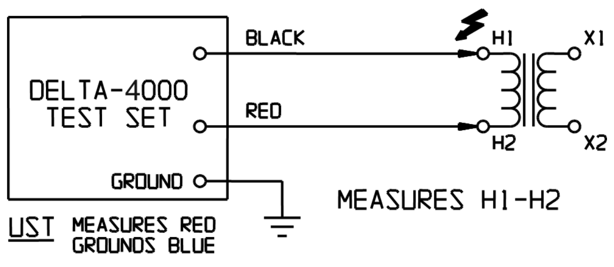
Transformer excitation current tests are helpful in determining possible winding or core problems in transformers, even when ratio and winding resistance tests appear normal. Excitation tests should be conducted routinely along with power factor testing.

Test connections

Test connection described in table 3.3.

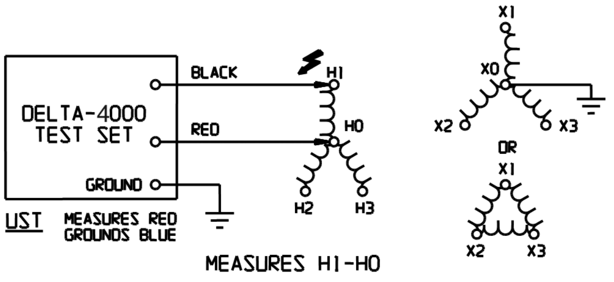
Table 3.3
Transformer excitation current test connections

Single phase



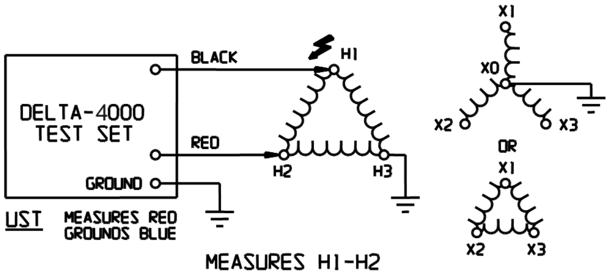
Measure	Test lead connections		
Terminal symbol	**High voltage**	**Red**	**Ground**
H1-H2	H1	H2	–
H2-H1	H2	H1	–

Three phase high side "Y"



Measures	Test lead connections		
Terminal symbol	**High voltage**	**Red**	**Ground**
H1-H0	H1	H0	–
H2-H0	H2	H0	–
H3-H0	H3	H0	–

Three phase high side "Δ"



Measures	Test lead connections		
Terminal symbol	**High voltage**	**Red**	**Ground**
H1-H2	H1	H2	H3
H2-H3	H2	H3	H1
H3-H1	H3	H1	H2

- Transformer excitation current tests are performed on the high voltage winding to minimize the excitation current. Problems in the low voltage windings will still be detected by this method.
- The secondary windings are left floating with the exception of a wye or zig-zag secondary. In this case the neutral bushing remains grounded as it is in normal service. Refer to the user manual for test connections for Single Phase, Three Phase High Side Wye and Three Phase High Side Delta transformers.
- Single Phase: The transformer is energized from the phase to neutral bushings (ANSI: H1-H2). Test connections can be reversed for additional data, but test results should be the same. H2 may also be designated as H0.
- Wye – Wye: Observe that the ground wire is removed from the high voltage side neutral bushing for testing, but remains connected on the low voltage side neutral bushing.

Test procedure

- Test voltages should be as high as possible, but limited to 10 kV, without exceeding the rating of the line-to-line voltages on delta connected transformers and line-to-ground on wye connected transformers. Also note that in many cases the maximum applied voltage is limited by the maximum current output
- Test voltage must always be the same as prior tests if any comparisons are made.
- All transformer excitation current tests are conducted in the UST test mode (normally UST-R, using Red low voltage lead).
- For routine testing, transformers with load tap changers should have tests performed in at least one raise and one lower position off of neutral. The no-load tap changer should be in the normal in service position.
- For new transformers, excitation tests should be performed in every tap position for both the load and no-load tap changers.
- The more information that is recorded at the time of testing will ensure the best comparison of results at the next routine test.
- Temperature corrections are not applied to transformer excitation current tests.

Test results

Compare test results to previous tests on the same transformer, or to manufacturers' data if available. Tests can also be compared to similar type units. It is essential that identical test voltages be used for repeat tests on a transformer. Fluctuation in the test voltage will produce inconsistent current readings. Three phase transformers should have the individual windings energized at both ends if the original test appears abnormal.

Transformer excitation current tests on the high voltage winding should detect problems in the secondary winding if they exist. Winding resistance testing in addition to the excitation tests could be helpful in isolating either a core or winding defect.

Test results on three phase transformers, especially wye-connected windings, could produce high but similar readings on two phases compared to the third phase. This is the result of the low phase being wound around the center leg of a three-legged core. The reluctance of the magnetic circuit is less for the center leg of the core resulting in a lower charging current.

Shunt reactors

When electrical energy is transmitted at extra high voltages, special problems arise that require the installation of large compensating devices to regulate the over-voltage conditions and to guarantee stability. Among these devices are shunt reactors. Shunt reactors are composed of a large coil placed inside a tank and immersed in oil. They can be single phase units or three phases in one tank. In both cases each phase has its own neutral bushing.

Test connections

- For all tests, the line and neutral bushings for corresponding phases must remain shorted.

Test procedure

- Record test results on the test form for Miscellaneous Equipment Capacitance and Power Factor Tests.
- Test voltages are at 10kV. If 10kV exceeds the insulation rating, test at or slightly below the insulation rating.
- For single phase units only one overall ground test is performed in the GST mode.

Test results

Power factor and capacitance results should be recorded in the same manner as for oil filled power transformers. Temperature correction should be to the top oil temperature. Compare test results to previous tests or tests on similar units. Additional bushing tests should be performed if test results are suspect.

Potential transformers

Potential transformers are installed on power systems for the purpose of stepping down the voltage for the operation of instruments such as Volt-meters, Watt-meters and relays for various protective purposes. Typically the secondary voltage of potential transformers is 120 V, so power factor testing is performed on the primary winding. Potential transformers are typically single phase with either single or two bushing primaries. Single bushing primaries have one end of the high voltage winding connected to ground. Secondary windings are normally three wire and dual identical secondary windings are common.

Test connections

Ensure that the potential transformer is disconnected from the primary source before testing begins.

1] Remove any fusing on the secondary circuits to prevent any type of back-feeding to the secondary.

2] Ground one leg of each secondary winding for all tests on two primary bushing transformers, for dual secondary transformers it is typically X1 and Y1.

3] Ensure that the case of the potential transformer is securely grounded to a system ground before testing begins, this also includes testing of spare transformers.

Test procedure

Ensure the test set is securely grounded.

1] Record all tests results. Power factor tests should be corrected to ambient temperature.

2] Compare test results to prior tests on the same or similar equipment.

Current transformers

Current transformers are used for stepping down primary current for Ampere-meters, Watt-meters and for relaying. Typical secondary current rating is 5 A. Current transformers have ratings for high voltage and extra high voltage application. The higher voltage classifications can be oiled filled, dry type or porcelain construction. Tests on two bushing primary currents transformers are performed by shorting the primary winding, grounding all secondary windings and test in the GST mode. Some current transformers in the high voltage classifications have test taps similar to bushings. Tests can be performed on units equipped with a test tap for the C_1 insulation and the C_2 tap insulation. Assure that the unit under test is grounded before testing. Record all test results and correct the power factor readings to the ambient temperature at the time of the test.

Voltage regulators

Regulators are generally induction or step-by- step. The induction regulator is a special type of transformer, built like an induction motor with a coil-wound secondary, which is used for varying the voltage delivered to a synchronous converter or an ac feeder system. The step-by-step regulator is a stationary transformer provided with a large number of secondary taps and equipped with a switching mechanism for joining any desired pair of these taps to the delivery circuit. Voltage regulators may be single or three phase. Single phase regulators consist of three bushings identified as S (Source), L (Load) and SL (Neutral). The windings in the regulator cannot be effectively separated, so one overall power factor test is performed. All the bushings are shorted together and tested in the GST-GND test mode.

Tests should be conducted with the tap changer moved to some position off of neutral. Additional Hot Collar tests may be conducted on bushings of suspect units. Excitation tests may also be performed by energizing terminal L with the high voltage lead and the low voltage lead on SL in the UST position. Terminal S should be left floating. Power factor results should be corrected to top oil temperature on regulators just taken out of service. Ambient temperature should be used for those that have been out of service for any length of time. Power factor results should be compare to previous tests on the same equipment or similar tests on similar units.

Dry-type transformers

Testing notes

Test voltages should be limited to line-to-ground ratings of the transformer windings. Insulation power factor tests should be made from windings to ground and between windings. Temperature at the time of testing should be at or near 20°C. ANSI/IEEE C57.12.91 - 1997 recommends correcting results other than 20°C. However, there is very little data available for temperature correction of dry-type transformers. Repeat tests should be performed as near as possible, in the same conditions as the original test.

Higher overall power factor results may be expected on dry-type transformers. The majority of test results for power factor is found to be below 2.0%, but can range up to 10%. The insulation materials necessary for dry-type construction, must meet the thermal and stress requirements.

If power factor results appear to be unacceptable, an additional Tip-Up Test can be performed if a 10kV test set is used. This test can be performed to evaluate whether moisture or corona is present in the insulation system. The applied test voltage is varied starting at about 1kV and increased in intervals up to 10 kV or the line-to-ground rating of the winding insulation. If the power factor does not change as the test voltage is increased, moisture is suspected to be the probable cause. If the power factor increases as the voltage is increased, carbonization of the insulation or ionization of voids is the cause.

Note *DELTA 4000 has a specific feature where the test set recognizes voltage dependence and will automatically indicate a non-linear behavior and by this indicate to the user to perform a tip-up test*

Bushings

Introduction

Bushings provide an insulated path for energized conductors to enter grounded electrical power apparatus. Bushings are a critical part of the electrical system that transforms and switches ac voltages ranging from a few hundred volts to several thousand volts. Bushings not only handle high electrical stress, they could be subjected to mechanical stresses, affiliated with connectors and bus support, as well. Although a bushing may be thought of as somewhat of a simple device, its deterioration could have severe consequences.

All modern bushings rated 23 kV and higher have a power factor or a capacitance tap which permits dissipation factor testing of the bushing while it is in place on the apparatus without disconnecting any leads to the bushing. The dissipation factor is measured by the ungrounded specimen test (UST) which eliminates the influence of transformer winding insulation, breaker arc-interrupters, or support structures which are connected to the bushing terminal.

Figure 11 shows the test connections between the test set and bushing when using the UST test mode.

1] Connect test ground to apparatus ground.

2] Connect the high-voltage lead to the terminal at the top of the bushing and the low-voltage lead (red) to the power factor tap.

3] Ground the apparatus tank. The tap is normally grounded through a spring and it is necessary, when making measurements, to remove the plug which seals and grounds the tap. Use the UST measure red, ground blue test mode setting (UST-R).

The UST test also can be used for making measurements on bushings which have provisions for flange isolation. The normal method of isolating the flange from the apparatus cover is to use insulating gaskets between the flange and cover and insulating bushings on all but one of the bolts securing the mounting flange to the cover. During normal operation, the flange is grounded by a single metal bolt; however, when testing the bushing, this bolt is removed. The measurement is identical to that when testing bushings which have a power factor tap except that the low-voltage lead, red in this case, is connected to the isolated bushing flange.

Definitions

Bushing voltage tap

A connection to one of the conducting layers of a capacitance graded bushing providing a capacitance voltage divider. Note: additional equipment can be designed, connected to this tap and calibrated to indicate the voltage applied to the bushing. This tap can also be used for measurement of power factor and capacitance values.

Bushing test tap
A connection to one of the conducting layers of a capacitance graded bushing for measurement of power factor and capacitance values.

Capacitance (of bushing)
(1) the main capacitance, c_1, of a bushing is the capacitance between the high-voltage conductor and the voltage tap or test tap.

(2) the tap capacitance, c_2, of a capacitance graded bushing is the capacitance between the voltage tap and mounting flange (ground).

(3) the capacitance, c, of a bushing without a voltage or test tap is the capacitance between the high-voltage conductor and the mounting flange (ground).

Capacitance graded bushing
A bushing in which metallic or non-metallic conducting layers are arranged within the insulating material for the purpose of controlling the distribution of the electric field of the bushing, both axially and radially.

Cast insulation bushing
A bushing in which the internal insulation consists of a solid cast material with or without an inorganic filler.

Composite bushing
A bushing in which the internal insulation consists of several coaxial layers of different insulation materials.

Compound-filled bushing
A bushing in which the radial space between the internal insulation (or conductor where no internal insulation is used) and the inside surface of the insulating envelope is filled with insulating compound

Creep distance
The distance measured along the external contour of the insulating envelope which separates the metal part operating at line voltage and the metal flange at ground voltage.

Insulating envelope
An envelope of inorganic or organic material such as a ceramic or cast resin placed around the energized conductor and insulating material.

Internal insulation
Insulating material provided in a radial direction around the energized conductor in order to insulate it from ground voltage.

Major insulation
The insulating material providing the dielectric, which is necessary to maintain proper isolation between the energized conductor and ground voltage. It consists of internal insulation and the insulating envelope(s).

Oil-filled bushing
A bushing in which the radial space between the inside surface of the insulating envelope and the internal insulation (or conductor where no internal insulation is used) is filled with oil.

Oil-impregnated paper insulated bushing
A bushing in which the internal insulation consists of a core wound from paper and subsequently impregnated with oil. The core is contained in an insulating envelope, the space between the core and the insulating envelope being filled with oil.

Resin-bonded paper-insulated bushing
A bushing in which the internal insulation consists of a core wound from resin coated paper. During the winding process, each paper layer is bonded to the previous layer by its resin coating and the bonding is achieved by curing the resin. Note: a resin bond paper-insulated bushing may be provided with an insulating envelope, in which case the intervening space may be filled with another insulating medium.

Resin impregnated paper-insulated bushing
A bushing in which the internal insulation consists of a core wound from untreated paper and subsequently impregnated with a curable resin.

Solid bushing
A bushing in which the major insulation is provided by a ceramic or analogous material

Non-condenser bushings
Non-condenser bushings include the following designs: solid porcelain, gas-filled hollow shell bushings (porcelain or epoxy shells). Solid porcelain bushings were used exclusively in early electrical systems, but it became apparent that there was a voltage limit to the application of these solid porcelain bushings. Solid porcelain bushings were utilized up through 23kV, but after that point alternative insulation mediums had to be employed. The next step in bushing construction used other materials between the metal conductor and the solid porcelain shell. Some of the early materials included oil, asphalt, & air. These designs worked well, but given the ever increasing voltages of the world's developing electrical systems, it became apparent that ever increasing diameter bushings would be required. These large diameter bushings were impractical for an industry determined to construct smaller apparatus. A new solution had to be found. That solution was condenser bushings. Today, our new sf_6 gas breakers are equipped with hollow shell bushings, constructed of either porcelain or epoxy, which are filled with sf_6 gas.

Condenser bushings
The major goal of condenser designed bushings is to reduce the physical size of the bushing. This compaction allows not only for a smaller bushing, but also a smaller host apparatus (i.e. oil circuit breaker or transformer).

Condenser bushings allowed for this compaction by placing the foil condenser layers at varying intervals during the winding of the paper core, which resulted in uniform voltage stress distribution axially throughout the bushing. Additionally, varying the lengths of the foil layers provided even voltage distribution along the upper and lower ends of the bushing. The incorporation of condenser layers in bushings provided both radial and axial voltage stress control, which resulted in smaller compact bushings. The condenser layers are basically a series of concentric capacitors between the center conductor and ground. This design is employed on a wide range of voltage levels, up to and including 765kV. Modern condenser bushings are usually equipped with test taps. Bushings rated 115 kV and above usually have voltage taps, bushings rated below 115kV have test taps. The availability of either a voltage tap or a test tap allows for the testing of the main insulation c_1. The test tap is normally designed to withstand only about 500 volts while a voltage tap may have a normal rating of 2.5 to 5 kV. This voltage is only a concern when performing the c_2 (tap insulation test) or the inverted ungrounded specimen test (UST), both of which will be discussed later in this guide. Before applying a test voltage to the tap, the maximum safe test voltage must be known and observed. An excessive voltage may puncture the insulation and render the tap useless. If absolutely no information is available on the tap test voltage, do not exceed 500 volts.

Bushing troubles

Operating records show that about 90 percent of all preventable bushing failures are caused by moisture entering the bushing through leaky gaskets or other openings. Close periodic inspection to find leaks and make repairs as needed will prevent most outages due to bushing failures. Such an external inspection requires little time and expense and will be well worth the effort. High-voltage bushings, if allowed to deteriorate, may explode with considerable violence and cause extensive damages to adjacent equipment.

Flashovers may be caused by deposits of dirt on the bushings, particularly in areas where there are contaminants such as salts or conducting dusts in the air. These deposits should be removed by periodic cleaning.

Table 3.9 lists the common causes of bushing troubles and the inspection methods used to detect them.

Table 3.9
Bushing troubles

Trouble	Possible results	Methods of detection
Cracked porcelain	Moisture enters Oil and/or gas leaks Filler leaks out	Visual inspection Power factor/Tan delta test Hot-collar test
Deterioration of cemented joints	Moisture enters Oil and/or gas leaks Filler leaks out	Visual inspection Power factor/Tan delta test Hot-collar test
Gasket leaks	Moisture enters Oil and/or gas leaks Filler leaks out	Visual inspection Power factor/Tan delta test Hot-collar test Hot-wire test for moisture Insulation resistance
Moisture in insulation	Moisture enters	Power factor/Tan delta test Hot-collar test
Solder seal leaks	Moisture enters Filler leaks out	Visual inspection Power factor/Tan delta test Hot-collar test
Broken connection between ground sleeve and flange	Sparking in apparatus tank or within bushing Discolored oil	Power factor/Tan delta test DGA
Voids in compound	Internal corona	Visual inspection Power factor/Tan delta test Hot-collar test
Oil migration	Filler contamination	Visual inspection Power factor/Tan delta test Hot-collar test
No oil	Oil leaks out Moisture enters	Visual inspection Power factor/Tan delta test Hot-collar test
Displaced grading shield	Internal sparking discolors oil	Hot-collar test DGA
Electrical flashover	Cracked or broken porcelain Complete failure	Visual inspection Hot-collar test
Lightning	Cracked or broken porcelain Complete failure	Visual inspection Test surge arresters
Corona	Internal breakdown Radio interference Treeing along surface of paper or internal surface	Power factor/Tan delta test Hot-collar test Hot-wire test Thermographic scanning DGA
Short-circuited condenser sections	Increased capacitance Reduced voltage at capacitance tap Adds internal stress to insulation	Power factor/Tan delta test Voltage test at capacitance tap Capacitance test
Darkened oil	Radio interference Poor test results	Power factor/Tan delta test Hot-collar test

Bushing tests

Power and dissipation factor & capacitance test C1 for main insulation

The voltage or test tap allows for testing the main bushing insulation while it is in place in the apparatus without disconnecting any leads from the bushing. The main insulation is the condenser core between the center conductor and the tap layer. The test is conducted in the UST test mode which eliminates the losses going to grounded portions of the bushing. The UST method measures only the bushing and is not appreciably affected by conditions external to the bushing.

Test connections (UST)

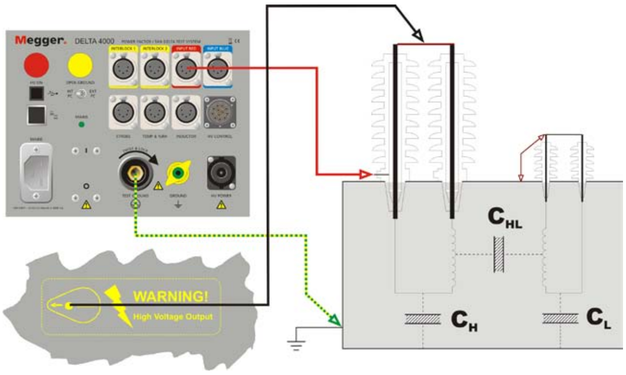


Figure 11: UST-R, test on transformer bushing

Connect a ground wire from the test set to the host apparatus for the bushing under test.

1] Connect the high voltage lead from the test set to the center conductor of the bushing. If the bushing under test is in a transformer, jumper all the bushings of the same winding. Also jumper the bushings of the other windings and connect them to ground. Make sure the bare connector on the high voltage lead extends away from the bushing under test to avoid contact with the bushing porcelain.

2] Connect the low voltage lead from the test set to the test tap. Test tap accessibility will differ with the bushings' style and rating. Some test taps are terminated in a miniature bushing mounted on the grounded mounting flange of the bushing. The tap is grounded in normal service by a screw cap on the miniature bushing housing. By removing the screw cap the tap terminal is available to perform the tests. Most taps are readily accessible, but a special probe is necessary to make contact with the tap in certain bushing designs.

3] The tap housing may contain a small amount of oil or compound. Care must be taken when removing the screw cap to catch the oil. Be sure the oil is replaced after testing is completed.

Test procedure

For all power factor testing, the more information you record at the time of testing will ensure the best comparison of results at the next routine test. Test data should be compared to the nameplate data. If nameplate or factory readings are not available, compare the results of prior tests on the same bushing and results of similar tests on similar bushings.

Always observe safety rules when conducting tests. Have a conference before testing begins and make sure all personnel understand the danger areas.

1] Power factor testing is extremely sensitive to weather conditions. Tests should be conducted in favorable conditions whenever possible.

2] The c1 main insulation test is normally performed at 10kV in the UST test mode. Always refer to the name plate voltage rating of the bushing under test. If 10kV exceeds the rating of the bushing, test at or slightly below the voltage rating.

3] Proceed with the test and record the results.

4] Identify each set of readings with the bushing serial number. Record manufacturer, type or model and other nameplate ratings. Especially be aware to record nameplate c1 capacitance and power factor values. Note any special or unusual test connections or conditions.

5] Record actual test voltage, current, Watts, power factor and capacitance.

6] Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

7] Correct the power factor readings to 20°C. If the bushing is mounted in a transformer, use an average of the top oil temperature and the ambient.

Test results

Interpretation of capacitance and dissipation factor measurements on a bushing requires a knowledge of the bushing construction since each type bushing has its own peculiar characteristics. For example, an increase in dissipation factor in an oil-filled bushing may indicate that the oil is contaminated, whereas an increase in both dissipation factor and capacitance indicates that the contamination is likely to be water. For a condenser type bushing which has shorted layers, the capacitance value will increase, whereas the dissipation factor value may be the same in comparison with previous tests.

Except for the specific purpose of investigating surface leakage, the exposed insulation surface of the bushing should be clean and dry to prevent surface leakage from influencing the measurement. The effects of surface leakage are eliminated from the measurement when testing by the UST test method.

Temperature correction curves for each design of bushing should be carefully established by measurement and all measurements should be temperature corrected to a base temperature, usually 20°C. The temperature measurement should be based on that at the bushing surface. The air temperature should also be recorded. When testing a bushing by the grounded specimen method, the surface of the bushing should be at a temperature above the dew point to avoid moisture condensation.

General guidelines for evaluating the C1 power and dissipation factor test data are as follows:

- Between nameplate tan delta and up to twice nameplate tan delta - bushing acceptable

- Between twice nameplate tan delta and up to 3 times nameplate tan delta - monitor bushing closely
- Above 3 times nameplate tan delta - replace bushing

General guidelines for evaluating the C1 capacitance data are as follows:

- Nameplate capacitance +/-5% - bushing acceptable
- Nameplate capacitance +/-5% to +/-10% - monitor bushing closely
- Nameplate capacitance +/-10% or greater - replace bushing

Changes in C1 test data are usually contamination issues caused by moisture ingress, oil contamination or breakdown and short-circuited condenser layers.

Inverted tap to center conductor test C1 (UST)

The inverted tap test can be performed on bushings with test taps. The high voltage lead and the low voltage lead are reversed for this test. The high voltage lead is connected to the test tap and the low voltage lead is connected to the center conductor of the bushing. The test tap may have to be accessed with a special probe as previously described. This test is normally not performed except on bushings that have abnormal test results from the standard UST method. Care must be taken to ensure test voltages do not exceed the tap rating. All windings must be shorted and test results recorded as in the standard C1 UST method.

Power and dissipation factor & capacitance test C2

The C2 test measures only the insulation between the tap and ground and is not appreciably affected by connections to the bushing center conductor. The tap is energized to a pre-determined test voltage and measured to ground in the grounded specimen test (GST) mode.

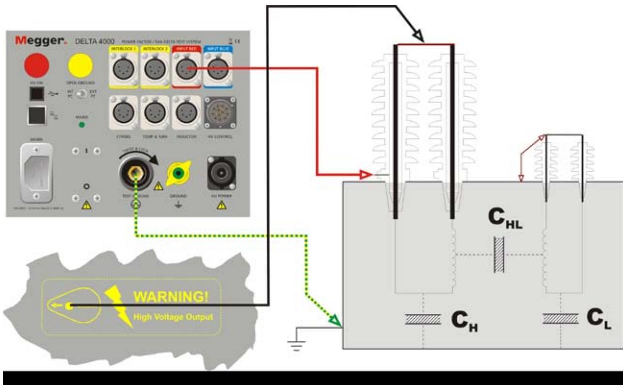


Figure 12: C2, GST GND, test on transformer bushing

Always refer to nameplate data or manufacturer's literature on the bushing for tap test voltages. Please note that the power factor tap is normally designed to withstand only about 500 V while a capacitance tap may have a normal rating of 2.5 to 5 kV. Before applying a test voltage to the tap, the maximum safe test voltage must be known and observed. Typical test voltages for potential taps are between .5kV and 2kV. Power factor taps test voltages should not exceed .5kV. If no information is given, do not exceed .5kV to prevent inadvertent damage to the insulation. An excessive voltage may puncture the insulation and render the tap useless.

Some bushings do not have a power factor or capacitance tap or an isolated mounting flange. These bushings must be electrically isolated from the apparatus for test. This can be accomplished by removing the metal bolts and temporarily replacing them with insulated bolts. The insulating gasket between the bushing flange and apparatus cover will normally provide sufficient insulation so that a UST type measurement can be made on the bushing in the same manner as for a bushing which has provisions for flange isolation. Verify isolation with an ohmmeter.

Test connections (GST)

Connect a ground wire between the test set and the host apparatus for the bushing under test.

1] Connect the high voltage lead from the test set to the test tap. Test tap accessibility will differ with the bushings' style and rating. Refer to previous discussion on test taps. Care must be taken to support the high voltage lead, as the test tap electrode may be fragile.

2] Connect the low voltage lead from the test set to the center conductor of the bushing for the guarded test method.

Test procedure

Before energizing the test specimen, double check that the test set will initially energize at low or zero potential. Carefully increase test set output to desired test voltage.

1] Identify each set of readings with the bushing serial number. Record manufacturer, type or model and other nameplate ratings. Note any special or unusual test connections or conditions.

2] Record actual test voltage, current, Watts, power factor and capacitance.

3] Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

4] Correct the power factor readings to 20°C

Test results

- Changes in C2 power/dissipation factor, which is not usually included on the nameplate, are most commonly indicative of oil contamination.
- Changes in C2 capacitance are typically indicative of physical change, such as tap electrode problems or tap connection problems. Nameplate values for C2 are not typically found on nameplates of bushings rated below 115 kV.

General guidelines for evaluating the C2 power and dissipation factor data are as follows:

- Compare test results to prior tests on the same bushing.

- Compare test results to similar tests on similar bushings. (note: power and dissipation factor results are generally around 1%)

Hot collar test

For bushings not equipped with either a test tap or a voltage tap, the only field measurement which can be performed is the hot collar test. The dielectric losses through the various sections of any bushing or pothead can be investigated by means of the test which generates localized high-voltage stresses. This is accomplished by using a conductive hot collar band designed to fit closely to the porcelain surface, usually directly under the top petticoat, and applying a high voltage to the band. The center conductor of the bushing is grounded. The test provides a measurement of the losses in the section directly beneath the collar and is especially effective in detecting conditions such as voids in compound filled bushings or moisture penetration since the insulation can be subjected to a higher voltage gradient than can be obtained with the normal bushing tests.

This method is also useful in detecting faults within condenser layers in condenser-type bushings and in checking the oil level of oil-filled bushings after a pattern of readings for a normal bushing has been established. If abnormal mA or Watts reading is obtained, the test should be repeated with the hot collar band wrapped around the porcelain surface directly under the second petticoat rather than the first. If necessary, move the band further down on the bushing to determine the depth that the fault has progressed. The hot collar measurements are made by normal GST GROUND test method and the bushing need not be disconnected from other components or circuits. Make sure that the collar band is drawn tightly around the porcelain bushing to ensure a good contact and eliminate possible partial discharge problems at the interface. Refer to the sections on “Significance of Humidity” and “Surface Leakage” if tests are made under unfavorable weather conditions.

Test connections (GST)

Connect a ground wire between the test set and the host apparatus for the bushing under test.

1] Install the collar just under the top petticoat of the bushing under test. Ensure the collar is drawn tight around the bushing for good contact.

2] Connect the high voltage lead from the test set to the collar. Ensure the high voltage cable extends away from the bushing at a 90 degree angle and not resting against the porcelain.

3] Ground the center conductor of the bushing.

Test procedure

Energize the collar to 10 kV, if 10 kV exceeds the rating of the bushing, test at or slightly below the rating of the bushing.

1] Identify each set of readings with the bushing serial number. Record manufacturer, type or model and other nameplate ratings. Note any special or unusual test connections or conditions.

2] Record actual test voltage, current, and Watts. Power factor and dissipation factor data is not recorded.

3] Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

Test results

General guidelines for evaluating the hot collar data are as follows:

- Watts-loss values less than 100 mW - bushing acceptable
- Watts-loss values of 100 mW or more - bushing unacceptable (contamination)
- Current values within 10% of similar bushings - bushing acceptable
- Current values less than 10% of similar bushings - bushing unacceptable (low level of liquid or compound)

If Watt-loss values are in the unacceptable range, cleaning may be necessary on the exposed insulation surface of the bushing. Effects of surface leakage can be substantially minimized by cleaning and drying the porcelain surface and applying a very thin coat of Dow Corning #4 insulating grease (or equal) to the entire porcelain surface.

Spare bushing tests

All the tests discussed thus far are for bushings installed in apparatus. These same tests can be performed on spare bushings with minor changes in the test criteria. All tests of spare bushings should be performed on bushings mounted vertical or at an angle of inclination to the vertical not to exceed 20 degrees.

Circuit breakers

Introduction

Circuit-breakers are designed to interrupt either normal or short-circuit currents. They behave like big switches that may be opened or closed by local push-buttons or by distant telecommunication signals emitted by the system protection. Thus, circuit-breakers will automatically open a circuit whenever the line current, line voltage, frequency, etc. exceeds their limit values. The most common types of circuit-breakers are:

- Oil Circuit-Breakers (OCB's)
- Air-Blast Circuit-Breakers
- SF_6 Circuit-Breakers
- Vacuum Circuit-Breakers
- Air Magnetic Circuit-Breakers
- Oil Circuit Reclosers

The nameplate on a circuit breaker usually indicates (1) the maximum steady-state current it can carry, (2) the maximum interrupting current, (3) the maximum line voltage, and (4) the interrupting time in cycles. It is critical that large currents are interrupted quickly. High speed interruption limits the damage to transmission lines and equipment and, equally important, it helps to maintain the stability of the system when a contingency occurs. Also of critical importance is the insulation of the bushings and tank members of the circuit-breakers. Power and dissipation factor testing provides a means of verifying the integrity of the insulation.

The most important insulation in medium and high-voltage outdoor power switch gear is that of the bushings themselves, the guide assembly, the lift rods, and, in the case of oil circuit breakers, the oil. Measurements should be made from each bushing terminal to the ground tank with the breaker open, and from each phase (each pair of phase bushing terminals) to the grounded tank with the breaker closed. When an individual bushing assembly is tested in each phase, the other bushing terminal in that phase should be guarded. It is also desirable to test samples of the liquid insulation.

Oil circuit-breakers

Oil circuit-breakers are composed of a steel tank filled with insulating oil. A typical three-phase oil circuit breaker has six bushings. Three bushings channel the three-phase line currents to a set of fixed contacts. Three movable contacts, actuated simultaneously by an insulated rod, open and close the circuit. When the circuit breaker is closed, the line current for each phase penetrates the tank by way of one bushing, flows through the first fixed contact, the movable contact, the second fixed contact, and then out by the second bushing.

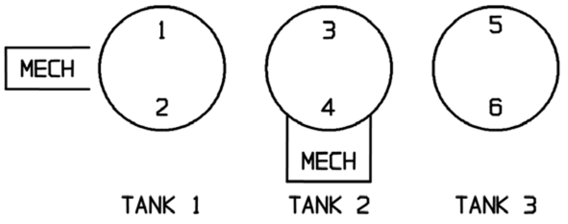
Test connections

There are six overall tests performed when the breaker is open. Each bushing is individually tested in the overall GST test mode. If the bushing is equipped with a test tap, the C_1 main insulation test can be performed in the UST mode along with the overall GST test without making a lead change. Three overall tests are performed with the breaker closed in the GST test mode.

Table 3.4
Dead tank circuit breaker test connections

Test No.	CB	Insulation tested	Low voltage lead configuration				Test connections to bushings			Remarks
			Test mode	Measure	Ground	Guard	High voltage	Red	Blue	
1	OPEN	C1G	GST-GND		Red & Blue		1			Bushing 2 floating
2		C2G	GST-GND		Red & Blue		2			Bushing 1 floating
3		C3G	GST-GND		Red & Blue		3			Bushing 4 floating
4		C4G	GST-GND		Red & Blue		4			Bushing 3 floating
5		C5G	GST-GND		Red & Blue		5			Bushing 6 floating
6		C6G	GST-GND		Red & Blue		6			Bushing 5 floating
7		C12	UST-R	Red	Blue		1	2		
8		C34	UST-R	Red	Blue		3	4		
9		C56	UST-R	Red	Blue		5	6		
10	CLOSED	C1G + C2G	GST-GND		Red & Blue		1 or 2			
11		C3G + C4G	GST-GND		Red & Blue		3 or 4			
12		C5G + C6G	GST-GND		Red & Blue		5 or 6			

Diagram



Insulation tested
1 to 6 = Bushing terminals
G = Ground
Note: No. in High Voltage column is bushing energized. Tests 1 through 6, 10, 11, and 12 all other bushings must be floating.

Connect a ground wire from the test set to the grounded frame of the breaker.

1] Connect the high voltage lead to the main conductor lug of the bushing under test. Ensure that the cable extends out away from the bushing and does not rest on the porcelain.

2] If the bushing is equipped with a test tap, connect the low voltage lead to the tap. Test tap connections can be difficult to make on some bushing styles. Accessibility will differ with the bushings' style and rating. Power factor taps are usually terminated in a miniature bushing mounted on the grounded mounting flange of the bushing. The tap is grounded in normal service by a screw cap on the miniature bushing housing. By removing the screw cap the tap terminal is available to perform the tests. Most taps are readily accessible, but a special probe is necessary to make contact with the tap in certain bushing designs. In some cases the power factor tap housing may contain a small amount of oil or compound. Care must be taken when removing the screw cap to catch the oil. Ensure that the oil or compound is replaced after testing is completed.

3] When the overall GST-GND test is performed, the low voltage lead is grounded. The test path is through the high voltage lead, through the bushing to ground.

4] When the UST UST-R test is performed, the test path is through the high voltage lead, the C1 main insulation and the low voltage lead.

Test Procedure

Always observe safety rules when conducting tests. Power factor testing is extremely sensitive to weather conditions. Tests should be conducted in favorable conditions whenever possible.

With the breaker in the open position , start with the #1 bushing and perform the GST test. If the bushing is equipped with a test tap, perform the UST test. Repeat the tests for all six bushings.

1] With the breaker in the closed position, perform the GST test on all three phases.

2] All tests are performed at 2.5kv or 10kv or a voltage suitable for the insulation.

Test Results

For all power factor testing, the more information you record at the time of testing will ensure the best comparison of results at the next routine test. Test data should be compared to the nameplate data. If nameplate or factory readings are not available, compare the results of prior tests on the same breaker and results of similar tests on similar breakers. The following additional information should be recorded on the test form.

Enter all the nameplate information of the oil circuit breaker. Identify each set of readings with the bushing serial number. Record manufacturer, type or model and other nameplate ratings. Especially be aware to record nameplate C1 capacitance and power factor values if available.

1] Note any special or unusual test connections or conditions.

2] Calculate the tank-loss index per formulas below.

3] Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

4] Correct the power factor readings on the bushings to 20°C using the ambient temperature.

The specific term tank-loss index has been developed to assist in evaluating the results of the open and closed oil circuit-breaker tests.

It is defined for each phase as the measurement Watts of the closed breaker minus the measured Watts of the two measurements the breaker open. Referring to Table 7 above the Tank-loss indexes are

- Tank 1: Watts[test 7] – {Watts[test 1] – Watts[test 2]}
- Tank 2: Watts[test 8] – {Watts[test 3] – Watts[test 4]}
- Tank 3: Watts[test 9] – {Watts[test 5] – Watts[test 6]}

It is defined for each phase as the difference of the measured open circuit and the closed circuit power, in watts. To obtain the open circuit value, the individual values measured on the two bushings of each phase must be summed. Tank-loss index may have values ranging from positive to negative which will give an indication of the possible source of a problem. Positive indexes occur when the closed circuit values are larger than the sum of the open circuit values. Conversely, negative indexes occur when the closed circuit values are smaller than the sum of the open circuit values.

Comparison of tank-loss indexes taken when an oil circuit breaker is new and initially installed will give the general range of values to expect from a good unit. This practice also will avoid condemning a good unit as the result of the inherent design of a particular manufacturer that normally may show tank-loss indexes without the unit being defective or deteriorated.

The losses in an oil circuit breaker are different between an open circuit test and a closed circuit test because the voltage stress on the insulating members is distributed differently. Tables 3.5 and 3.6 summarize what may be defective based upon the polarity of the tank-loss index. Once a particular section has given indications of deterioration, the test results should be verified by systematically isolating the suspected insulating member before disassembling the unit.

Table 3.5
Tank-loss index of oil circuit breakers (Equivalent to 10 kV losses)

Tank loss index	Test remarks	Probable problem	Insulation rating
<±0.16 W	Normal results for both open CB tests	None	Good
>+0.16 W	Normal results for both open CB tests	1. Tank oil 2. Tank liner 3. Lift rod 4. Auxiliary contact insulation	Investigate
>-0.16 W	High losses for both open CB tests Closed CB test near normal	1. Cross guide assembly 2. Isolated cross guide 3. Contact assembly insulation 4. Lift rod upper section (moisture contaminated)	Investigate
<±0.16 W	Normal results for one open CB test Other has high losses	1. Bushing with high loss reading 2. Arc interruption assembly	Investigate
<±0.16 W	High losses for both open CB tests and closed CB test	1. Bushings 2. Arc interruption assembly 3. Tank oil 4. Tank liner 5. Lift rod 6. Auxiliary contact insulation 7. Cross guide assembly 8. Isolated cross guide 9. Contact assembly insulation	Investigate

Oil circuit breakers are composed of many different materials each having its own temperature coefficient. For this reason it may be difficult to correct tank-loss indexes for a standard temperature. On this basis, an attempt should be made to conduct tests at approximately the same time of the year to minimize temperature variations. The measurements on the bushings, however, may readily be corrected to the base temperature; usually 20°C.

Comparison of tank-loss indexes taken when an oil circuit-breaker is new and initially installed will give the general range of values to expect from a good unit. This practice also will avoid condemning a good unit as the result of the inherent design of a particular manufacturer that normally may show tank-loss indexes without the unit being defective or deteriorated. The losses in an oil circuit-breaker are different between an open circuit test and a closed circuit test because the voltage stress on the insulating members is distributed differently.

Air-blast circuit-breakers

These circuit-breakers interrupt the circuit by blowing compressed air at supersonic speed across the opening contacts. Compressed air is stored in reservoirs and is replenished by a compressor located in the substation. There are two interrupters mounted in a live tank which is then mounted on an insulated column. The interrupting capacity of the circuit determines the height of the column and the number of tanks per-phase connected in series. The most powerful circuit-breakers can typically open short-circuit currents of 40 kA at a line voltage of 765 kV in a matter of 3 to 6 cycles on an AC line. Other designs of live tank breakers may be of a T or Y design with one interrupter mounted in each arm of the porcelain housing.

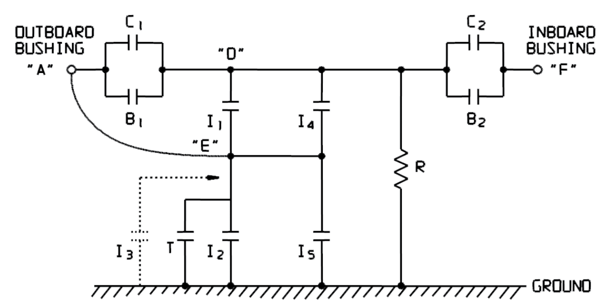
Test connections

Air and gas circuit breakers vary so much in construction that specific instructions and interpretation would be too lengthy. This section, however, does contain a detailed test connection chart (Table 3.7) outlining the normal series of measurements performed on a General Electric Type ATB Air-Blast Circuit Breaker. Table 3.8 outlines the normal series of measurements performed on a three-column live tank breaker.

Table 3.7
General Electric Air-blast type circuit breaker test connections

Test No.	Insulation tested	Low voltage lead configuration				Test connections to breaker			Remarks
		Test mode	Measure	Ground	Guard	High voltage	Red	Blue	
1	C2 + B2	UST-R	Red	Blue		D	F	A	A Grounded
2	C1 + B1 + I1	UST-B	Blue	Red		D	F	A	F Grounded
3	C2 + B2 + C1 + B1 + I1	UST	Red & Blue			D	F	A	
4	R (or R + I3)	GST			Red & Blue	D	F	A	F & A Guarded
5	I2 + T *	GST		Red	Blue	A	F	D	D Guarded F Grounded

* Test performed only on units with current transformer.

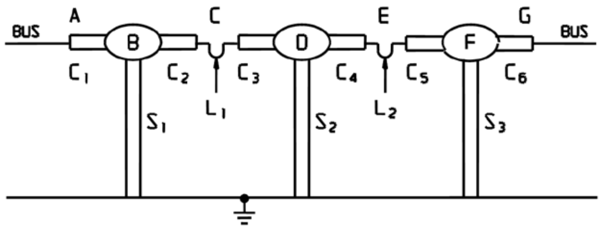


Measurement Intercheck	
Capacitance	$C_1 = C_3 - C_2$
Watts:	$W_1 = W_3 - W_2$
Note: Subscripts are test no.'s.	

B1 & B2	Entrance bushings
C1 & C2	Grading capacitors
D	Module live tank
I1	Upper insulator
I2	Lower insulator
I3	Insulator for units without current transformer
R	Glass fiber air supply tube, open rods and wood tie rods
T	Current transformer insulation
I4 and I5	Protective glass fiber tube that encloses R tube is slit at "E" with metal guard ring

Table 3.8
Live tank circuit breaker test connections (Typical three-column support per phase)

Test No.	Insulation tested	Φ	Low voltage lead configuration				Test connections to breaker			Remarks
			Test mode	Measure	Ground	Guard	High voltage	Red	Blue	
1	C1		UST-R	Red	Blue		B	A	C	C Grounded
2	C2		UST-B	Blue	Red		B	A	C	A Grounded
3	S1		GSTg-RB			Red & Blue	B	A	C	A & C Guarded
4	C3		UST-R	Red	Blue		D	C	E	E Grounded
5	C4		UST-B	Blue	Red		D	C	E	C Grounded
6	S2		GSTg-RB			Red & Blue	D	C	E	C & E Guarded
7	C5		UST-R	Red	Blue		F	E	G	G Grounded
8	C6		UST-B	Blue	Red		F	E	G	E Grounded
9	S3		GSTg-RB			Red & Blue	F	E	G	E & G Guarded



A, C, E & G	Low lead test connections
B, D, F	Module live tanks
C1 thru C6	Module entrance bushing and grading capacitors
L1, L2	Connection links joining modules
S1, S2, S3	Module support columns

Note: To reduce the effects of severe electrostatic interference, disconnect one side of L1 and L2 links to break circuit between modules. All terminals and bus work not in measurement circuit must be solidly grounded.

Test procedure

Tests are performed at 10kV or a voltage suitable for the insulation rating.

1] All tests are conducted with the breaker in the open position.

2] Identify each set of readings with the apparatus serial number. Enter the manufacturer, type or model and other nameplate ratings. Note any special or unusual test connections or conditions.

3] Enter ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

4] Record actual test voltage, current, watts, power factor and capacitance. Correct current and watts to a standard test voltage 10 kV if necessary.

5] Unless specifically noted, power factor readings do not need to be temperature corrected.

Test results

- High power factor readings on entrance bushings or grading capacitors may be the result of deteriorated grading capacitors or, in some cases, surface leakage. If higher capacitance values occur, compared to prior tests, it could be the result of short-circuited sections of the grading capacitor.
- High losses on the column structure could be the result of moisture or surface leakage.
- Test results for power factor and capacitance are significantly different between manufacturers, model numbers, style, type and date the apparatus was manufactured. Test data should be compared to the manufacturers' data. If nameplate or factory readings are not available, compare the results of prior tests on the same apparatus and results of similar tests on similar apparatus.

SF_6 Circuit-breakers

These totally enclosed circuit-breakers, insulated with SF_6 gas (Sulfur Hexafluoride), are used whenever space is at a premium, such as in downtown substations. They are much smaller than any other type of circuit-breaker of equivalent power and are far less noisy than air circuit-breakers.

Test connections

Test setup is essentially the same for all live tank circuit breakers. Additional Hot-Collar tests may be conducted on breakers equipped with gas-filled bushings to detect internal contamination or exterior cracks and other problems that may have occurred along the surface of the bushing. See also section bushing testing.

Connect a ground wire from the test set to the grounded frame of the breaker.

1] Connect the high voltage lead to the main conductor lug of the bushing under test. Ensure that the cable extends out away from the bushing and does not rest on the porcelain.

2] Connect the low voltage lead to the test tap if available. Refer to previous discussion on test taps. Both the overall GST test and the C_1 UST test can be performed without a lead change.

Test procedure

- Tests are performed at 2.5kv or 10kv or a voltage suitable for the insulation.
- Tests 1 - 9 are conducted with the breaker open. Tests 10 - 12 are conducted with the breaker closed.
- Some breaker designs have internal insulators to support other linkage and apparatus inside the tank.

The closed breaker tests verify the insulation integrity of these components.

Identify each set of readings with the apparatus and/or bushing serial number. Record the manufacturer, type, style, model and other nameplate ratings. Note any special or unusual test connections or conditions.

1] Measure actual test voltage, current, watts, power factor and capacitance. Correct current and watts to a standard test voltage 2.5kv or 10kv if necessary.

2] Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

3] If the C1 test is performed on the bushings, correct power factor readings to 20°C.

Test results

High watts loss and power factor results on tests 1 - 6 and 10 - 12 could be related to an excess of moisture on the internal apparatus. If moisture is the problem, opening and closing the breaker several times in succession could improve the test results.

The results of the UST measurements in tests 7 - 9 are meaningful to breakers that have grading capacitors across the contacts. High capacitance's compared to similar tests may be the result of short-circuited sections in one or more of the grading capacitors .

Vacuum circuit breakers

These circuit-breakers operate on a different principle from other breakers because there is no gas to ionize when the contacts open. They are hermetically sealed; consequently, they are silent and never become polluted. Their interrupting capacity is limited to about 30kv. For higher voltages, several circuit-breakers are connected in series. Vacuum circuit-breakers are often used in underground systems.

Test connections

Connections are the same as for dead-tank oil breakers. Additional Hot-Collar tests may be performed on suspect bushings that have unusually high losses.

Connect a ground wire from the test set to the grounded frame of the breaker.

1] Connect the high voltage lead to the main conductor lug of the bushing under test. Ensure that the cable extends out away from the bushing and does not rest on the porcelain. All other bushings should float.

2] Connect the low voltage lead to the test tap if available. Refer to the previous discussion on test taps.

Both the overall GST test and the C_1 UST test can be performed without a lead change.

Test procedure

Tests are performed at 2.5kv or 10kv or a voltage suitable for the insulation. All tests are performed with the vacuum breaker in the open position. Tests 1 - 6 are conducted in the GST mode and tests 7 - 9 are in the UST mode.

Identify each set of readings with the apparatus and/or bushing serial number. Record the manufacturer, type, style, model and other nameplate ratings. Note any special or unusual test connections or conditions.

1] Measure actual test voltage, current, watts, power factor and capacitance. Correct current and watts to a standard test voltage 2.5kv or 10kv if necessary.

2] Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.

If the C1 test is performed on the bushings, correct power factor readings to 20°C.

Test results

Charging currents are expected to be small. Under dry ambient conditions, power factor results will be small and dielectric losses close to zero. Higher than normal UST measurement could be due to a defective vacuum bottle allowing moisture to enter or surface leakage across the vacuum housing. Clean the surface of the vacuum bottle and retest. Ensure all cabinet heaters are working to maintain a sufficient temperature surrounding the vacuum bottles.

Air magnetic circuit-breakers

The tests and test modes on air-magnetic circuit-breakers are conducted in the same manner as the vacuum circuit-breakers. The test connections for tests 1 - 6 are conducted in the GST mode with the opposite bushing in the same phase guarded. Normally tests 1 - 6 are conducted with the arc-chutes in place. If it is desirable to eliminate the influence of the arc-chutes, raise or remove them and repeat tests 1 - 6. Follow the same test procedure as for the vacuum breakers and record the results. If nameplate or factory readings are not available, compare the results or prior tests on the same breaker and results of similar tests on similar breakers. Tests 1 - 6 and the UST tests should be analyzed on dielectric losses, not power factor. If bushings are equipped with test taps follow the tests procedures previously discussed in this guide.

Oil circuit reclosers

Testing of oil circuit reclosers is performed in the same manner as oil circuit-breakers. The current and watts are recorded and corrected to 2.5kv or 10kv if necessary. Power factor is recorded for the closed breaker tests, but not corrected for temperature. Test results are evaluated in the same manner as the oil circuit breakers and the tank-loss index is computed..

Rotating machines

The main purpose of capacitance and dissipation factor tests on rotating machines is to assess the extent of void formation within the winding insulation and the resulting damage to the insulation structure due to partial discharges (ionization in voids). An overall measurement on a winding will also give an indication of the inherent dissipation factor of the winding insulation and will reveal potential problems due to deterioration, contamination, or moisture penetration.

A power factor (dissipation factor) tip-up test is a widely used maintenance test in evaluating the extent of insulation deterioration caused by ionization. In this test, the dissipation factor is measured at two different voltages, the first low enough so that no ionization occurs (normally 25 percent of rated line-to-ground voltage), the second at rated line to ground voltage or slightly above rated voltage. The tip-up value is obtained by subtracting the value of the dissipation factor measured at the lower test voltage from that measured at the higher test voltage. When the dissipation factor increases significantly above a certain voltage, it is evident that ionization is active and producing some loss. An increase in dissipation factor above a certain voltage is a guide to the rate at which ionization is occurring and gives guidance as to how the ionization action may be expected to accelerate. If voids are short-circuited when ionization occurs, some increase of capacitance with voltage may also result. Any forecast of remaining useful life must be based upon knowledge of the resistance of the particular insulation to ionization.

In general, the coils nearest the line terminals and operating at the highest voltage to ground are most affected by ionization. The reliable life remaining in a winding can often be extended by obtaining dissipation factor versus voltage curves on all coils, replacing only the worst, and regrouping them so that the coils with the least increase of dissipation factor, and preferably lower value of dissipation factor, are nearest the line terminals. Considerable extension of winding life can also be realized in many cases by measuring dissipation factor versus voltage on groups of coils without removal and rearranging the line and neutral connections accordingly. This can be done several times in a lifetime so that the coils are evenly deteriorated.

An overall measurement on a rotor or stator winding is made on the insulation between the winding and ground. In the case of three-phase stator windings, where the connection between the winding phases and neutral can be conveniently opened, additional measurements are also made on the inter-winding or phase-to-phase insulation. When a tip-up test is made on a complete phase winding, only the average value is measured; an isolated section having an abnormally high tip-up may be completely masked.

Table 3.10 shows the specific connections between the test set and a typical generator three-phase stator winding as well as the routine series of measurements performed on the windings. It is assumed that the connection between the winding phases and also neutral are opened. The phase-to-ground insulation tests are made by the GST-GND test method, whereas, the phase-to-phase tests are made by the UST test method.

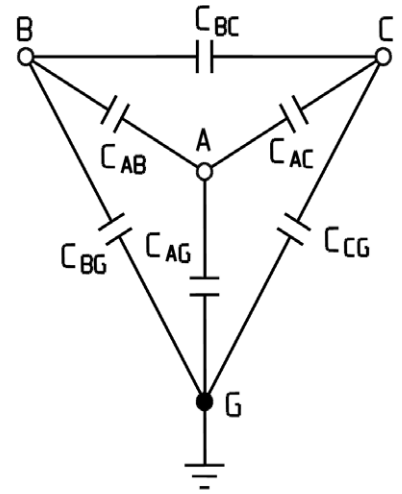
When testing large generator windings which have a very high value of capacitance per phase, the maximum specimen capacitance measurable at a particular test voltage may be limited due to maximum output current from test equipment. For this case tests will have to be made at a reduced voltage level or with the use of Resonating Inductor (Cat. No. 670600).

The temperature of the windings should be above and never below the ambient temperature to avoid the effects of moisture condensation on the exposed insulating surface. Temperature measurements when using temperature correction curves should be based on that at the winding surface.

Avoid prolonged exposure to high humidity conditions before testing because such exposure may result in moisture absorption in the insulating materials. It is desirable to make tests on the winding insulation shortly after shutdown.

Table 3.10
Three-phase rotating machinery
Stator test connections (Motors and generators)

Test No.	Insulation tested	Low voltage lead configuration				Test connections to windings			Remarks
		Test mode	Measure	Ground	Guard	High voltage	Red	Blue	
1	A to ⏚	GSTg-RB			Red & Blue	A	B	C	B & C Guarded
2	A to B	UST-R	Red	Blue		A	B	C	C Grounded
3	B to ⏚	GSTg-RB			Red & Blue	B	C	A	C & A Guarded
4	B to C	UST	Red	Blue		B	C	A	A Grounded
5	C to ⏚	GSTg-RB			Red & Blue	C	A	B	A & B Guarded
6	C to A	UST	Red	Blue		C	A	B	B Grounded
7	A + B + C to ⏚	GST-GND				A, B, C	–	–	May require Resonating Inductor

Equivalent Circuit		Remarks
		
A	Phase A winding	
B	Phase B winding	
C	Phase C winding	
G	Ground	
Note: Short each winding on itself if possible.		

Cables

Cables rated for operation at 5 kV and above are usually shielded by a metal cable sheath. Measurements for this type cable are made by the GST GROUND test method and are confined to the insulation between the conductor and the sheath. The high-voltage lead is connected to the cable conductor and the cable sheath solidly connected to the same grounding system as the test set.

When testing three conductor cables which have a single metal cable sheath, UST tests should be made between each conductor combination with the remaining cable grounded. A second set of tests should be made between each conductor and ground with the remaining two conductors guarded (GST test with guarding). A third test should be made between all conductors connected together and ground (GST GROUND test). This test procedure is similar to that when testing three winding transformers.

The test set measures the average dissipation factor of the cable; therefore, if a long length of cable is measured, an isolated section of cable having an abnormally high dissipation factor may be completely masked and have no significant effect on the average value. Thus, the ability to detect localized defects will diminish as the cable length increases. Tests on long lengths of cable give a good indication of the inherent dissipation factor of the insulation and when compared with previous tests or measurements on similar cable may reveal potential problems due to general deterioration, contamination, or moisture penetration.

Cables are inherently of relatively high capacitances per unit length (0.5uF per phase per mile / 0,3 uF per phase per km) so that for long lengths the kVA capacity of the test set power supply may be exceeded. Refer to Section 3, Specifications, for maximum specimen capacitance measurable at a particular test voltage.

Surge (lightning) arresters

Introduction

The purpose of a surge (lighting) arrester is to limit the over voltages that may occur across transformers and other electrical apparatus due either to lightning or switching surges. The upper end of the arrester is connected to the line or terminal that has to be protected, while the lower end is solidly connected to ground. The arrester is composed of an external porcelain tube containing an ingenious arrangement of stacked discs (or valve blocks) that are composed of a silicon carbide material known by trade names such as thyrite, autovalve, etc. This material has a resistance that decreases dramatically with increasing voltage. Arresters are effectively switching devices that serve as an insulator under normal conditions and as a conductor under over voltage conditions. After an over voltage condition is cleared the arrester must return to its normal insulating condition. The measurement of power loss is an effective method of evaluating the integrity of an arrester and isolating potential failure hazards. This test reveals conditions which could affect the protective functions of the arrester, such as: the presence of moisture, salt deposits, corrosion, cracked porcelain, open shunt resistors, defective pre-ionizing elements, and defective gaps.

A complete test on a surge arrester involves impulse and overvoltage testing as well as a test for power loss at a specified test voltage using normal 50/60 Hz operating frequency. Impulse and overvoltage testing is not generally performed in the field since it involves a large amount of test equipment that is not easily transportable.

To evaluate the insulation integrity of an arrester, measure the power loss (watts-loss or dissipation factor) at a specified voltage and compare it with previous measurements on the same or similar arrester. Measurements on a surge arrester should always be performed at the same or recommended test voltage since nonlinear elements may be built into an arrester. When using this test set, all measurements should normally be made at 10 kV. Except for the specific purpose of investigating surface leakage, the exposed insulation surface of an arrester should be clean and dry to prevent leakage from influencing the measurements.

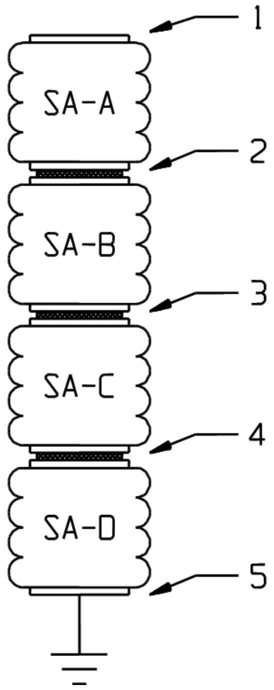
Some types of arresters show a substantial temperature dependence, while others show very little dependence. Temperature correction curves for each arrester design should be carefully established by measurement, and all measurements should be temperature corrected to a base temperature, usually 20°C. The temperature measurement should be based on that at the arrester surface. The air temperature should also be recorded. The surface of the arrester should be at a temperature above the dew point to avoid moisture condensation.

It is recommended that tests be made on individual arrester units rather than on a complete multi-unit arrester stack. A single arrester unit can be tested by the normal ungrounded specimen test (UST) in the shop; however, it can only be tested by the grounded specimen test (GST) when mounted on a support structure in the field. Table 3.11 shows the recommended test procedure for testing installed multi-unit arrester stacks. When testing in the field, disconnect the related high-voltage bus from the arrester. Surge arresters are often rated on the basis of watts loss.

Test connections

Table 3.11
Surge arrester test connections

Test No.	Surge arrester symbol Insulation tested	Low voltage lead configuration				Test connections to surge arrester			Remarks
		Test mode	Measures	Ground	Guard	High voltage	Red	Blue	
1	SA -A	UST-B	Blue	Red		2	3	1	Terminal 3 Grounded
2	SA - B	UST-R	Red	Blue		2	3	1	Terminal 1 Grounded
3	SA - C	UST-R	Red	Blue		4	3	–	
4	SA - D	GST			Red	4	3	–	Terminal 3 Guarded
Note: All tests normally made at 10 kV.									



Typical multi-unit arrester stack

It is recommended that tests be made on individual arrester units rather than on a complete multi-unit arrester stack. A single arrester unit can be tested by the normal ungrounded specimen test (UST) in the shop; however, it can only be tested by the grounded specimen test (GST) when mounted on a support structure in the field.

- When testing in the field, disconnect the related high-voltage bus from the arrester.
- Connect a ground wire from the test set to the steel support structure of the arrester stack,
- When connecting the high voltage lead, ensure that the cable extends out away from the arrester and does not rest on the porcelain.

Test procedure

Always observe safety rules when conducting tests. Power factor testing is extremely sensitive to weather conditions. Tests should be conducted in favorable conditions whenever possible. Measurements on surge arresters should always be performed at the same or recommended test voltage since voltage dependent (non-linear) may be built into an arrester. Except for the specific purpose of investigation surface leakage, the exposed insulation surface of an arrester should be clean and dry to prevent leakage from influencing the measurements. Follow the test sequence as in the table. The test mode and the number of tests performed will be depending on the number of arresters in the stack.

Test results

For all power factor testing, the more information recorded at the time of testing will ensure the best comparison of results at the next routine test. Test data should be compared to factory or nameplate data if available. If no data is available, compare the test results to prior tests on the same arrester and results of similar tests on similar arresters. The following additional information should be recorded on the test form.

- Record all the nameplate information of the arrester.
- Identify each set of readings with the arrester serial number.
- Note any special or unusual test connections or conditions.
- Record actual test voltage, current, watts, power factor and capacitance. Correct the current and watts to a standard test voltage 10kV.
- Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test

Surge arresters are often rated on the basis of watts loss (10 kV equivalent). On multi-unit arrester stacks the UST loss readings may be less that the arresters tested in the GST mode because stray currents do not affect the UST test results.

An increase in watts loss values compared with a previous test or tests on identical arresters under the same conditions may indicate:

- Contamination by moisture
- Contamination by salt deposits
- Cracked porcelain housing
- Corroded gaps.

A decrease in watts loss values may indicate:

- Open shunt resistors
- Defective pre-ionizing elements.

Liquids

Test procedure

To measure the dissipation factor of insulating liquids, a special test cell such as the Megger Catalog No. 670511 Oil Test Cell is required. It is constructed with electrodes which form the plates of a capacitor and the liquid constitutes the dielectric. The test cell is a three-terminal type with a guard electrode to avoid measuring fringe effects and the insulation for the electrode supports.

When samples of insulating liquid are tested, the specimen capacitance may also be used for etermining the dielectric constant (permittivity) of the insulating liquid. The ratio of the test cell capacitance measured when filled (liquid dielectric) to the test cell capacitance measured when empty (air dielectric) is the value of dielectric constant of the liquid.

Miscellaneous assemblies and components

When an apparatus is dismantled to locate internal trouble and make repairs, dissipation factor measurements can be valuable in detecting damaged areas of insulation to such parts as wood or fiberglass lift-rods, guides or support members. Sometimes existing metal parts can be used as the electrodes between which measurements can be made. Sometimes it will be necessary to provide electrodes. Conductive collars, can be used; aluminum foil also works well. Whenever conducting material is used, ensure that intimate contact is made with the critical areas of the insulation. Petroleum jelly or Dow Corning #4 insulating grease applied at the interface surface often helps to obtain better physical contact.

It may sometimes be necessary to separate volume losses from surface losses by providing a third (guard) terminal on or within the specimen insulation system. For example, an insulating tube formed over a metal rod may be tested for internal damage in the insulation. A conductive band (or foil) is applied near the center of the insulating tube with additional conductive (guard) bands on each side, separated from the center band by enough clean insulation to withstand the intended test voltage. With the metal rod grounded, the test set will measure the capacitance and dissipation factor of the volume of insulation between the center conductive band (high-voltage) and the metal rod. Figure 13 shows a typical test setup.

Comparisons between dissipation factors of suspected areas and components against similar parts which can be assumed to be in good condition are of prime importance in analyzing insulation components. Dissipation factor voltage measurements can indicate the presence of ionization in a component by a sudden tip-up of dissipation factor as the test voltage is increased. Delaminations within a material can also be detected in this way. Avoid overstressing component insulation by indiscriminate use of the available test voltage. Consider the voltage on the component under normal operating conditions.

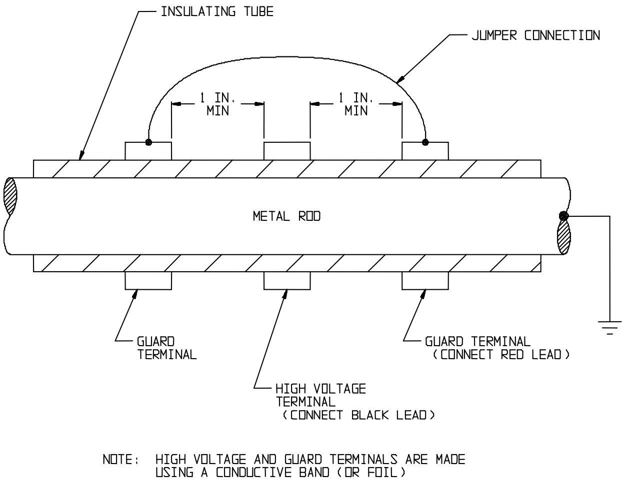


Figure 13: GST test with guarding on insulated tube covering metal rod

High-Voltage turns-ratio measurements

Ratio measurements on HV transformers are commonly made using low voltage instruments designed specifically for that purpose. Those test instruments apply a relatively low voltage (<100V) to either the primary or the secondary of the transformer. The resultant voltage is measured and the voltage ratio is calculated automatically by the test set.

Occasionally there are instances when it is desired to perform higher voltage ratio tests for diagnostic purposes. Using a power factor test set like the Delta4000, voltages of up to 12kV can be applied to a transformer winding, generating a higher turn-to-turn stress on the winding under test. It is believed that higher voltage stress on a winding may break down weak turn-to-turn insulation and help detect faults that might be overlooked by low voltage test equipment. It is important to recognize that the voltage rating of the winding being energized must not be exceeded or damage to good insulation may result.

Test procedure

Determining the ratio of a transformer using the HV TTR Capacitor involves taking a capacitance measurement of the HV TTR Capacitor by itself, then taking another measurement with the capacitor connected to the low-voltage winding of the transformer. The ratio of the capacitance values is equal to the voltage ratio of the transformer windings. The figures below will help explain the procedure.

Figure 1 shows the connection used for accurately determining the capacitance value of the HV TTR Capacitor. The instrument HV output lead is connected to one side of the capacitor, and a LV measuring lead is connected to the other side. Both connections must be isolated from ground, and the test set measuring configuration should be UST (Ungrounded Specimen Test). The capacitance value from this test is C1.

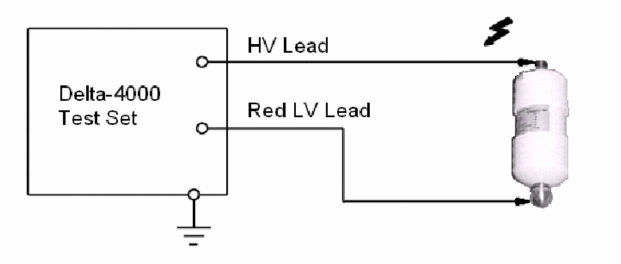


Figure 14: TTR Capacitor measurement

The second step of the procedure is to connect the test set and the HV TTR Capacitor to the transformer winding to be tested. Figure 2 shows this connection on a single-phase transformer. The test set output is connected to one end of the high voltage winding. The other side of the winding must be grounded. The HV TTR Capacitor is connected to one end of the low voltage winding, and is then connected to the measuring lead of the test set. The other side of the low voltage winding is grounded as well.

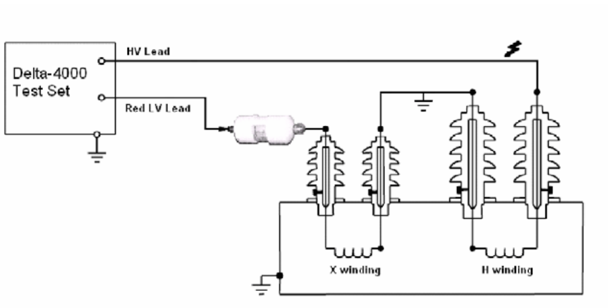


Figure 15: Single-phase transformer

The test set measuring configuration should again be UST. The value of capacitance from this measurement will be identified as C2. NOTE: The polarity of the winding connections should be made per the polarity markings shown on the nameplate of the transformer.

Once the values of C1 and C2 have been established, the ratio (N) of the transformer (for the tap connection being measured) is determined as;

N = C1 / C2

The procedure for testing a three-phase transformer is the same as that for single-phase. Figure 3 shows a typical three-phase configuration (Δ-Δ). As in the previous example, connect the HV output lead to the high voltage winding, and the capacitor plus low voltage measuring lead to the low voltage winding.

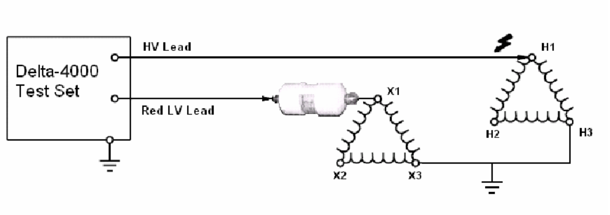


Figure 16: Three-phase Delta-Delta transformer

The test set measuring configuration should again be UST. The capacitance reading obtained from this measurement is also identified as C2. Calculate the transformer ratio using the same formula as the previous example.

For further example, Figure 4 is provided to show a three-phase delta-wye transformer winding and the connections that are required.

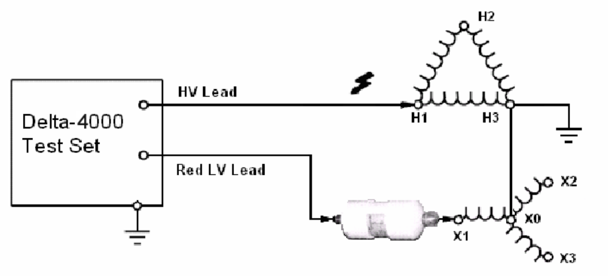


Figure 17: Three-phase Delta-Wye transformer

Temperature considerations

Due to the design of HV TTR Capacitors, their capacitance value may be sensitive to changes in temperature. Once the value of C1 is obtained, it is recommended to promptly take the C2 measurement without delay. This will ensure that no temperature change has occurred and the transformer ratio determined by this method is correct.

Index

References

[1] ANSI Standard 62-1995: “IEEE Guide for Diagnostic Field testing of Electric Power Apparatus - Part 1: Oil Filled Power Transformers, Regulators, and Reactors”, IEEE New York, 1995

[2] US Bureau of Reclamation: “Transformer Diagnostics”, Facility instructions, standards and techniques - Vol. 3-31, 2003

[3] US Bureau of Reclamation: “Testing and Maintenance of High Voltage Bushings”, Facility instructions, standards and techniques - Vol. 3-2, 1991

[4] Schurman, D.: Testing and maintenance of high voltage bushings, Western Area Power administration, 1999

Appendix A
Temperature correction tables

Table A1
Temperature correction factors for liquids, transformers, and regulators

Test temperature		Oil-filled power transformers			
°C	°F	*Askarel filled XFMRS*	*Free-breathing & conservator type*	*Sealed & gasket blanketed type*	*Oil-filled instrument XFMRS*
0	32.0		1.56	1.57	1.67
1	33.8		1.54	1.54	1.64
2	35.6		1.52	1.50	1.61
3	37.4		1.50	1.47	1.58
4	39.2		1.48	1.44	1.55
5	41.0		1.46	1.41	1.52
6	42.8		1.45	1.37	1.49
7	44.6		1.44	1.34	1.46
8	46.4		1.43	1.31	1.43
9	48.2		1.41	1.28	1.40
10	50.0		1.38	1.25	1.36
11	51.8		1.35	1.22	1.33
12	53.6		1.31	1.19	1.30
13	55.4		1.27	1.16	1.27
14	57.2		1.24	1.14	1.23
15	59.0		1.20	1.11	1.19
16	60.8		1.16	1.09	1.16
17	62.6		1.12	1.07	1.12
18	64.4		1.08	1.05	1.08
19	66.2		1.04	1.02	1.04
20	68.0	1.00	1.00	1.00	1.00
21	69.8	0.95	0.96	0.98	0.97
22	71.6	0.90	0.91	0.96	0.93
23	73.4	0.85	0.87	0.94	0.90
24	75.2	0.81	0.83	0.92	0.86
25	77.0	0.76	0.79	0.90	0.83
26	78.8	0.72	0.76	0.88	0.80
27	80.6	0.68	0.73	0.86	0.77
28	82.4	0.64	0.70	0.84	0.74
29	84.2	0.60	0.67	0.82	0.71
30	86.0	0.56	0.63	0.80	0.69
31	87.8	0.53	0.60	0.78	0.67
32	89.6	0.51	0.58	0.76	0.65
33	91.4	0.48	0.56	0.75	0.62
34	93.2	0.46	0.53	0.73	0.60
35	95.0	0.44	0.51	0.71	0.58
36	96.8	0.42	0.49	0.70	0.56
37	98.6	0.40	0.47	0.69	0.54
38	100.4	0.39	0.45	0.67	0.52
39	102.2	0.37	0.44	0.66	0.50
40	104.0	0.35	0.42	0.65	0.48
42	107.6	0.33	0.38	0.62	0.45
44	111.2	0.30	0.36	0.59	0.42
46	114.8	0.28	0.33	0.56	
48	118.4	0.26	0.30	0.54	
50	122.0	0.24	0.28	0.51	
52	125.6	0.22	0.26	0.49	
54	129.2	0.21	0.23	0.47	
56	132.8	0.19	0.21	0.45	
58	136.4	0.18	0.19	0.43	
60	140.0	0.16	0.17	0.41	
62	143.6	0.15	0.16	0.40	
66	150.8	0.14	0.14	0.36	
70	158.0	0.12	0.12	0.33	

Table A2
Bushing temperature correction factors

Test temperature		General Electric					
°C	°F	TYPE B	TYPE F	TYPES L-LC LI-LM	TYPES OF-OFI-OFM	TYPES S-SI-SM	TYPE U
0	32.0	1.09	0.93	1.00	1.18	1.26	1.02
1	33.8	1.09	0.94	1.00	1.17	1.25	1.02
2	35.6	1.09	0.95	1.00	1.16	1.24	1.02
3	37.4	1.09	0.96	1.00	1.15	1.22	1.02
4	39.2	1.09	0.97	1.00	1.15	1.21	1.02
5	41.0	1.09	0.98	1.00	1.14	1.20	1.02
6	42.8	1.08	0.98	1.00	1.13	1.19	1.01
7	44.6	1.08	0.98	1.00	1.12	1.17	1.01
8	46.4	1.08	0.99	1.00	1.11	1.16	1.01
9	48.2	1.07	0.99	1.00	1.11	1.15	1.01
10	50.0	1.07	0.99	1.00	1.10	1.14	1.01
11	51.8	1.07	0.99	1.00	1.09	1.12	1.01
12	53.6	1.06	0.99	1.00	1.08	1.11	1.01
13	55.4	1.06	0.99	1.00	1.07	1.10	1.01
14	57.2	1.05	1.00	1.00	1.06	1.08	1.01
15	59.0	1.05	1.00	1.00	1.05	1.07	1.01
16	60.8	1.04	1.00	1.00	1.04	1.06	1.00
17	62.6	1.03	1.00	1.00	1.03	1.04	1.00
18	64.4	1.02	1.00	1.00	1.02	1.03	1.00
19	66.2	1.01	1.00	1.00	1.01	1.01	1.00
20	68.0	1.00	1.00	1.00	1.00	1.00	1.00
21	69.8	0.98	0.99	1.00	0.99	0.98	1.00
22	71.6	0.97	0.99	0.99	0.97	0.97	1.00
23	73.4	0.95	0.98	0.99	0.96	0.95	1.00
24	75.2	0.93	0.97	0.99	0.94	0.93	1.00
25	77.0	0.92	0.97	0.99	0.93	0.92	1.00
26	78.8	0.90	0.96	0.98	0.91	0.90	0.99
27	80.6	0.88	0.95	0.98	0.90	0.89	0.99
28	82.4	0.85	0.94	0.97	0.88	0.87	0.99
29	84.2	0.83	0.93	0.96	0.87	0.86	0.99
30	86.0	0.81	0.92	0.96	0.86	0.84	0.99
31	87.8	0.80	0.91	0.95	0.84	0.83	0.99
32	89.6	0.77	0.89	0.95	0.83	0.81	0.99
33	91.4	0.75	0.88	0.95	0.81	0.79	0.99
34	93.2	0.73	0.87	0.94	0.80	0.77	0.99
35	95.0	0.71	0.85	0.94	0.78	0.76	0.98
36	96.8	0.69	0.84	0.93	0.77	0.74	0.98
37	98.6	0.67	0.83	0.92	0.75	0.72	0.98
38	100.4	0.65	0.81	0.91	0.74	0.70	0.98
39	102.2	0.63	0.80	0.90	0.72	0.68	0.98
40	104.0	0.61	0.78	0.89	0.70	0.67	0.98
42	107.6		0.74	0.87	0.67	0.63	0.98
44	111.2		0.70	0.85	0.63	0.60	0.98
46	114.8		0.64	0.83	0.61	0.56	0.97
48	118.4		0.58	0.82	0.58	0.53	0.97
50	122.0		0.52	0.80	0.56	0.50	0.97
52	125.6			0.79	0.53	0.47	0.97
54	129.2			0.78	0.51	0.44	0.97
56	132.8			0.77	0.49	0.41	0.96
58	136.4			0.76	0.46	0.38	0.96
60	140.0			0.74	0.44	0.36	0.96
62	143.6			0.73	0.40	0.33	
66	150.8			0.70	0.39	0.28	
70	158.0			0.66	0.36	0.23	

Table A3
Bushing temperature correction factors

Test temperature		**Lapp insulator company**		**Micanite and insulators company**	
°C	*°F*	*Class P O C 15 to 69 kV*	*P R C*	*25 to 69 kV*	*Above 69 kV*
0	32.0	1.00	0.80	1.55	1.13
1	33.8	1.00			
2	35.6	1.00			
3	37.4	1.00			
4	39.2	1.00			
5	41.0	1.00	0.86	1.40	1.09
6	42.8	1.00			
7	44.6	1.00			
8	46.4	1.00			
9	48.2	1.00			
10	50.0	1.00	0.91	1.25	1.06
11	51.8	1.00			
12	53.6	1.00			
13	55.4	1.00			
14	57.2	1.00			
15	59.0	1.00	0.95	1.12	1.03
16	60.8	1.00			
17	62.6	1.00			
18	64.4	1.00			
19	66.2	1.00			
20	68.0	1.00	1.00	1.00	1.00
21	69.8	1.00			
22	71.6	1.00			
23	73.4	1.00			
24	75.2	1.00			
25	77.0	1.00	1.04	0.89	0.97
26	78.8	1.00			
27	80.6	1.00			
28	82.4	1.00			
29	84.2	1.00			
30	86.0	1.00	1.08	0.80	0.94
31	87.8	1.00			
32	89.6	1.00			
33	91.4	1.00			
34	93.2	1.00			
35	95.0	1.00	1.11	0.72	0.91
36	96.8	1.00			
37	98.6	1.00			
38	100.4	1.00			
39	102.2	1.00			
40	104.0	1.00	1.13	0.64	0.88
41	105.8	1.00			
42	107.6	1.00			
43	109.4	1.00			
44	111.2	1.00			
45	113.0	1.00	1.13	0.56	0.86
46	114.8	1.00			
47	116.6	1.00			
48	118.4	1.00			
49	120.2	1.00			
50	122.0	1.00	1.11	0.50	0.8
52	125.6	1.00			
54	129.2	1.00			
56	132.8	1.00			
58	136.4	1.00			
60	140.0	1.00	1.01		

Your "One Stop" Source for all your electrical test equipment needs

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- Cable Fault Locating Equipment
- Circuit Breaker Test Equipment
- Data Communications Test Equipment
- Fiber Optic Test Equipment
- Ground Resistance Test Equipment
- Insulation Power Factor (C&DF) Test Equipment
- Insulation Resistance Test Equipment
- Line Testing Equipment
- Low Resistance Ohmmeters
- Motor & Phase Rotation Test Equipment
- Multimeters
- Oil Test Equipment
- Portable Appliance & Tool Testers
- Power Quality Instruments
- Recloser Test Equipment
- Relay Test Equipment
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- Tachometers & Speed Measuring Instruments
- TDR Test Equipment
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- Professional Hands-On Technical and
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Megger is a world leading manufacturer and supplier of test and measurement instruments used within the electric power, building wiring and telecommunication industries.

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USA
Valley Forge Corporate Centre
2621 Van Buren Avenue
Norristown, PA 19403 USA
T +1-610 676 8500
F +1-610-676-8610
UK
Archcliffe Road, Dover
CT17 9EN England
T +44 (0) 1304 502101
F +44 (0) 1304 207342
E UKsales@megger.com

Other Technical Sales Offices
Dallas, USA
Toronto CANADA
Trappes FRANCE
Oberursel GERMANY
Oberkulm, SWITZERLAND
Johannesburg SOUTH AFRICA
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