Doble Test Procedures

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Preface

Structure of this Manual

This manual consists of 17 chapters.

Chapter 1	"General" introduces the general concepts of Doble testing.
Chapter 2	"Using A Resonator" explains how to use a Resonator with the M4000 when testing items with a capacitance too large to be handled by the M4000 alone.
Chapter 3	"Leakage Reactance Testing" describes procedures for executing Leakage Reactance tests.
Chapter 4	"Bushings" explains testing of bushings inside and outside of an apparatus.
Chapter 5	"Circuit Breakers And Reclosers" explains testing of various types of breakers.
Chapter 6	"Transformers, Reactors, And Regulators" explains testing of these apparatus, and includes exciting current, leakage reactance, and turns ratio testing.
Chapter 7	"Surge Arresters" explains testing of surge arresters.
Chapter 8	"Capacitors" explains testing of various types of capacitors, including Coupling Capacitors.
Chapter 9	"Rotating Machinery" explains testing of generators, motors, and Synchronous Condensers.
Chapter 10	"Cables And Terminations" explains testing of various cable configurations and of potheads.
Chapter 11	"Liquid Insulation" explains the use of the Doble Insulating Fluids Test Cup for testing liquid insulation.
Chapter 12	"Insulators" explains testing of bus and suspension insulators.
Chapter 13	"Buswork" explains testing of iso-phase and non-segregated bus.
Chapter 14	"Wood And Other Insulating Members" explains testing of selected apparatus parts.

Chapter 15	“Resistive Coupled Potential Device” explains testing of Coupling Potential Devices with a resistive element.
Chapter 16	“Bucket Trucks” explains a method to test the insulating boom of a bucket truck.
Chapter 17	“Frequently Asked Questions (FAQ)” is a list of questions and answers frequently encountered.

Conventions Used in this Manual

The following terms and typographical conventions are used in the manual:

Convention	**Description**
Windows	Refers to the Microsoft Windows operating system, Version 95 or later.
Click	Quickly press and release the left mouse button.
Double-click	Quickly press and release the left mouse button twice without moving the mouse.
Select	Position the cursor on the desired option and click the left mouse button once. Or, highlight the desired option using the arrow keys and press ENTER. Or, press ALT and the underlined letter.
Press	Type a single keyboard key. For example, press ENTER.
FN+(appropriate key)	Press and hold the FN key, and press (appropriate key).
Bold Courier Text	Indicates characters to be typed.

1. General

Introduction To Doble Testing

Since 1929, the AC dielectric-loss and power-factor test has been applied in the field to electrical insulation of high-voltage apparatus using Doble test equipment. Today, this test is recognized as one of the single most effective methods for locating defective insulation. In the jargon of the electrical utility maintenance engineer, the dielectric-loss and power-factor test is often referred to as the **Doble Test**, primarily because of the extensive use and unique capabilities of Doble field-test equipment, and the orderly test methods which have been developed by the Doble Engineering Company in cooperation with its Client Group.

This Manual describes the operation and use of the ***Doble Type M4000 10 kV Portable Insulation Analyzer*** for field and factory acceptance, preventive-maintenance, and emergency diagnostic testing of all types of electrical power apparatus insulation. Apparatus insulation systems have measurable electrical parameters, such as capacitance, dielectric-loss, and power factor, in addition to other less well-known characteristics. By detecting changes in these important electrical characteristics, failure hazards can be revealed, thereby preventing loss of service by permitting orderly repair or reconditioning of defective insulation.

Interpretation of test results involves the use of guides based upon test data correlated by Doble for power apparatus insulation of various types. As power factor is the ratio of dielectric loss to charging voltamperes and, consequently, independent of the amount of insulation under test, it is the most commonly used criterion for judging the condition of insulation. Capacitance, parallel AC resistance, dielectric-loss, and total charging current are also useful indicators of insulation problems. Comments on the interpretation of test results will be found in the various sections relating to the testing of specific types of apparatus. The power-factor guides and other criteria given in this Instruction Manual are based on many years of Doble study and field experience on all types of apparatus.

Considerable supplementary background information and further data on test procedures and techniques will be found in the *Doble Client Conference Minutes* and in *Doble Reference Books*.

Insulation Test Specimens

Insulation *systems* associated with many types of high-voltage power apparatus and devices often consist of a mix of non-homogeneous component parts. As such, a complete and highly accurate schematic representation of an apparatus insulation *system* may be quite complex and difficult to compose, perhaps consisting of a number of resistor and capacitor elements arranged in many varied ways. For discussion and analysis, it is convenient to represent an insulation specimen by a single capacitor combined with a single resistor. (In this manual, a *specimen is* usually considered as an entity which cannot be subdivided further for test purposes.) The capacitor element represents the specimen's fundamental capacitance (i.e., its ability to store electrically separated charges), while the resistor element represents the dissipated loss in the insulation when voltage is applied. As shown in Figure 1.1, there are two possible ways to combine a capacitor with a resistor:

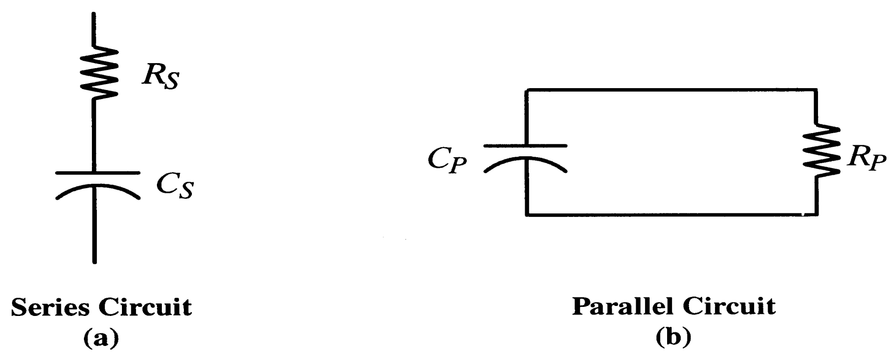

Figure 1.1 Simplified Equivalent Circuits of an Insulation Specimen

An insulation specimen having a given power factor as measured between its terminals can be represented equally by the *Series Circuit* shown in Figure 1.1(a) or by the *Parallel Circuit* of Figure 1.1(b). Mathematical formulas have been derived to show the correlation between the series network (C_S and R_S) and its parallel counterpart (C_P and R_P). Insulation systems of high-voltage apparatus are selected in part for their low dielectric losses (i.e., low power factor). For a specimen with zero power factor (i.e., no dissipated losses), R_S in the equivalent series circuit is zero ohms, whereas R_P in the equivalent parallel circuit is infinity. Thus, for zero power factor, C_S is precisely the same as C_P. It follows that for high-voltage apparatus insulation systems having low power factor, the equivalent C_S is essentially equal to C_P.

The M4000 test circuit commonly views the specimen as a parallel capacitor/resistor network as shown in Figure 1.1(b). This equivalent circuit is repeated in Figure 1.2 showing the various parameters of current with respect to the applied test voltage E:

E = test voltage

I_T = specimen total current

I_C = capacitive or quadrature of the total current

I_R = resistive or in-phase (loss) component of the total current

C_P = equivalent parallel capacitance of the insulation specimen

R_P = equivalent parallel resistance of the insulation specimen

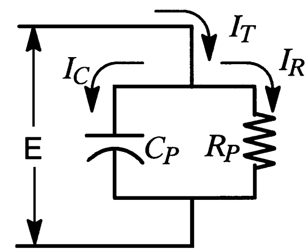

Figure 1.2 Simplified Equivalent Circuit of a Dielectric Showing the Various Parameters of Current as a Function of Test Voltage (Parallel R/C Network)

The resistor element of the equivalent dielectric circuit of Figure 1.2 represents the watts-loss dissipated in the insulation when a voltage is applied. In Figure 1.2, R_P represents that which is generally considered undesirable in a dielectric. It should be recognized that a certain amount of measurable loss is normal for most dielectrics and, therefore, the existence of loss, per se, does not necessarily suggest an operating hazard.

In a perfect or no-loss capacitor, the current leads the test voltage by exactly 90°. In *a perfect* resistor, the current and voltage are exactly *in-phase.* In Figure 1.2 the capacitor C_P and resistor R_P are both considered perfect. Figure 1.3 shows the relationship of the various current vectors and test voltage E:

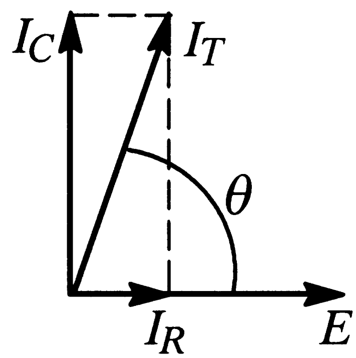

Figure 1.3 Vector Components of Test Voltage and Currents In a Parallel R/C Circuit

In an electric circuit with AC voltage applied:

$$\textbf{Watts} = \mathbf{E \times I_T \times Cosine}\ \Theta$$

The angle Θ, shown in Figure 1.3, represents the phase angle between the test voltage E impressed across the terminals of the dielectric specimen, and the total current I_T drawn by it. The cosine of the angle Θ is, by definition, power factor. Thus:

$$\textbf{Power Factor} = \textbf{Cosine}\ \Theta = \frac{\textbf{Watts}}{\mathbf{E \times I_T}}$$

Test Modes Of The M4000 Analyzer

To facilitate understanding of the M4000 Analyzer operation, it is important to consider the relative positions of the power source (i.e., the 10 kV winding of the M4000 high-voltage transformer), the measuring circuit, and the specimen, with respect to the test ground and the Low-Voltage (LV) Lead(s). The M4000 is capable of utilizing two LV Leads simultaneously.

Figure 1.4 to Figure 1.10 show the three basic test circuit configurations; GST-GROUND, GST-GUARD, and UST-MEASURE:

Grounded-Specimen Test Mode (GST)

With the M4000 Analyzer in GST-GROUND (R,B), Figure 1.4, the LV Leads are brought to ground potential. Thus, the LV Leads may be used to connect ground to a specimen terminal. While it may be convenient to use the LV Leads as grounds, it is also possible to use the ground terminal of the outboard pothead of the High-Voltage Test Cable (refer to Figure 1.11). Perhaps the most common method for applying a ground is simply to make a bare clip connection to the grounded apparatus frame or to a nearby, common, station ground.

GST-Ground Test Mode

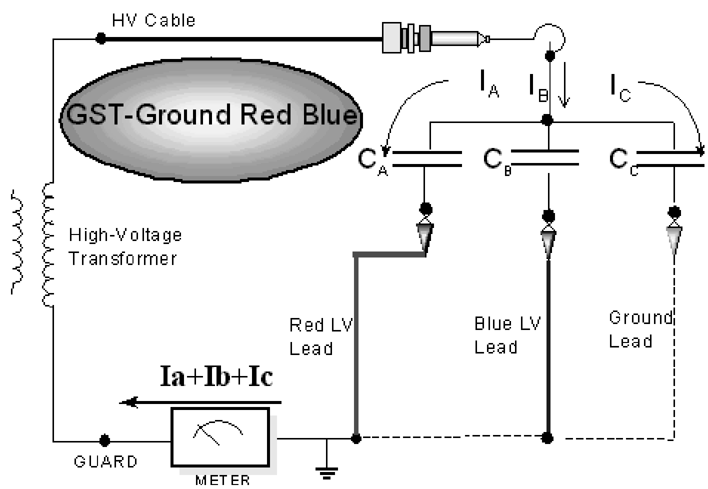

Figure 1.4 GST-Ground Test Mode

With the M4000 Analyzer in GST-GUARD (R,B) Figure 1.5, the LV Leads are both connected to the test circuit Guard. Compare Figure 1.6 and Figure 1.7 and note that both are Grounded Specimen Test (GST) modes; that is, both circuits measure the insulation between the High-Voltage Test Cable and ground. The single difference between Figure 1.6 and Figure 1.7 is the position of the LV Leads with respect to the measuring circuit. In Figure 1.6, blue will be measured and red not; and in Figure 1.7, red will be measured and blue not. In both cases, the grounded lead is measured and the guarded lead is not. In all three cases, the test set ground lead is also measured. Note that connection to the test-set Guard Circuit is also possible via the Guard Ring on the outboard pothead of the High-Voltage Test Cable (refer to Figure 1.11).

GST-Guard Test Modes

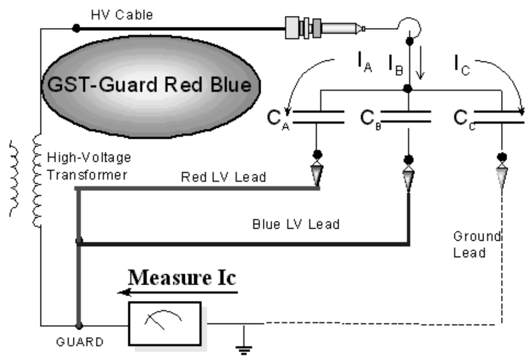

Figure 1.5 GST-Guard Red Blue Test Mode

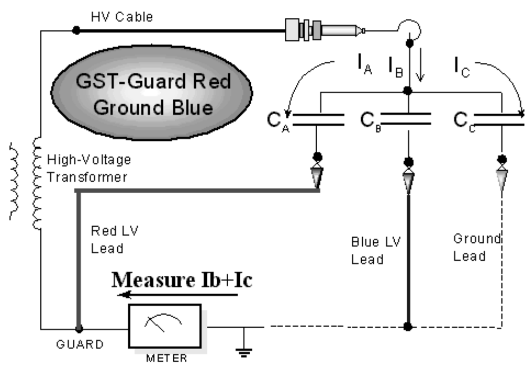

Figure 1.6 GST-Guard Red Test Mode

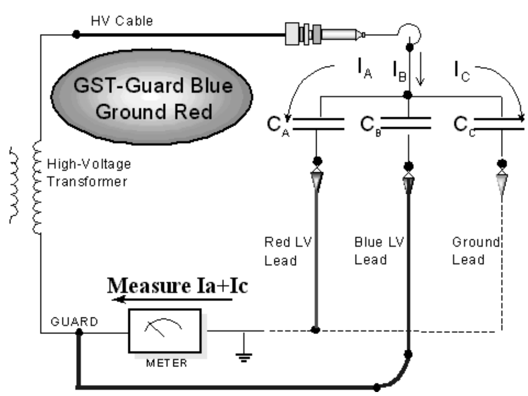

Figure 1.7 GST-Guard Blue Test Mode

Ungrounded-Specimen Test Mode (UST)

With the M4000 Analyzer in UST-MEASURE (R,B) Figure 1.8, the only input to the measuring circuit is through the LV Leads. Observe that the test set Guard and Ground are common in the UST mode; thus, current and losses to ground are not measured.

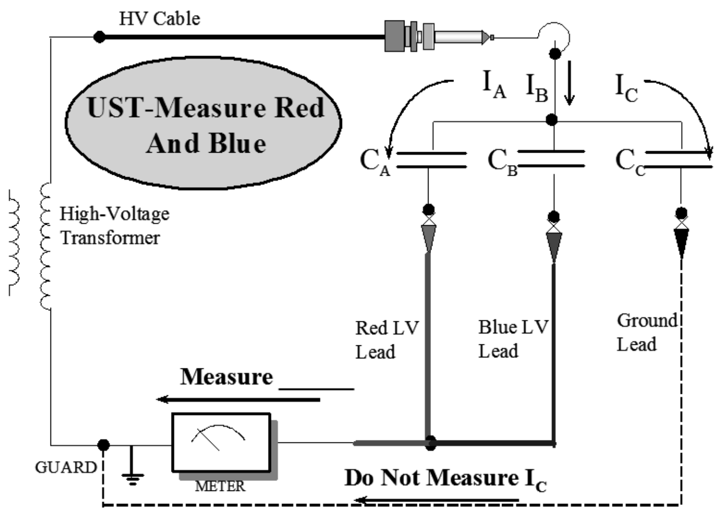

Figure 1.8 UST Measure Red Blue Test Mode

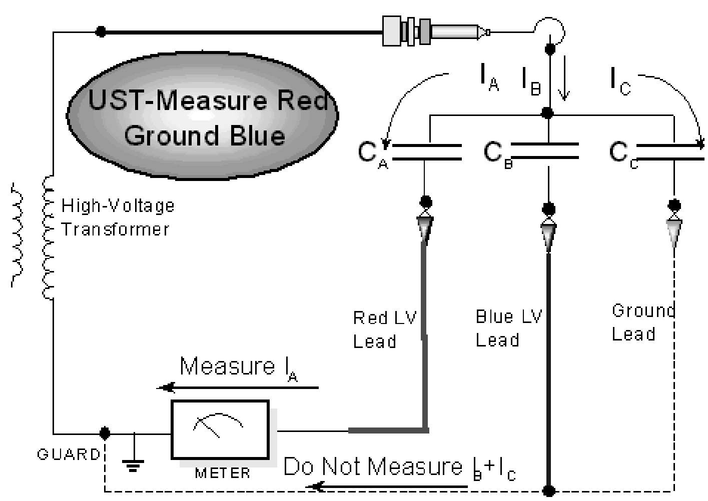

Figure 1.9 UST Measure Red Ground Blue Test Mode

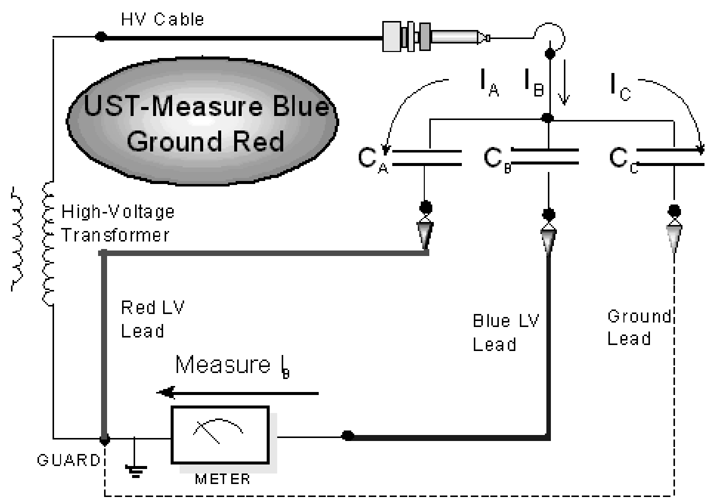

Figure 1.10 UST Measure Blue Ground Red Test Mode

In Figure 1.8, the red and blue leads are both measured; in Figure 1.9, only the red lead is measured; and in Figure 1.10, only the blue lead is measured.

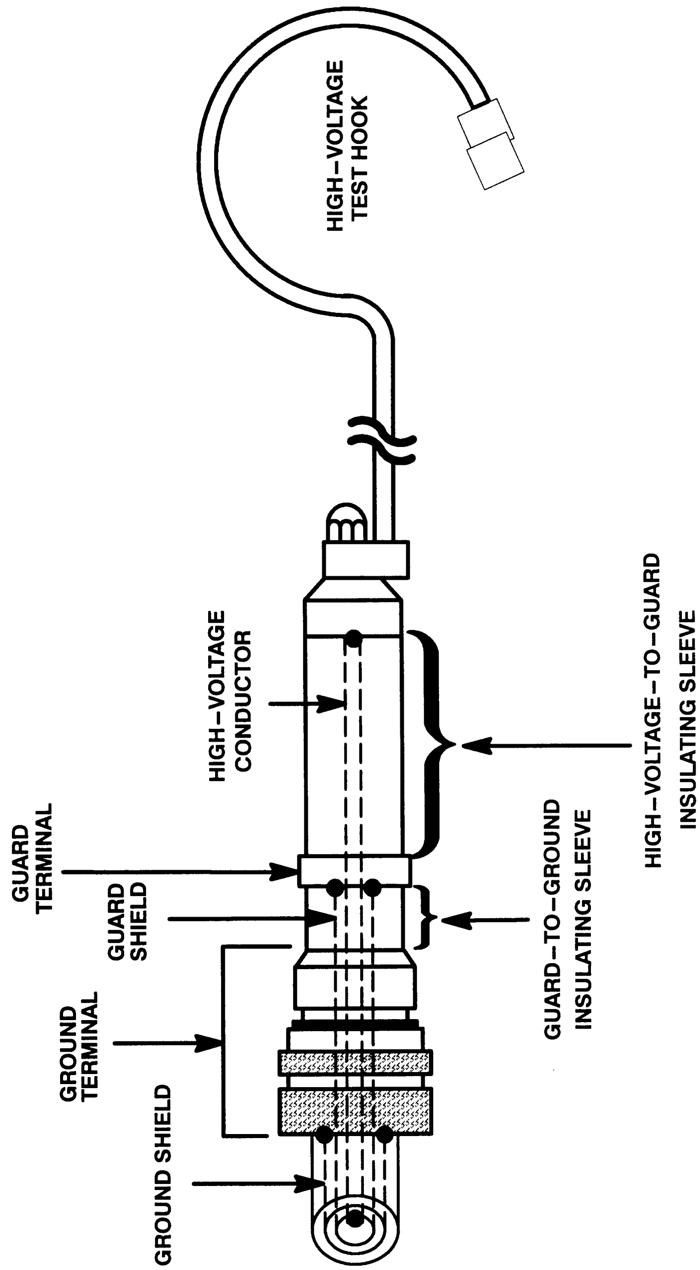

Figure 1.11 Doble High-Voltage Test Cable (Outboard Pothead)

Placement Of The High Voltage “Hook”

The high voltage cable’s outboard pothead, commonly called the “hook”, includes a Guard and a Ground ring, or terminal, which must be kept at a distance from any energized surfaces. It is therefore desirable that when the hook is attached to a terminal, it is kept from draping down along the surface below. The high voltage cable may have to be draped over an adjacent structure to keep the outboard pothead and its Guard and Ground rings pulled away from the energized area.

WARNING

Never hold onto the High Voltage Cable during a test! If draping the high voltage cable over an adjacent structure to keep the Guard and Ground rings away from the energized surface. Do not drape it over a terminal or surface that will be energized during the test.

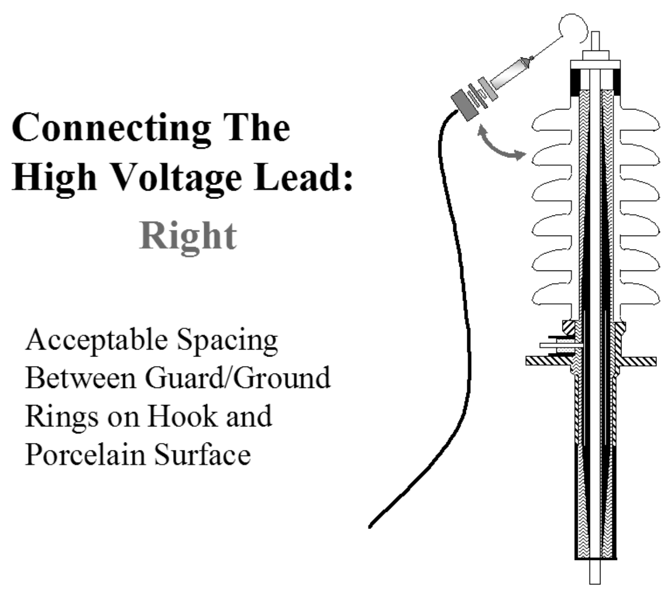

Figure 1.12 High Voltage Hook-Correct Placement

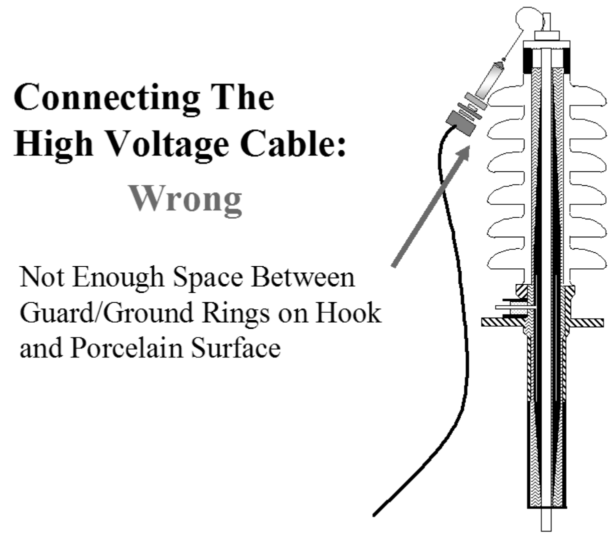

Figure 1.13 High Voltage Hook-Incorrect Placement

Test Voltages

General

The approach to making Doble Tests on high-voltage apparatus begins with an overall plan outlining the steps necessary to accomplish the various measurements, safely and effectively. Those involved in the operation cooperate in getting the apparatus removed from service, tagged, isolated, grounded, and prepared for test. Safety of personnel and apparatus is paramount. In the overall plan, those responsible for carrying out the tests should determine beforehand the tests to be performed and the test potentials to be applied for the various measurements. In particular, the test engineer should note those tests which must be made at reduced voltages (i.e., less than 10 kV).

The following are general comments concerning the selection of test voltages for Doble tests.

The basic principle of the Doble Test is to measure the fundamental AC electrical parameters of insulation (i.e., power factor, capacitance, dielectric-loss, etc.), applying test voltages which are moderate compared with the design rating of the insulation. Then, from these measurements, to detect changes and abnormalities in the insulation which may be associated with moisture, heat, ionization (corona), lightning, physical distortion (as of transformer windings), and other destructive agents known to reduce dielectric integrity.

Suspect Apparatus

With due regard for properly selected test voltages, the Doble Test is nondestructive, in that it should cause no measurable harm to serviceable insulation. In cases of insulation known or suspected to be severely weakened, damaged, deteriorated, or contaminated, the application of a relatively low voltage stress could conceivably be sufficient to cause breakdown. Equipment suspected of being damaged should always be approached with the view that it may not be able to sustain normal, routine test voltage. This might involve the following:

1. Equipment which has become badly contaminated with moisture in transit from the factory, repair shop, or between substations.

2. Power transformers and related equipment that have tripped off-line due to the operation of protective relays.

3. Equipment suspected of having become badly contaminated with moisture after being stored outdoors for prolonged periods.

When making Doble tests on suspect equipment, the test engineer should make an initial measurement at low voltage (2 kV or less), gradually increasing, in steps, up to the normal test level only if the readings at the previous lower voltage indicate no problem. If the M4000 Analyzer obtains an message such as "Overcurrent on Power Amp" while raising the test voltage, an investigation should be made to determine the probable cause before attempting to reapply test voltage. There may be improper test connections or, possibly, the specimen may be defective. If, after making an investigation, the matter is still uncertain, then only attempt to repeat the measurement at a very low voltage.

Routine Testing

General - Apparatus Rated Above 15 kV

While apparatus voltage ratings are based on system voltage (i.e., the line-to-line rating), Doble test voltage is applied line-to-ground. Liquid-filled and dry-type apparatus rated above 15 kV class (i.e., 25 kV class and above) have operating line-to-ground voltage ratings above 10 kV. Accordingly, for 25 kV class and above, the standard 10 kV voltage is generally applied for tests.

There are certain exceptions where the test voltage on equipment rated 25 kV and above should be limited to less than 10 kV. This includes line-to-ground potential transformers, in which the neutral terminal is rated at reduced voltage, and the tap insulation of bushings.

In the course of investigating questionable Doble test results on apparatus (oil-filled and dry-type), it is desirable to perform tests at several voltages, starting at some low voltage such as 1 or 2 kV, then continuing, in steps, up to the maximum voltage allowed.

Apparatus Rated l5 kV and Below

Apparatus rated 15 kV class and below requires special comment. It must be emphasized that the application of test voltages slightly above (i.e., 10% to 25%) the operating line-to-ground rating does not constitute a destructive test, since apparatus insulation is normally designed to withstand voltage levels which are considerably higher. Accordingly, for 15 kV class liquid-filled apparatus, the overall tests are generally performed at 10 kV, although this voltage may be slightly above the operating line-to-ground rating. For example, for 13.8 kV apparatus, the line-to-ground voltage is approximately 8 kV. Thus, while 10 kV may be approximately 25% higher than the line-to-ground rating, this is not considered an excessive test voltage considering the insulation design level. Whenever questions arise concerning proper test voltage for specific apparatus, reference should be made to manufacturers' specifications and industry standards.

For liquid-filled apparatus rated below 15 kV class, conventional practice is to select for test voltages convenient whole number values below the nominal system line-to-line voltage. There may be certain restrictions, as in the case of line-to-ground potential transformers with a low (voltage) rating at the neutral terminal of the primary winding.

Dry-type apparatus rated 15 kV and below are susceptible to corona damage (i.e., ionization losses) and, therefore, routine tests on this type of insulation are generally performed at several voltages. The initial test is performed at a low test voltage, such as 1 or 2 kV, and continuing, sometimes in intermediate steps, up to the operating line-to-ground voltage. Depending on the test results obtained up to the operating line-to-ground level, additional test(s) are performed at 10% to 25% above the operating line-to-ground level. The primary advantage of making additional tests at higher voltages on dry-type 15 kV class (and below) insulation is that corona conditions may be accentuated. Tests at 10% to 25% over the line-to-ground rating are not considered destructive for insulation in good condition, since they are designed to withstand considerably higher voltage levels. Good examples of apparatus which are subject to corona damage, and for which tests are desirable at several levels up to and exceeding line-to-ground ratings are: air-magnetic circuit breakers; cables; rotating machinery; and molded instrument transformers.

Surge Arresters

In selecting the proper test voltage(s), special note should be taken of surge arresters. Arresters are nonlinear devices and, therefore, in order to be able to compare results between similar units, it is necessary that Doble tests be made at prescribed voltages.

Summary

The decision concerning the application of test voltage is easily made in most cases, since the majority of apparatus are rated well above 10 kV, and insulated accordingly. Arrester stacks, comprised of multiple low-voltage units, PTs with neutral bushings, and tap-insulation of bushings, are examples where tests should be performed at less than 10 kV.

In the case of equipment rated 15 kV and below, particularly with dry-type insulation, consideration should be given to including test(s) at slightly above (10% to 25%) the operating line-to-ground voltage.

The test voltages suggested in this manual are based on a number of factors including: the collective experiences of the Doble Engineering Company and its Client Group, information contained in engineering standards, and manufacturers' information and recommendations.

Besides being familiar with the information herein, and specific recommendations given for the various apparatus, the test engineer should be aware of the apparatus owner's policy concerning test voltage. Ultimately, the final decision concerning the application of test voltage rests with apparatus owners.

Variation Of Power Factor with Temperature

Introduction

The electrical characteristics of practically all insulating materials vary with temperature. In order to compare results of periodic tests on the same apparatus while at different temperatures, it is necessary that the manner in which the results vary with temperature be known. The results then can be converted to a common temperature base, and any variation not accounted for by the conversion can be attributed to changes in the condition or other characteristics of the insulation.

Temperature-correction data available are average values at best, and therefore, subject to some error. The magnitude of error is minimized if tests are performed at temperatures near the reference temperature of 20°C (68°F). This is not always practical in the field. It is suggested, therefore, that tests be performed at whatever temperatures are normally encountered. If questionable power factors are recorded at relatively high temperatures, the apparatus should not be condemned until it has been allowed to cool down to near 20°C and repeat tests have been performed. This also applies to equipment which is tested near freezing where a large (greater than 1.00) correction may cause the result to be unacceptably high; in this case the equipment should be retested at a higher temperature.

NOTE **Since ice has a volumetric resistivity approximately 144 times that of water, tests for the presence of moisture in insulation should not be performed when apparatus temperatures are much below freezing.**

Doble power-factor test results are converted to a reference temperature of 20°C (68°F) using the tabulation of multipliers provided in the Temperature-Correction Table at the end of this section. The table is used in the following manner:

1. Calculate the specimen (e.g., bushing) power factor.

2. Determine the test-specimen temperature.

3. Obtain the appropriate correction factor from the Temperature-Correction Table corresponding to the specimen temperature.

4. Multiply (1) and (3) – see example below:

Example

Ohio Brass Company bushing Class GK, 115 kV

(1) Calculated power factor = 0.42%

(2) Ambient temperature = 30°C

(3) Multiplier from the Temperature-Correction Table at 30°C = 1.11

(4) Corrected to 20°C power factor = 0.42% x 1.11 = 0.47%

NOTE

The tables which are included in this manual are based on data obtained on good insulation. Insulation that is deteriorated, contaminated, or otherwise defective, may not behave with temperature the same as good insulation. Some discretion must be used when attempting to correct for temperature those test results which are obviously abnormal. It seems likely that contaminated or deteriorated insulation will have disproportionately higher losses and power factor at elevated temperatures.

The following summarizes the use of the Temperature-Correction Table for the various types of apparatus.

Bushings

Not all bushings require correction for the effects of temperature on insulation power factor. For example, dry-type, gas-filled or solid porcelain bushings generally show very little change in power factor over the temperature range normally encountered. Oil-filled and compound-filled bushings do show some power-factor change with temperature, although the effects of temperature differ for the various types. Refer to the Temperature-Correction Table to obtain temperature-correction multipliers for those bushings for which data are available.

NOTE

Bushing power factors are corrected using ambient temperatures. The one important exception is the case of bushings mounted in transformers. In such apparatus, the bushing temperature is approximated by taking the average between the ambient and transformer top-oil temperatures. Only the bushing main-insulation test (overall, or C) is corrected for the effects of temperature; hot-collar and tap-insulation tests are not.

Oil Circuit Breakers

The open- and closed-breaker power factors for oil circuit breakers are corrected for the effects of temperature solely on the basis of the bushing type installed in the breaker. In other words, the oil circuit breaker manufacturer and type are not factors in determining the temperature correction for Doble tests performed on this class of apparatus.

It is recognized that temperature will affect the tank losses in a circuit breaker. Because of the many variables involved, no good quantitative method has yet been devised for correcting tank losses for the effects of temperature. In general, it is known that the Tank-Loss Index is greater at higher temperatures, and this fact should be taken into account when analyzing circuit breaker test results (for comments on Tank-Loss Index (TLI) refer to Oil Circuit Breakers, Analysis and Interpretations, Bushings and Tank Members).

Oil-Filled Power and Distribution Transformers

The overall ground- and interwinding-insulation power factors of oil-filled power transformers are corrected for the effects of temperature using the temperature as indicated on the top-oil temperature gauge mounted on the transformer tank. Two curves are recommended for use with Doble equipment:

1. Doble Curve (1936) for:

   Oil and Oil-Filled Power Transformers (Free-Breathing and Older Conservator Types).

2. Doble Transformer Committee Curve (2002) for:

   Oil-Filled Power Transformers (Sealed, Gas-Blanketed and Modern Conservator Types.

The two sets of correction factors for oil-filled power transformers are given in the Temperature-Correction Table, with the column headings labeled accordingly. Additional information regarding power-factor correction factors for oil-filled power transformers may be found in the Power and Distribution Transformers section of the *Doble Test-Data Reference Book.*

In cases where the top-oil temperature gauge is defective or absent, the top-oil temperature must be approximated. A method for making a reasonable approximation is to measure (in the shade) the temperature of the air and the temperature of the outer tank wall in the vicinity of the top-oil level. A contact-type thermometer would be convenient for the latter measurement. The top-oil temperature is then assumed to be equal to the temperature of the tank wall plus two-thirds of the difference between the tank and air temperature.

Example

Oil-filled power transformer (sealed, 115/13.8 kV voltage rating)

Air temperature = 20°C

Tank-wall temperature = 26°C

Top-oil temperature = 26 + 2/3 (26 - 20) = 30°C

Multiplier from the Temperature-Correction Table at 30°C (Doble Transformer Committee Curve) = 0.95

Measured overall power factor = 0.61%

Corrected overall power factor at 20°C = 0.61 X 0.95 = 0.58%

While specific temperature correction curves are not available for oil-filled distribution transformers, the measured Overall power factors for this equipment probably should be corrected for the effects of (top-oil) temperature. Until specific curves have been developed, it is suggested that the Overall power factors be corrected using the curve: *Oil-Filled Power Transformers (Sealed, Gas-Blanketed and Modern Conservator Types Up Through 161* kV *750 kV BID).* Some experience may indicate that certain oil-filled distribution transformers, particularly older units, may be more accurately corrected for the effects of temperature by the curve: *Oil and Oil-Filled Power Transformers (Free-Breathing and Older Conservator Types).*

As noted earlier, the Overall or C_1 insulation power factor of bushings in power (and distribution) transformers is corrected based on the *average* of the ambient and transformer top oil temperatures.

Oil-Filled Voltage Regulators

Consideration must be given to the effects of temperature on the overall insulation power factor of high-voltage regulators. While data for specific makes and types of low-voltage regulators is lacking, it is suggested that the curve; *Oil and Oil-Filled Power Transformers (Free Breathing and Older Conservator Types),* be used for oil-filled units.

Oil-Filled Instrument Transformers and Metering Outfits

The measured Overall power factors of oil-filled instrument transformers are converted to 20°C, using multipliers listed in the Temperature-Correction Table under *Oil-Filled Instrument Transformers* corresponding to the top-oil temperature. These multipliers are used in the same manner as described for oil-filled power transformers.

It is suggested that, for the modern oil-filled PTs and CTs rated 220 kV and above, it may be more appropriate to correct for temperature using the power transformer curve labeled: *Oil-Filled Finer Transformers (Sealed, Gas Blanketed Types and Modern Conservator Types).*

If the top-oil temperature is not available directly, it can be approximated using the method outlined for oil-filled power transformers. Experience has indicated that, unless there has been a sudden change in ambient temperature causing a lag in the transformer oil temperature, another reasonable approximation is to assume that the top-oil and air temperatures are the same.

Askarel-Filled Transformers

Test results for these transformers are corrected for the effects of temperature in the same manner as oil-filled power transformers. The Overall power factors of all askarel-filled transformers are corrected using multipliers listed in the column labeled, *Askarel and Askarel-Filled Transformers*, in the Temperature-Correction Table.

Liquid Insulation (Oil and Askarel)

The measured power factors for insulating oil and askarel samples are converted to 20°C, using multipliers listed in Table under *Oil and Oil-Filled Finer Transformers (Free-Breathing and Older Conservator Types)* and *Askarel and Askarel-Filled Transformers*, respectively, and corresponding to the temperature recorded on an immersion-type thermometer immediately following the test on the sample.

Example

Oil Sample

Temperature of sample = 30°C

Multiplier from the Temperature-Correction Table at 30°C = 0.63
Measured power factor = 0.28%

Corrected power factor at 20°C = 0.63 x 0.28 = 0.18%

Although relatively complete, the Temperature-Correction Table does not include multipliers for converting power factors of all apparatus insulation being tested at the present time. This is due, in some cases, to a lack of sufficient data on the effects of temperature on the particular type of insulation, and in others to experience indicating that the effects of temperature are negligible over the range of temperatures encountered in the field. Some of these are discussed briefly below.

Dry-Type Power and Distribution Transformers

Consideration must be given to the effects of temperature on the insulation power factor of dry-type power and distribution transformers. Data for specific makes and types of dry-type transformers is lacking.

Air-Magnetic and Low-Voltage Air-Blast Breakers

Experience to date indicates that very little, if any, temperature correction is necessary throughout the normal range of temperature in which this apparatus would be tested.

Oil Switches, Reclosers, and Sectionalizers

Experience to date indicates that it is not necessary to correct the dielectric-loss and power-factor measurements for temperature throughout the range of temperatures normally encountered for these apparatus.

Vacuum Breakers and Reclosers

Experience to date indicates that very little, if any, temperature correction is necessary throughout the normal range of temperature in which this apparatus would be tested.

Cables

Multipliers are not listed in the Temperature-Correction Table for cable insulation. This is not a serious omission in the case of modern cable insulations, which generally have relatively flat power-factor versus temperature characteristics over the normal range of operating temperatures.

Collar Tests

Experience has indicated that the effects of temperature on the results of Hot-Collar Tests may be neglected without impairing the ability of the test to detect faults in bushings, potheads and insulators.

Contact Grading Capacitors (for Circuit Breakers)

Correction for the effects of temperature may be necessary on certain types and ratings of contact-grading capacitors in HV and EHV circuit breakers. Information on specific types may be found in the Circuit Breakers section of the *Doble Test-Data Reference Book.*

Coupling Capacitors

Experience to date indicates that very little, if any, temperature correction is necessary throughout the normal range of temperatures in which these capacitors probably would be tested.

Porcelain Insulators, Wood Members, and Dry-Type Porcelain Bushings

Experience has indicated that the effects of temperature on the results of dielectric-loss and power-factor tests may be neglected without impairing the ability of the tests to detect faults in porcelain insulators, dry-type porcelain bushings, and wood members.

Rotating Machinery

Tests on rotating machine insulation are usually performed indoors at or near ambient temperature. Experience to date indicates that very little temperature correction is necessary throughout the normal range of temperatures in which the apparatus would be tested.

Surge Arresters

Experience to date indicates that very little, if any, temperature correction is necessary throughout the normal range of temperature in which surge arresters would be tested.

TABLE OF MULTIPLIERS FOR USE IN CONVERTING POWER FACTORS AT TEST TEMPERATURES TO POWER FACTORS AT 20°C

TEST TEMPERATURES		INSULATING FLUIDS			
		ASKAREL	CONVENTIONAL INSULATING OIL	SILICONE OILS	
°C	°F			New	Service Aged
0	32.0	–	1.56	–	–
2	35.6	–	1.52	–	–
4	39.2	–	1.48	–	–
6	42.8	–	1.45	–	–
8	46.4	–	1.43	–	–
10	50.0	–	1.38	–	–
12	53.6	–	1.31	–	–
14	57.2	–	1.24	–	–
16	60.8	–	1.16	–	–
18	64.4	–	1.08	–	–
20	68.0	1.00	1.00	1.00	1.00
22	71.6	.90	.91	0.81	0.76
24	75.2	.81	.83	0.66	0.57
26	78.8	.72	.76	0.65	0.50
28	82.4	.64	.70	0.62	0.45
30	86.0	.56	.63	0.54	0.40
32	89.6	.51	.58	0.52	0.37
34	93.2	.46	.53	0.45	0.34
36	96.8	.42	.49	0.42	0.31
38	100.4	.39	.45	0.36	0.29
40	104.0	.35	.42	0.30	0.26
42	107.6	.33	.38	0.26	0.25
44	111.2	.30	.36	0.24	0.23
46	114.8	.28	.33	0.18	0.21
48	118.4	.26	.30	0.16	0.19
50	122.0	.24	.28	0.13	0.18
52	125.6	.22	.26	0.11	0.16
54	129.2	.21	.23	–	–
56	132.8	.19	.21	–	–
58	136.4	.18	.19	–	–
60	140.0	.16	.17	–	–

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GRADING-CAPACITOR ASSEMBLIES FOR GENERAL ELECTRIC 115/230/345-kV ATB BREAKERS			
TEST TEMPERATURES		POWER FACTOR	CAPACITANCE
°C	°F		
-17.8	0	.09	.80
-15.0	5	.10	.80
-12.2	10	.11	.80
-9.4	15	.12	.80
-6.7	20	.14	.80
-4.0	25	.17	.80
-1.1	30	.21	.82
1.7	35	.27	.84
4.5	40	.32	.85
7.2	45	.40	.88
10.0	50	.47	.90
12.8	55	.61	.92
15.5	60	.80	.94
18.3	65	.89	.98
20.0	68	1.00	1.00
21.1	70		1.01
23.9	75		1.04
26.7	80		1.06
29.4	85		1.10
32.2	90		1.12
35.0	95		1.15
37.8	100		1.19
43.3	110		1.25
48.9	120		1.32
–	–		–
–	–		–
–	–		–
–	–		–
–	–		–
–	–		–
–	–		–

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Figure 1.14 Table of Multipliers – Table 1 of 4

TABLE OF MULTIPLIERS FOR USE IN CONVERTING POWER FACTORS AT TEST TEMPERATURES TO POWER FACTORS AT 20°C

BUSHINGS													
ABB		ASEA	BROWN BOVERI				GENERAL ELECTRIC						HAEFELY
Type T	Type O + C	All GO Types 25-765 kV	Types CTF, CTKF 20-60 kV	Types CTF, CTKF 85-330 kV	TEST TEMPERATURES °C	°F	Type B	Type F	Types L, LC, LI, LM	Types OF, OFI, OFM	Types S, SI, SIM (Cpd.-Filled)	Types TandU	Types COT, COS, SOT
1.02	.87	.79	1.24	1.00	0	32.0	1.09	.93	1.00	1.18	1.26	1.02	–
1.02	.89	.81	1.22		2	35.6	1.09	.95	1.00	1.16	1.24	1.02	–
1.02	.91	.83	1.20		4	39.2	1.09	.97	1.00	1.15	1.21	1.02	–
1.01	.92	.85	1.17		6	42.8	1.08	.98	1.00	1.13	1.19	1.01	–
1.01	.93	.87	1.15		8	46.4	1.08	.99	1.00	1.11	1.16	1.01	–
1.01	.94	.89	1.12		10	50.0	1.07	.99	1.00	1.10	1.14	1.01	0.88
1.01	.95	.92	1.10		12	53.6	1.06	.99	1.00	1.08	1.11	1.01	0.90
1.01	.96	.94	1.06		14	57.2	1.05	1.00	1.00	1.06	1.08	1.01	0.93
1.00	.98	.95	1.05		16	60.8	1.04	1.00	1.00	1.04	1.06	1.00	0.95
1.00	.99	.98	1.03		18	64.4	1.02	1.00	1.00	1.02	1.03	1.00	0.98
1.00	1.00	1.00	1.00	1.00	20	68.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.01	1.03	.98		22	71.6	.97	.99	.99	.97	.97	1.00	1.02
1.00	1.02	1.05	.96		24	75.2	.93	.97	.99	.94	.93	1.00	1.04
.99	1.03	1.07	.94		26	78.8	.90	.96	.98	.91	.90	.99	1.07
.99	1.04	1.09	.91		28	82.4	.85	.94	.97	.88	.87	.99	1.09
.98	1.05	1.12	.88		30	86.0	.81	.92	.96	.86	.84	.98	1.11
.97	1.06	1.14	.86		32	89.6	.77	.89	.95	.83	.81	.97	1.13
.97	1.07	1.17	.84		34	93.2	.73	.87	.94	.80	.77	.97	1.15
.96	1.07	1.19	.82		36	96.8	.69	.84	.93	.77	.74	.96	1.17
.95	1.08	1.21	.80		38	100.4	.65	.81	.91	.74	.70	.95	1.19
.94	1.08	1.23	.78		40	104.0	.61	.78	.89	.70	.67	.94	1.21
.93	1.09	1.26	.76		42	107.6	–	.74	.87	.67	.63	.93	1.22
.91	1.10	1.28	.74		44	111.2	–	.70	.85	.63	.60	.91	1.24
.89	1.10	1.30	.72		46	114.8	–	.64	.83	.61	.56	.89	1.25
.87	1.11	1.31	.70		48	118.4	–	.58	.82	.58	.53	.87	1.26
.86	1.11	1.33	.68		50	122.0	–	.52	.80	.56	.50	.86	1.27
.84	1.11	1.34	.66		52	125.6	–	–	.79	.53	.47	.84	1.28
.82	1.11	1.36	.64		54	129.2	–	–	.78	.51	.44	.82	1.29
.79	1.11	1.37	.62		56	132.8	–	–	.77	.49	.41	.79	1.30
.77	1.12	1.37	.60		58	136.4	–	–	.76	.46	.38	.77	1.29
.75	1.12	1.38	.58	1.00	60	140.0	–	–	.74	.44	.36	.75	1.27

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Figure 1.15 Table of Multipliers – Table 2 of 4

TABLE OF MULTIPLIERS FOR USE IN CONVERTING POWER FACTORS AT TEST TEMPERATURES TO POWER FACTORS AT 20°C (BUSHINGS – continued)

LAPP			McGRAW-EDISON	MICAFIL	MICANITE AND INSULATORS CO.		TEST TEMPERATURES		OHIO BRASS				PASSONI VILLA	WESTINGHOUSE		
Class[1] ERC 15-23 kV	Class PRC 15-69 kV	Class POC 15-765 kV	Types P, PA, PB	Types WTxF	25-69 kV	Above 69 kV	°C	°F	Class G or L 46-138 kV	Class L 7.5-34.5 kV	Class GK 15-500 kV	Class LK 15-69 kV	Types PTAO, 3 PV.F 25-230 kV	Con-denser, except Type O	Types O O-Al OC	Types O+ and O + C
.90	.81	1.00	.68	–	1.55	1.13	0	32.0	1.54	1.29	.90	.85	.65	1.61	.88	.87
.91	.83		.70	–	1.49	1.11	2	35.6	1.47	1.26	.91	.86	.69	1.52	.89	.89
.92	.86		.72	–	1.43	1.10	4	39.2	1.40	1.24	.91	.87	.74	1.44	.90	.91
.93	.88		.76	–	1.37	1.08	6	42.8	1.34	1.21	.92	.89	.78	1.36	.91	.92
.94	.89		.79	–	1.31	1.07	8	46.4	1.29	1.19	.92	.90	.82	1.30	.93	.93
.95	.92		.82	–	1.25	1.06	10	50.0	1.24	1.16	.93	.92	.86	1.23	.94	.94
.96	.94		.85	–	1.20	1.05	12	53.6	1.18	1.12	.94	.93	.89	1.18	.95	.95
.97	.95		.87	1.00	1.15	1.04	14	57.2	1.14	1.09	.95	.95	.92	1.13	.96	.96
.98	.97		.93	1.00	1.10	1.02	16	60.8	1.09	1.06	.97	.96	.95	1.09	.98	.98
.99	.98		.96	1.00	1.05	1.01	18	64.4	1.04	1.03	.98	.98	.97	1.04	.99	.99
1.00	1.00	1.00	1.00	1.00	1.00	1.00	20	68.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00		1.02		.96	.99	22	71.6	.95	.97	1.02	1.02	1.02	.96	1.01	1.01
1.01	1.03		1.10		.91	.98	24	75.2	.91	.94	1.04	1.04	1.05	.92	1.02	1.02
1.02	1.05		1.14		.87	.96	26	78.8	.88	.91	1.06	1.06	1.07	.88	1.04	1.03
1.02	1.07		1.18		.84	.95	28	82.4	.84	.88	1.09	1.08	1.09	.84	1.05	1.04
1.03	1.10		1.24		.80	.94	30	86.0	.80	.86	1.11	1.10	1.11	.81	1.06	1.05
1.03	1.11		1.29		.77	.93	32	89.6	.77	.83	1.13	1.12	1.13	.77	1.07	1.06
1.04	1.12		1.32		.74	.92	34	93.2	.74	.80	1.15	1.14	1.16	.74	1.08	1.07
1.04	1.13		1.36	1.00	.70	.90	36	96.8	.71	.78	1.17	1.15	1.17	.70	1.08	1.07
1.05	1.14		1.41	.99	.67	.89	38	100.4	.68	.75	1.19	1.17	1.18	.67	1.09	1.08
1.05	1.15		1.45	.98	.64	.88	40	104.0	.65	.72	1.21	1.18	1.18	.64	1.09	1.08
1.05	1.15		1.50	.98	.61	.87	42	107.6	–	–	1.22	1.19	1.20	.62	1.10	1.09
1.06	1.15		1.55	.97	.58	.86	44	111.2	–	–	1.24	1.20	1.22	.59	1.11	1.10
1.06	1.15		1.58	.97	.55	.85	46	114.8	–	–	1.26	1.21	1.24	.56	1.11	1.10
1.07	1.14		1.61	.96	.52	.84	48	118.4	–	–	1.27	1.21	1.24	.53	1.10	1.11
1.07	1.13		1.65	.95	.50	.83	50	122.0	–	–	1.29	1.22	1.25	.51	1.10	1.11
1.07	1.11		1.67	.94	–	–	52	125.6	–	–	1.30	1.22	1.26	.50	1.10	1.11
1.08	1.09		1.67	.94	–	–	54	129.2	–	–	1.31	1.22	1.26	.48	1.09	1.11
1.08	1.07		1.67	.90	–	–	56	132.8	–	–	1.33	1.22	1.26	.47	1.08	1.11
1.07	1.06		1.68	.90	–	–	58	136.4	–	–	1.34	1.21	1.26	.46	1.07	1.12
1.07	1.05	1.00	1.68	.92	–	–	60	140.0	–	–	1.35	1.21	1.25	.45	1.06	1.12

[1]This curve is applicable to those ERC bushings which were manufactured after March 1967 (S/N 3530 or higher).

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Figure 1.16 Table of Multipliers – Table 3 of 4

TABLE OF MULTIPLIERS FOR USE IN CONVERTING POWER FACTORS AT TEST TEMPERATURES TO POWER FACTORS AT 20°C

LIQUID-FILLED TRANSFORMERS, SHUNT REACTORS, AND VOLTAGE REGULATORS

POWER TRANSFORMERS (Above 500 kVA)				DISTRIBUTION TRANSFORMERS (500 kVA and Below)								PTs/VTs, CTs, and MOs		
	Oil-Filled Transformers				Oil-Filled			TEST TEMPERATURES					Oil-Filled	
Askarel-Filled Trans.	Free Breathing and Pre-1955 Conservator Types	Sealed, Gas-blanketed, and Modern Conservator Types	Silicone	Askarel	Prior to 1950	Modern	Silicone	°C	°F	HV/EHV Shunt Reactors (Oil-Filled)	Voltage Regulators (Oil-Filled)	Askarel	Modern, Rated 220 kV and Above	All Others
–	1.56	.95	–	–	1.56	1.57	–	0	32.0	.95	1.56	–	1.57	1.67
–	1.52	.96	–	–	1.52	1.50	–	2	35.6	.96	1.52	–	1.50	1.61
–	1.48	.98	–	–	1.48	1.44	–	4	39.2	.98	1.48	–	1.44	1.55
–	1.45	.98	–	–	1.45	1.37	–	6	42.8	.98	1.45	–	1.37	1.49
–	1.43	.99	–	–	1.43	1.31	–	8	46.4	.99	1.43	–	1.31	1.43
–	1.38	.99	–	–	1.38	1.25	–	10	50.0	.99	1.38	–	1.25	1.36
–	1.31	1.00	–	–	1.31	1.19	–	12	53.6	1.00	1.31	–	1.19	1.30
–	1.24	1.01	–	–	1.24	1.14	–	14	57.2	1.01	1.24	–	1.14	1.23
–	1.16	1.01	–	–	1.16	1.09	–	16	60.8	1.01	1.16	–	1.09	1.16
–	1.08	1.00	–	–	1.08	1.05	–	18	64.4	1.00	1.08	–	1.05	1.08
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	20	68.0	1.00	1.00	1.00	1.00	1.00
.90	.91	.99	.96	.90	.91	.96	.96	22	71.6	.99	.91	.90	.96	.93
.81	.83	.98	.92	.81	.83	.92	.92	24	75.2	.98	.83	.81	.92	.86
.72	.76	.97	.88	.72	.76	.88	.88	26	78.8	.97	.76	.72	.88	.80
.64	.70	.96	.84	.64	.70	.84	.84	28	82.4	.96	.70	.64	.84	.74
.56	.63	.95	.80	.56	.63	.80	.80	30	86.0	.95	.63	.56	.80	.69
.51	.58	.94	.76	.51	.58	.76	.76	32	89.6	.94	.58	.51	.76	.65
.46	.53	.93	.73	.46	.53	.73	.73	34	93.2	.93	.53	.46	.73	.60
.42	.49	.91	.70	.42	.49	.70	.70	36	96.8	.91	.49	.42	.70	.56
.39	.45	.90	.67	.39	.45	.67	.67	38	100.4	.90	.45	.39	.67	.52
.35	.42	.89	.65	.35	.42	.65	.65	40	104.0	.89	.42	.35	.65	.48
.33	.38	.87	.62	.33	.38	.62	.62	42	107.6	.87	.38	.33	.62	.45
.30	.36	.86	.59	.30	.36	.59	.59	44	111.2	.86	.36	.30	.59	.42
.28	.33	.84	.56	.28	.33	.56	.56	46	114.8	.84	.33	.28	.56	–
.26	.30	.83	.54	.26	.30	.54	.54	48	118.4	.83	.30	.26	.54	–
.24	.28	.81	.51	.24	.28	.51	.51	50	122.0	.81	.28	.24	.51	–
.22	.26	.79	.49	.22	.26	.49	.49	52	125.6	.79	.26	.22	.49	–
.21	.23	.77	.47	.21	.23	.47	.47	54	129.2	.77	.23	.21	.47	–
.19	.21	.75	.45	.19	.21	.45	.45	56	132.8	.75	.21	.19	.45	–
.18	.19	.72	.43	.18	.19	.43	.43	58	136.4	.72	.19	.18	.43	–
.16	.17	.70	.41	.16	.17	.41	.41	60	140.0	.70	.17	.16	.41	–

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Figure 1.17 Table of Multipliers – Table 4 of 4

Surface Leakage

Introduction

The Doble test is a searching diagnostic tool for evaluating insulation condition. It is a fundamental concept that changes in insulation quality (for whatever reason or cause) and results in measurable changes in one or more of the basic electrical characteristics of the insulation system, such as dielectric-loss, capacitance, and power factor. Thus, by measuring these important electrical parameters periodically, changes in the integrity of the insulation are revealed. (This concept assumes that there are no variables to distort the analysis.)

Unfortunately, Doble tests cannot always be made routinely under the conditions most generally preferred, since the equipment is located outdoors. Two environmental variables arise which cannot be controlled easily are temperature and humidity (also humidity in combination with air pollutants).

The effects of temperature may be accounted for in some measure by subjecting samples of the insulating materials or insulating systems to temperature changes under controlled conditions, and then measuring the changes in electrical characteristics. In this manner, temperature correction tables may be derived. This subject is covered in further detail in this section under ”Variation Of Power Factor with Temperature” on page 1-14. On the other hand, the effects of humidity cannot be so easily accounted for, because their effect on a Doble test is, in turn, related to other variables as follow:

- UST versus GST measurement. Except under extreme conditions, surface leakage to ground has only minimal effect on tests performed in the UST mode. Thus, while Overall tests on apparatus may be influenced by surface leakage across the bushings, UST measurement of the C insulation of the bushings will not be affected significantly; refer to ”Bushings” on page 1-16.
- The influence of surface leakage may be negligible when testing a large capacitance specimen (such as a power transformer), since the “normal” losses of the specimen may be quite large compared to the surface leakage losses. On the other hand, the same degree of surface leakage may be significant for a low-loss specimen, such as a surge arrester or bushing.
- Power transformers, because of the heat they generate, are able to dispel surface moisture more effectively than equipment which does not operate significantly above ambient temperature. Note that atmospheric moisture will not condense on warmer surfaces as readily as on cooler surfaces.

- Moderate surface moisture may not be a test problem if the specimen surface is otherwise clean. The surface losses may be appreciably higher if, in addition to moisture, the surface is dirty with soot, ash, quarry dust, etc.
- Physically smaller apparatus may be affected to a greater extent by surface leakage. For example, if testing two bushings of different voltage ratings, the surface leakage losses may not be as great on the physically larger bushing because the same test voltage is applied across a longer creepage path.

Thus, correction factors cannot be developed to account for the effects of surface leakage and humidity. The following general guidelines can be used to describe relative humidity:

- Below 50% – Low
- 50% to 70% – Medium
- Above 70% – High

The test engineer must recognize the effects of surface leakage (due to humidity, dirt, etc.) and be able to cope reasonably with various situations which may arise. Some cases may be handled quite readily, with little or no thought or effort as to control of surface leakage. Others may require a modest extra effort to produce good test results. It should also be recognized that there will be times when it will be best to postpone tests until another day.

There are two basic approaches to minimizing the effects of surface leakage:

1. Clean and dry exposed external surfaces (usually porcelain) to reduce the losses.

2. Employ Guard Collars to divert the undesirable surface leakage currents from the measuring circuit.

It is apparent that a combination of both approaches will be most effective.

Surface Cleaning

Wiping a moist/dirty porcelain surface with a clean and dry cloth may be effective, provided that the amount of contamination is not too great. Sometimes wiping the surface simply spreads the contamination, and may actually increase surface losses. In such cases it may be necessary to apply a silicone-base or hard-base wax or grease (after surface dirt has been removed) in order to break up conducting paths.

Solvents may be used to help clean surfaces which are stained or laden with particulate matter such as dirt, soot, etc. Upon evaporation, solvents tend to cool a porcelain surface and this, in turn, may increase moisture condensation. Thus, solvents should not be used where the problem is one of moisture condensation alone.

Heat is an excellent method for reducing surface leakage due to moisture. Infrared lamps and hot-air blowers have been used successfully. In the particular cases of the Hot-Collar and Three-Electrode tests, or other tests involving relatively short creepage paths between the energized and measuring electrodes, the application of heat for a relatively short interval is usually all that is required to elevate surface temperature and to dry the surface long enough for a good test to be made.

Guard Collars

Guard Collars (alone or in conjunction with surface cleaning) provide a very effective method for coping with surface leakage. The basic principle of using Guard Collars is to place them very close to (but not touching) the low-voltage terminal of the specimen. Note that, for a Grounded Specimen Test (GST), the low voltage terminal is grounded (see Figure 1.18a). For a UST measurement (Figure 1.18b) the Guard Collar is grounded. The conducting rubber collars provided with Doble test sets are suitable for use as Guard Collars. Electrodes of other conducting material (such as aluminum foil and bare-stranded copper wire) may be fabricated for this application.

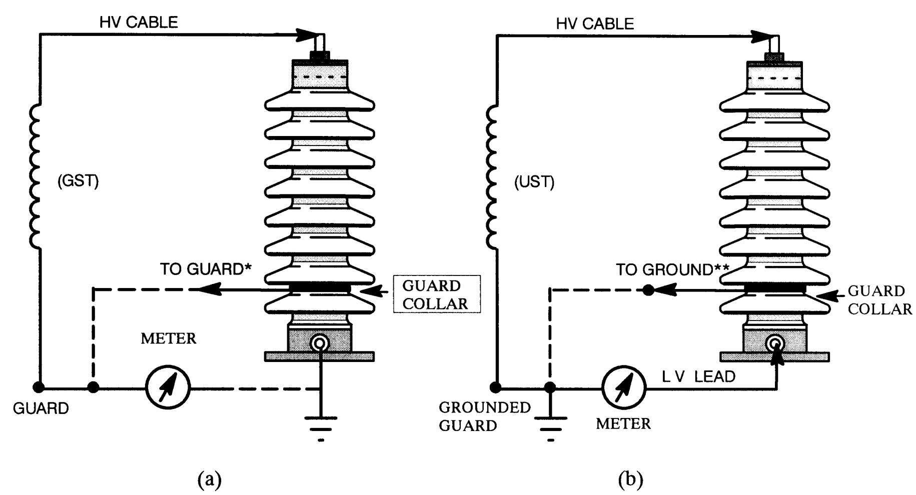


Figure 1.18 Application of Surface Guard Collars

*Connect either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to the LV Lead in the GUARD mode.

**Make connection to test ground, or connect to either the Ground terminal or the Guard terminal on the outboard pothead of the High-Voltage Test Cable.

Figure 1.19 illustrates the use of the Guard Collar when making an Overall test on apparatus connected through a bushing. Guard Collars, when required, should be placed on all energized bushings. For example, with reference to oil circuit breakers, Guard Collars are placed on both tank bushings for the Closed-Breaker test.

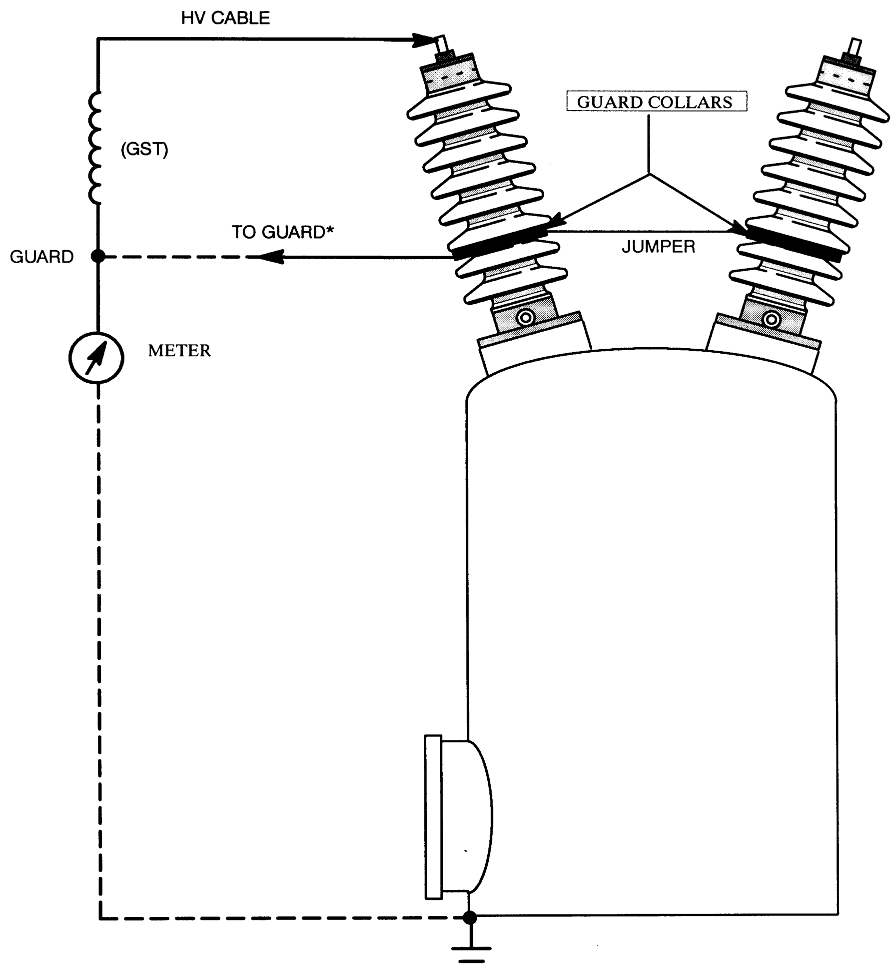


Figure 1.19 Application of Surface Guard for Overall test of Bushings

*Connect either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to the LV Lead in the GUARD mode.

Figure 1.20 illustrates the use of Guard Collars for Hot-Collar tests on bushings and potheads.

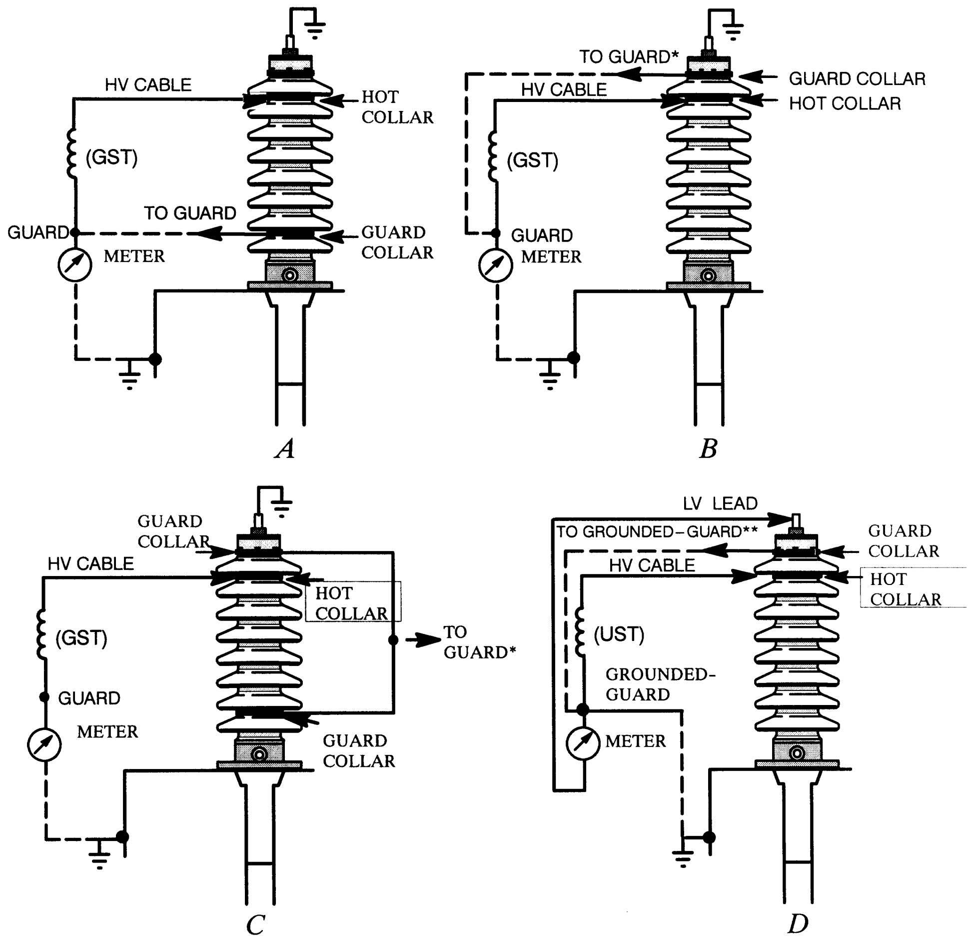


Figure 1.20 Application of Guard Collars for Hot-Collar test on Bushings and Potheads

*Connect either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to the LV Lead in the GUARD mode.

**Make connection to test ground, or connect to either the Ground terminal or the Guard terminal on the outboard pothead of the High-Voltage Test Cable.

Connected Bus and Insulators

Doble tests on apparatus should not be performed with bus and insulators connected to the terminals of the apparatus if their effect cannot be guarded away. In some cases the decision may be made to leave a relatively short section of bus connected. This may be undesirable because connected bus and insulators contribute charging current and losses to the measurement, and thus may significantly reduce the sensitivity of the test and mask incipient defects in the apparatus being tested.

In some cases where it is desirable for bus and insulators to remain connected to the apparatus under test, the effect of charging current and losses in the connected insulators may be minimized by the use of a Guard connection, as shown in Figure 1.21 and Figure 1.22.

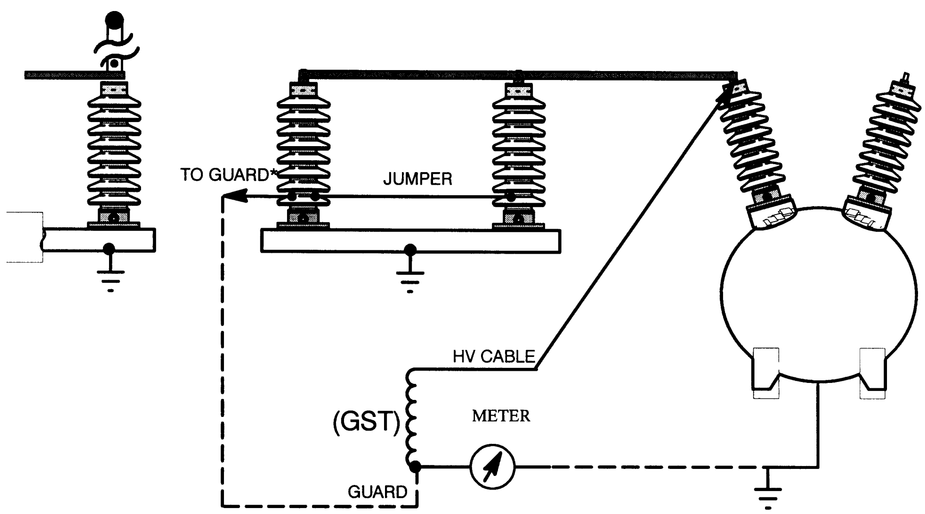


Figure 1.21 Application of Guard Collar for Single-insulator stacks

* Connect either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to the LV Lead in the GUARD mode.

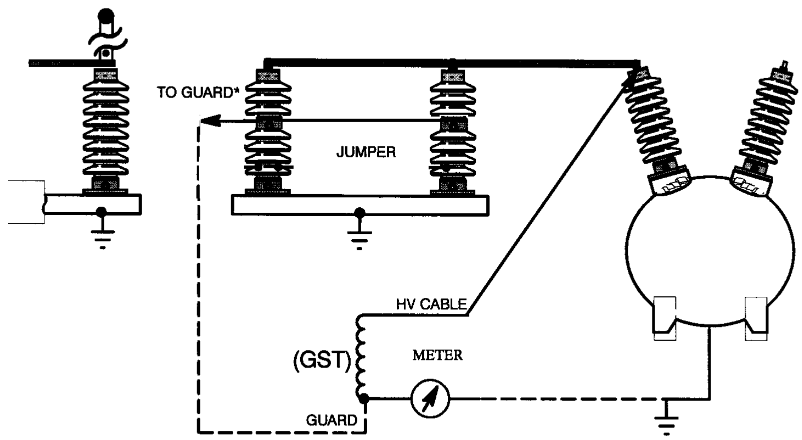


Figure 1.22 Application of LV Lead for Multi-insulator stacks

* Connect to the LV Lead in the GUARD mode.

Attached Bus And DTA

DTA has always allowed for testing with attached bus. The OCB and Live Tank SF6 Breakers have columns on the overall test sheet to enter information about attached bus that cannot be guarded off, so as to help explain the changes in charging current and percent Power Factor it will cause. But for the best results, buswork that cannot be guarded should be detached whenever possible.

Using the Guard circuit is a convenient way to test free-standing Current Transformers without disconnecting them from buswork, and for testing live tank breakers without detaching the free-standing CT. If using DTA, normal test circuits may have to be modified. For example, the normal test for a CT is a GST-Ground circuit. If the adjacent Disconnect Switch and Live Tank Breaker are left attached, they will have to be guarded by means of Low Voltage Leads and/or Hot Collars, and GST-Guard circuits will have to be used. For more details, see”Tests Made Possible By The M4000” on page 4-32, and ”Testing A Free-Standing CT Without Disconnecting From Attached Switch Or Breaker” on page 5-33

Disconnecting Buswork

For certain applications, particularly in EHV and UHV apparatus involving the use of long and heavy sections of bus, special consideration should be given to providing reasonable means for disconnecting bus from apparatus terminals. One method is to install Test Terminals similar to that shown in Figure 1.23. The use of terminals of this type greatly reduces the test time, minimizes the effects of electrostatic interference, and adds a measure of safety by permitting the work and tests to be performed between grounds.

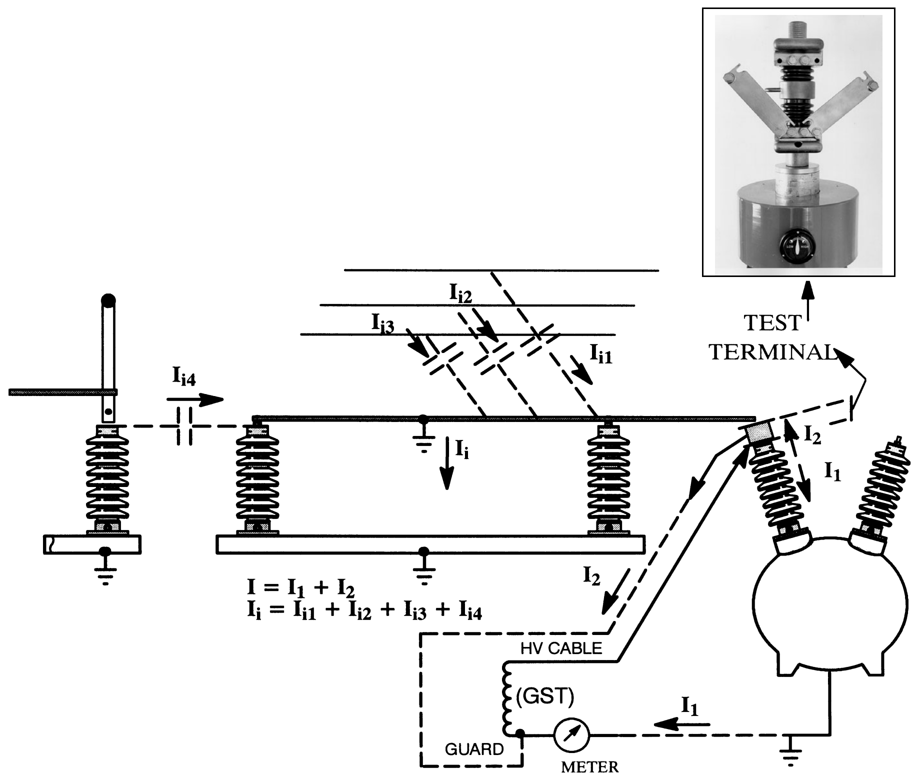


Figure 1.23 Use of Test Terminals

* Connect either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to the LV Lead in the GUARD mode.

2. Using A Resonator

Figure 2.1 The Doble Resonator

The Doble Type C Resonating Inductor is an iron-core reactor with an adjustable air gap, capable of resonating capacitances within a range of 0.05 to 1.0 microfarads at 60 Hz, and a range of 0.07-1.4 at 50 Hz. It is designed to extend the current range of Doble 10 kV Power-Factor Test Sets up to four Amps, assuming a lossless specimen, at voltages up to 10 kV. It extends the use of the set for testing relatively long cable lengths, large rotating machines, and other high-capacitance specimens. The ultimate range of the resonator depends not only on the capacitance of the specimen but also the total losses of the specimen under test.

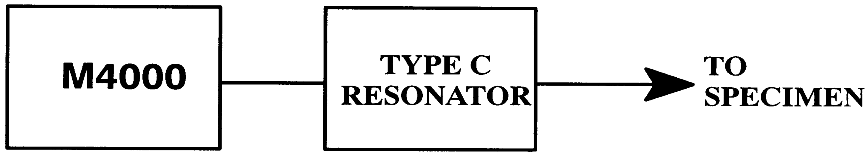


Figure 2.2 Power-Factor Test Set and Type C Resonating Inductor

The Resonator, shown schematically in Figure 2.3, is contained in a metal housing measuring 24 x 17 x 15 inches, and weighs approximately 185 pounds.

NOTE

L adjustable from 7 to 140 Henries @60Hz.

Counter dial calibrated per calibration chart supplied with each unit.

Resonator chassis ground connected to test ground through cable shield or external test ground lead.

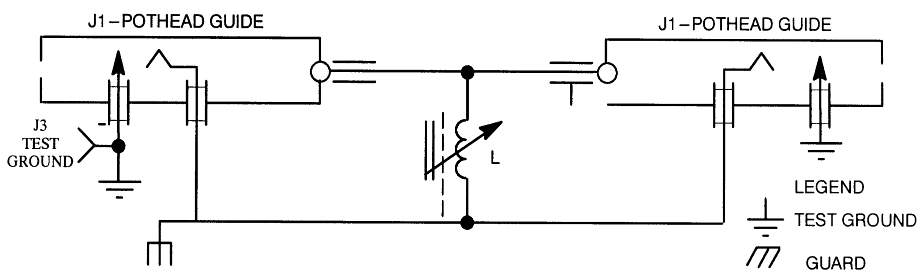


Figure 2.3 Schematic of Type C Resonating Inductor

Operating Procedure of Type C Resonating Inductor

The Resonator is connected to the M4100 Instrument by means of an 8-ft,10 kV jumper cable. The regular 10 kV test cable is connected between the Resonator and the test specimen. Cable receptacles will be found in the rear of the Resonator case and can be used interchangeably (see Figure 2.3).

The Resonator is equipped with a core-clamping arrangement to reduce the noise level when the Resonator is in use, and more importantly, to minimize vibration. A speeder-type wrench is provided for use with this clamping arrangement and for use in tuning the Resonator. The clamping adjustment is located in the front vertical face of the Resonator while the tuning control is located in the top panel. Turning the clamping adjustment approximately 180° counterclockwise or clockwise will either unclamp or clamp the core, respectively.

If the equivalent 10 kV charging current of the test specimen is known, the Resonator may be set approximately by adjusting the tuning control until the counter setting corresponds to this current. Mounted on the Resonator panel is a reference chart relating the approximate counter reading to the specimen current.

Accurate tuning of the Resonator is obtained by turning the tuning control until the current taken from the 120 volt supply is a minimum. To do this in the Clipboard test mode, follow this procedure:

1. Set the test for Line Sync Reversal (Under the LC column, select C).
2. Connect the M4000, the resonator, and the specimen as shown in Figure 2.2
3. Select the “System” tab from the “Tools/Configuration” menu of the M4000.
4. Set the M4000 to the “Manual Set Voltage” Ramp Mode.

NOTE ☝ **Do not raise the test voltage beyond the allowed limit for the attached specimen.**

5. Unclamp the Resonator Core.
6. Raise the test voltage to about 2 kV, using the Page Up (fast) or Up Arrow (slow) keys.
7. Observe the “input current” in the “Test Results” box.
8. Tune the Resonator until the “input current” of the M4000 is at a minimum.
9. To fine tune, raise the voltage to the final test voltage, or as close to it as possible, and repeat steps 7 and 8.
10. Reclamp the Resonator core.
11. Lower the voltage. The Resonator is tuned and you are ready to enter information on the row in the clipboard you are using for the test.

12. When filling in the clipboard row prior to starting the test, remember to select one of the "Line Sync Reversal" choices, C or F, in the LC (Line Configuration) column. For a description of all the Line Configuration choices, see "Glossary", in the "Contents" selection of the M4000 "Help" menu.

13. When finished using the Resonator, you may wish to return to *Tools/Configuration* and return the M4000 to its original settings of "Auto. Ramp Voltage" Ramp Mode in the *System* Configuration.

Due to the high currents involved requiring the use of the Resonator, the 120 volt supply cord to the M4100 should be of relatively large wire gauge in order to minimize the line voltage drop.

General Description of Type C-1 Coupler - RIV Test Procedure

NOTE **Recommended for M2H only.**

RIV (Radio-Influence Voltage) measurements may be of value in detecting corona on all types of insulation systems. One of the most common applications of RIV is with reference to rotating machinery insulation. The RIV Coupler in Figure 2.4 permits coupling of the radio-noise meter to the specimen with AC test voltage provided by the test set (refer to ANSI Guide C68.3- and IEEE Standard 454, "IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests"). The method usually employed detects partial discharges in the 1 MHz range. While some radio-noise meters use a diode-noise generator to produce reference signals, it is also feasible to use a radio receiver in conjunction with a standard signal generator. The signal generator should be capable of putting out a signal in the vicinity of 1 MHz, 50% modulated at 400 Hz, with a metered, adjustable output between 1 and 100,000 microvolts.

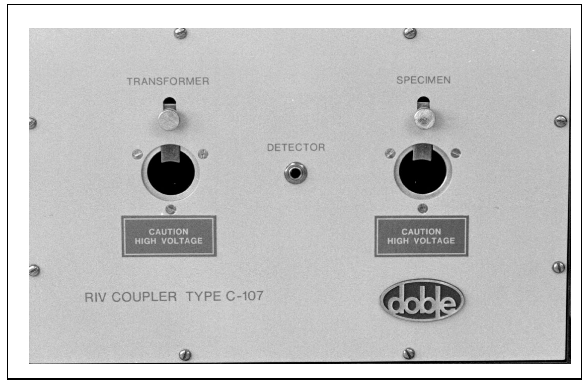
Figure 2.4 is a schematic of the Test Set complete with Resonator and coupling network (i.e., RIV Coupler) arranged for RIV (Radio-Influence Voltage) measurements. Note that the three components are arranged physically in series by means of two shielded jumper cables furnished with this equipment. One of the cables is connected between the M4100 Instrument and the Resonator. The second is connected between the Resonator and the RIV Coupler terminal marked "TRANSFORMER". A standard 60-ft cable is used between the specimen and the RIV Coupler terminal marked "SPECIMEN."

For low-capacitance specimens, when the Resonator is not used, connection is made directly from the M4100 Instrument to the RIV Coupler terminal marked “TRANSFORMER.”

Connection between the RIV Coupler and the radio-noise meter used for making RIV measurements is made by means of a single-circuit lead and telephone plug which plugs into the receptacle marked “DETECTOR” in the front of the Coupler. A separate common ground must be run from the M2H transformer case to the ground terminal of the radio-noise meter. To minimize shunting effects on the radio-noise meter, the capacitance between the RIV measuring lead and ground must be kept low. For this reason, use of a common two-conductor or shielded single-conductor lead is not recommended between the RIV Coupler and radio-noise meter.

Note that the circuit in Figure 2.4 is so arranged that, when the telephone plug is removed from the Coupler, the lower terminal of the coupling capacitor is connected to the test-setguard circuit. In this way, the Coupler may be left connected for power-factor tests. The telephone plug must be removed or the capacitor current and losses will be included in the measurement. Note that if the telephone plug (i.e., the radio-noise meter) is left connected, the Coupler adds only a small watts loss to the measurement being made. Despite the shielding, some stray capacitive currents are measured. The stray currents (at 10 kV) may be measured with the Coupler connected for test but with no specimen connected. For low-capacitance specimens, this current may be subtracted before the power-factor calculation is made, if it is appreciable compared with the specimen current.

The RIV Coupler is contained in a metal housing measuring 9¼ x 14½ x 11½ inches, and weighs approximately 25 pounds.



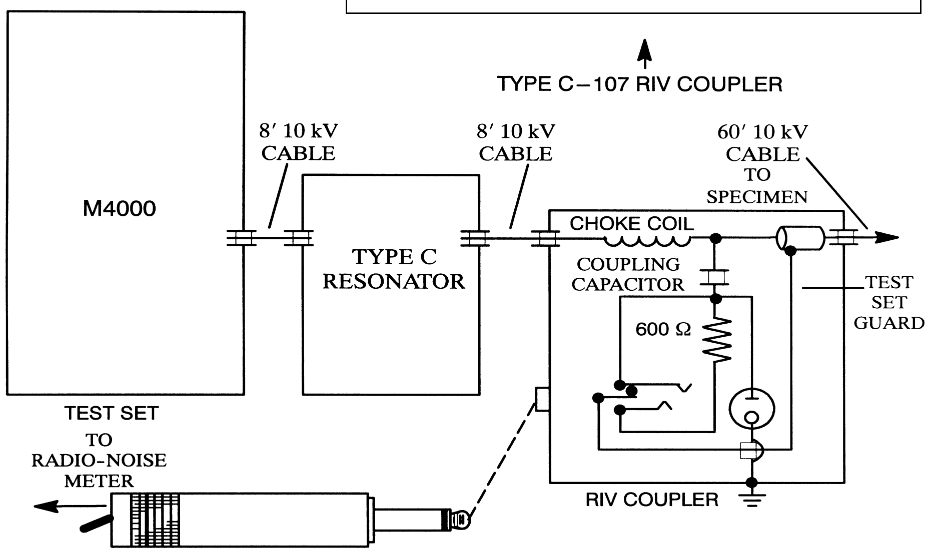


Figure 2.4 Coupling Arrangement for RIV Measurements with 10 kV Test Sets

NOTE **When the telephone plug is not connected to the Coupling Box, the lower terminal of the Coupling Capacitor is connected to the Test Set Guard Circuit. When the telephone plug is inserted into the receptacle, the Guard connection to the lower terminal of the Coupling Capacitor is removed and ground is applied to the low end of the 600 Ohm resistor via the barrel of the telephone plug.**

3. Bushings

Introduction

The primary function of a bushing is to provide an insulated entrance for an energized conductor into an apparatus tank or chamber. A bushing may also serve as a support for other energized parts of the apparatus.

Bushings may be classified generally by design as follows (information concerning construction of specific bushing types is included in the *Doble Bushing Field-Test Guide*):

Condenser Type:

- Oil-Impregnated Paper Insulation, with Interspersed Conducting (Condenser) Layers or Oil-Impregnated Paper Insulation, Continuously Wound with Interleaved Lined Paper Layers.
- Resin-Bonded Paper Insulation, with Interspersed Conducting (Condenser) Layers.

Noncondenser Type:

- Solid Core, or Alternate Layers of Solid and Liquid Insulation.
- Solid Mass of Homogeneous Insulating Material (e.g., Solid Porcelain).
- Gas Filled.

For outdoor bushings, the primary insulation is contained in a weatherproof housing, usually porcelain. The space between the primary insulation and the weathershed is generally filled with an insulating oil or compound (also used are plastic and foam). Some of the solid homogeneous types may use oil to fill the space between the conductor and the inner wall of the weathershed. Bushings also may use gas, such as SF_6 as an insulating medium between the center conductor and outer weathershed.

Bushings may be further classified generally as being equipped, or not equipped, with a potential tap or power-factor test tap or electrode.

NOTE ☛ **“Potential” taps are sometimes also referred to as “capacitance” or “voltage” taps.**

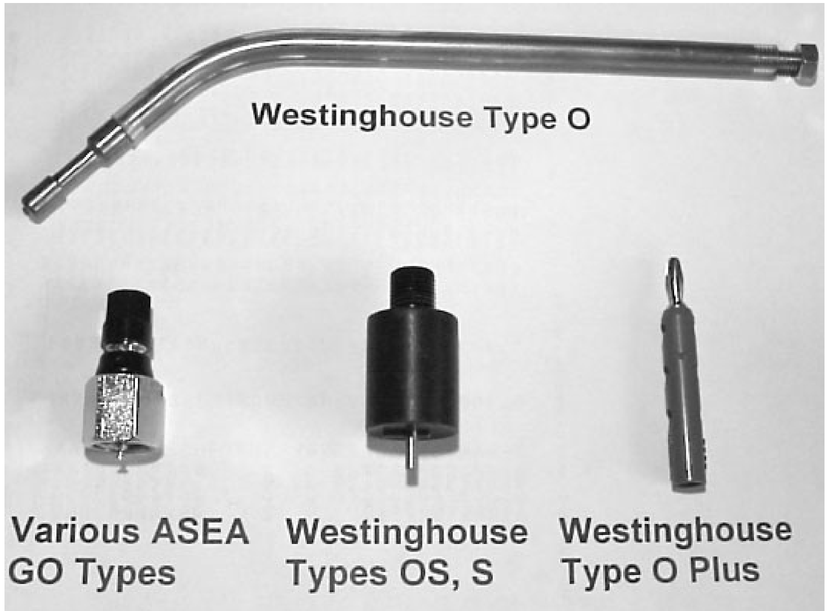
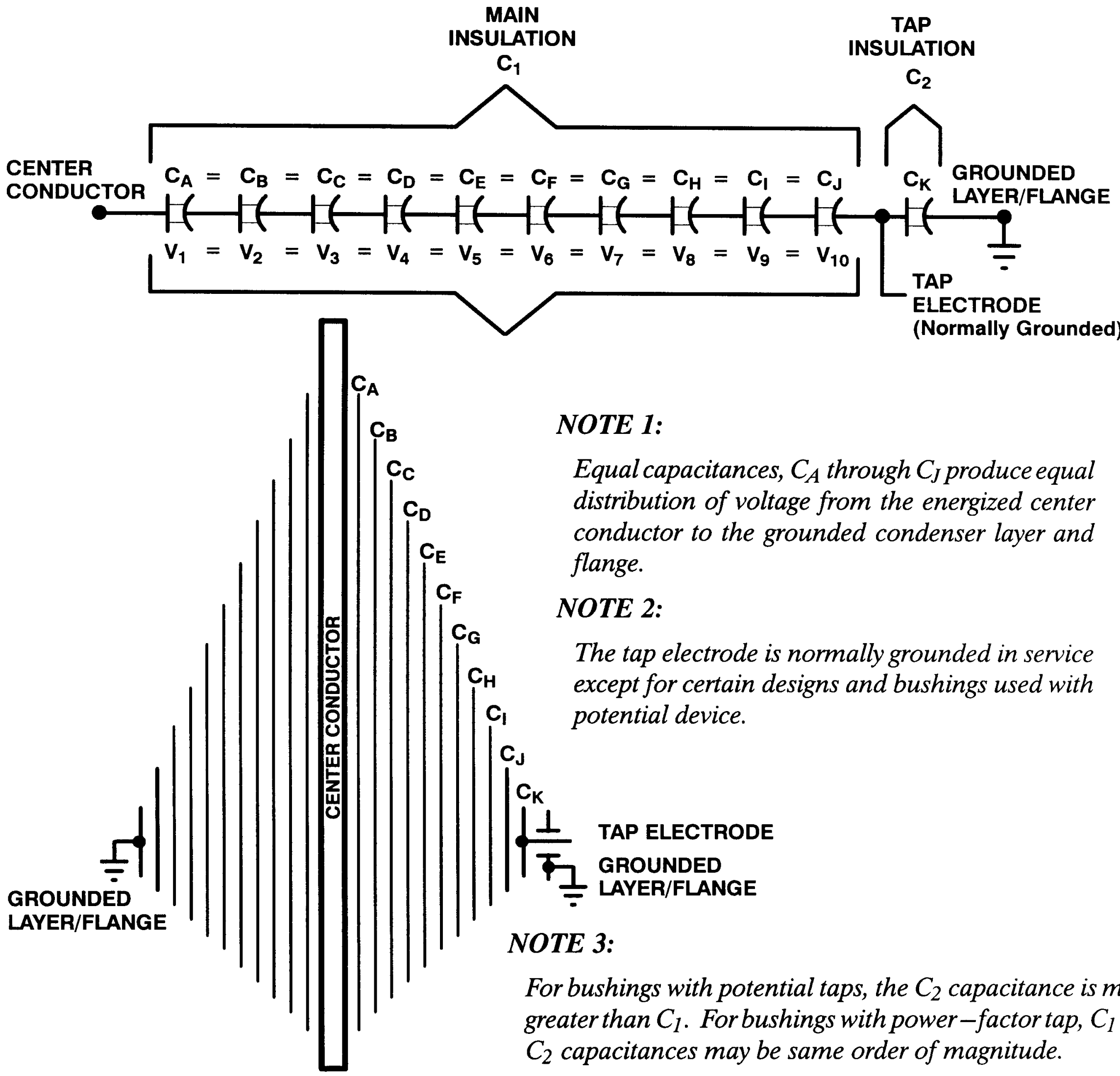


Figure 3.1 Bushing Potential Tap Adapters

The bushing without a potential tap or power-factor tap is a two-terminal device, which is generally tested overall (center conductor to flange) by the GST method. If the bushing is installed in apparatus, such as a circuit breaker, the Overall GST measurement will include all connected and energized insulating components between the conductor and ground.

A condenser bushing is essentially a series of concentric capacitors between the center conductor and ground sleeve or mounting flange. A conducting layer near the ground sleeve may be tapped and brought out to a tap terminal to provide a three-terminal specimen. The tapped bushing is essentially a voltage divider and, in higher voltage designs, the tap potential may be utilized to supply a bushing potential device for relay and other purposes. In this design the potential tap also acts as a low-voltage power-factor test terminal for the main bushing insulation, C_1. Refer to Figure 3.2.



NOTE 1:

Equal capacitances, C_A through C_J produce equal distribution of voltage from the energized center conductor to the grounded condenser layer and flange.

NOTE 2:

The tap electrode is normally grounded in service except for certain designs and bushings used with potential device.

NOTE 3:

For bushings with potential taps, the C_2 capacitance is much greater than C_1. For bushings with power–factor tap, C_1 and C_2 capacitances may be same order of magnitude.

Figure 3.2 Typical Condenser Bushing Design

Modern bushings rated above 69 kV are usually equipped with potential taps. Bushings rated 69 kV and below may also be equipped with power-factor taps. In the power-factor tap design, the ground layer of the bushing core is tapped and terminated in a miniature bushing on the main bushing mounting flange. The tap is connected to the grounded mounting flange by a screw cap on the miniature bushing housing. With the grounding cap removed, the tap terminal is available as a low-voltage terminal for a UST measurement on the main bushing insulation, C_1 conductor to tapped layer.

In some (IEEE Type B) bushing designs, such as certain Westinghouse Electric Corporation Type "O", for example, the tapped layer is brought out into an oil-filled compartment. The potential tap is allowed to float in service. A special probe is inserted through an oil filling hole to make contact with the tapped layer, to permit a UST measurement.

There may be modifications of the power-factor-tap principle. For example, bushings have been designed with mounting flanges which can be temporarily isolated from ground for UST measurements.

A bushing is a relatively simple device, and field test techniques have been devised by the Doble Engineering Company, in cooperation with its clients, to facilitate the detection of defective, deteriorated, contaminated, or otherwise damaged insulation. The various types of Doble tests applicable to bushings may be summarized as follows:

- Overall (Center Conductor to Flange).
- Ungrounded-Specimen Test, or UST (Center Conductor to Tap, C_1).
- Inverted UST Test (Tap to Center Conductor, C_1)
- Cold Guard (Center Conductor to Flange).
- Tap Insulation Test (Tap to Flange, C_2).
- Alternate C_2 Test: C_1 and C_2 in Parallel.
- Collar Tests (Externally Applied Collar to Center Conductor).

Test Voltages

The following summarizes recommended Doble test voltages for various bushing tests:

Overall Test and Ungrounded-Specimen Test (UST) on C_1 (Center Conductor Energized)

1. For bushings rated above 8.7 kV insulation class, test at 10 kV.

2. For bushings rated 8.7 kV class and below, test at a convenient voltage which is at or below the bushing nameplate rating. For example, the following is a list of recommended test voltages for several low-voltage ratings:

Bushing Rating (kV)	Recommended Test Voltage (kV)
8.7	5
5.0	5
4.3	2
1.2	1

NOTE ☝ **The test voltages recommended herein for the Overall test and Ungrounded-Specimen Test (UST) are applicable to spare bushings and for bushings installed in apparatus. For bushings in apparatus there may be unusual circumstances whereby the voltage rating of a bushing(s) is greater than the voltage rating of the apparatus terminal to which it is connected. (This may involve the neutral terminal of a transformer winding.) In such cases, though rare, the normal test voltage for the Overall and UST bushing tests may have to be reduced to that which can be applied for the Overall tests on the apparatus itself. In this regard, make reference to the comments under Test Voltages for the specific apparatus.**

Cold-Guard Test

For draw-lead transformer bushings.

Limit to 500 volts, or less, since the insulation between the bushing center conductor and the draw-lead conductor may be of poor quality or have low dielectric strength.

Tap-Insulation Test and Inverted Ungrounded-Specimen Test

1. Potential (Capacitance) Taps (bushings rated higher than 69 kV) – Test at 2 kV. If a higher test potential is desired, 5 kV should be considered as the maximum allowable voltage unless the tap is known to be rated higher.
2. Power-Factor Taps (bushings rated 69 kV and below) – Power-factor taps of bushings are energized for test at 500 volts except as noted below.

NOTE ☝ **a. In the case of Ohio Brass Company Class L bushings, the manufacturer has recommended that no more than 250 volts be applied to the power-factor tap.**

b. Potentials above 500 volts may be applied to power-factor taps only with manufacturers approval.

Hot-Collar Tests

Single and Multiple Collars.

Test at 10 kV.

Sometimes it is useful to investigate abnormal results by making a series of tests at several voltages to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This may involve increasing the test voltage to 12 kV in the case of bushing tests normally performed at 10 kV.

Test Technique - Spare Bushings

Of the seven test techniques listed above, all but the Cold-Guard Methods are applicable to spare bushings. The Cold-Guard tests are applicable to draw-lead, shielded-layer, and insulated-head bushings in transformers.

A spare bushing that is to be tested should be mounted in a grounded metal rack with nothing connected to its terminals, so that the results are solely indicative of the condition of the bushing. Tests should not be performed with the bushings mounted in wooden crates or lying on a floor. If bushings are tested in wooden crates, the test results (GST and UST) will be affected by the wood in the proximity of the terminals. Even a cement floor can affect the results, unless the bushing center conductor (bottom terminal) is more than a few inches above the floor. Bushings, especially tall bushings, have been successfully tested while supported above ground using slings. Care must be taken in the method used to hoist the bushing, making certain that the bushing center conductor is not in contact with the sling material (rope, etc.).

For spare bushings, with or without taps, an Overall test is performed by the GST method as outlined in Figure 3.3. The current, watts, and capacitance are recorded in the conventional manner, and the overall power factor is calculated and corrected for temperature using the air temperature around the bushing at the time of test. See “Analysis Of Results”, ”Condenser Bushings Without Potential Taps or Power-Factor Test Electrodes” on page 3-26 in this section.

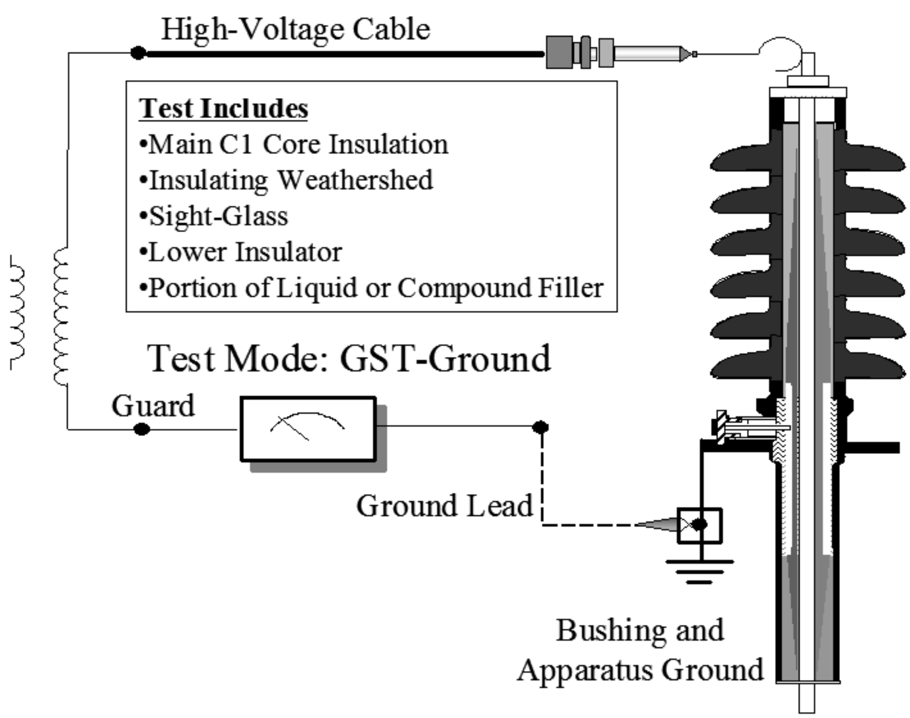


Figure 3.3 Overall Bushing Test

For bushings equipped with taps, in addition to the Overall GST measurement, the C_1 insulation should be checked by the UST method as shown in Figure 3.4. Record current, watts, and capacitance for C_1 (conductor to tap) in the conventional manner. The power factor is then calculated and corrected using a multiplier corresponding to air temperature. The power factor and capacitance should be compared with bushing nameplate values (if any). For further comments, refer to the discussion in this section under: ”Test Technique - Bushings in Apparatus” – ”Ungrounded-Specimen Test (UST) (Center Conductor to Tap, C1)” on page 3-10; and under ”Analysis of Test Results” – ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

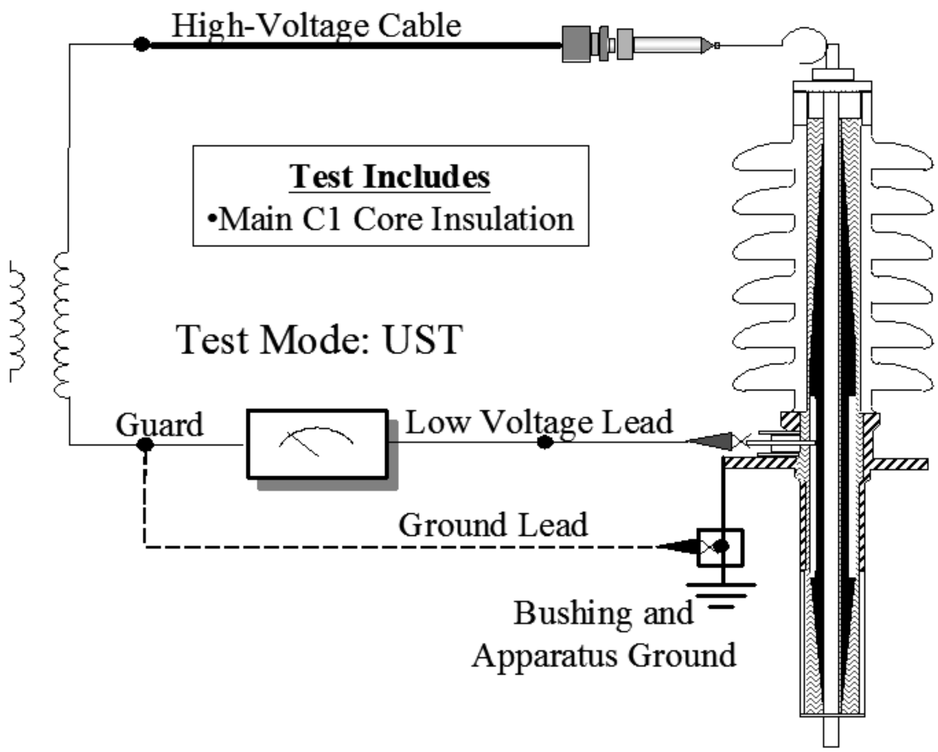


Figure 3.4 Bushing C_1 Insulation Test by the Standard UST Method

The tap insulation, C_2, is tested as shown in Figure 3.5. For C_2 (tap to flange) the current, watts, and capacitance are recorded, and the power factor is calculated but not corrected for temperature. In the case of bushings with potential taps, the C_2 capacitance recorded is compared with the nameplate value (if any). For further comments, refer to”Test Technique - Bushings in Apparatus” – ”Tap-Insulation Test (Tap to Flange, C2)” on page 3-17, and to”Analysis of Test Results” – ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

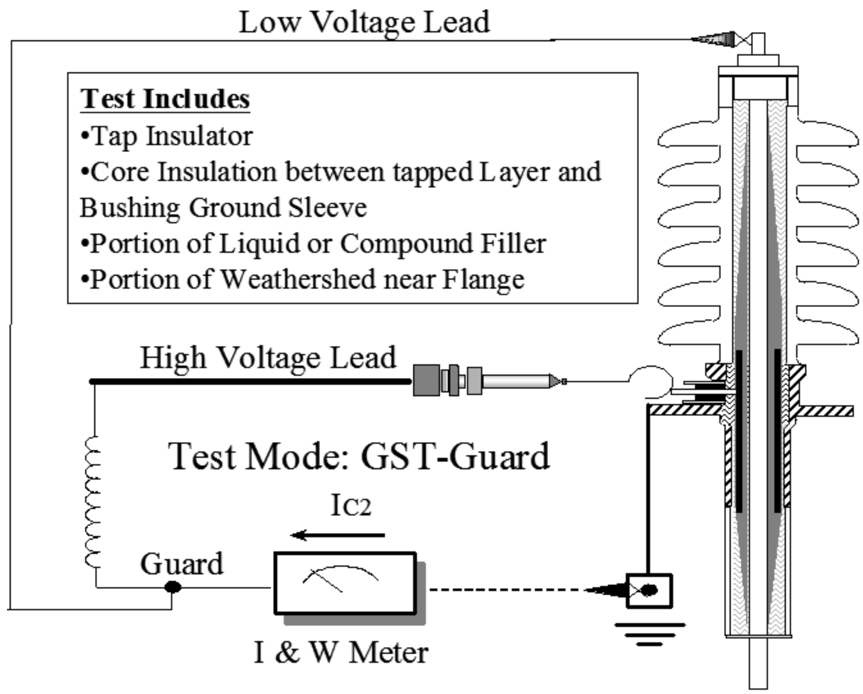


Figure 3.5 Bushing Tap-Insulation (C_2) Test by GST

Connect the bushing center conductor either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to a LV Lead in the GUARD mode.

In addition to the Overall and UST tests, compound-filled bushings should also be tested by the Single Hot-Collar (SHC) method (Figure 3.6) in order to detect contamination, deterioration, or cracks in the upper bushing area. Liquid-filled bushings, oil or compound, are also tested by this method to detect low liquid level. Hot-Collar Tests on solid porcelain bushings may reveal the presence of cracks. For Single Hot-Collar Tests the current and watts-loss are recorded; power factor is not calculated. Refer to further comments under ”Test Technique - Bushings in Apparatus” – ”Collar Tests” on page 3-19, and under ”Analysis of Test Results” – ”Single Hot-Collar Test” on page 3-29.

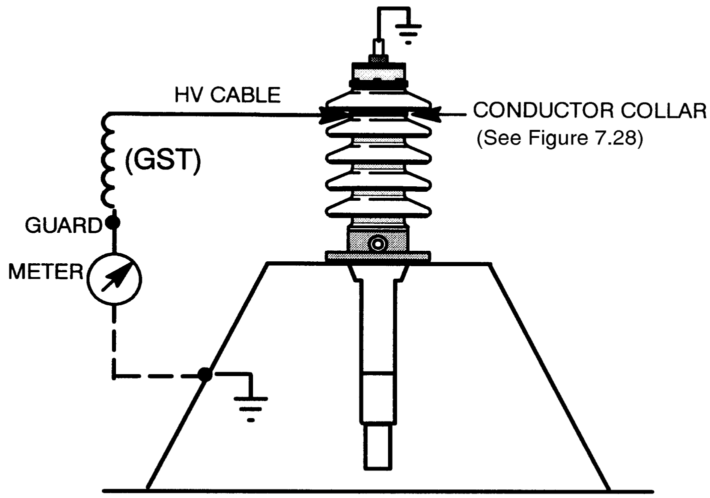


Figure 3.6 Bushing Single Hot-Collar (SHC) Test

Test Technique - Bushings in Apparatus

The bushing tests referred to in the Introduction of this section are applicable to bushings in apparatus. These are discussed separately as follows.

Overall Test (Center Conductor To Flange)

In the case of a bushing mounted in apparatus, the Overall GST measurement on the bushing would include winding, interrupter, and/or other insulation connected between the bushing center conductor and ground. Unless the bushing conductor can be completely isolated, the overall GST method is not recommended for separate tests on bushings in apparatus. It is necessary to resort to one or more of the following tests.

Ungrounded-Specimen Test (UST) (Center Conductor to Tap, C_1)

Most modem high-voltage condenser-type bushings are equipped with either potential or power-factor test taps. These permit separate tests on the main bushing insulation (commonly referred to as C_1) without the need to disconnect a bushing from the apparatus or bus to which it is connected. The test technique is illustrated in Figure 3.7 for a bushing mounted in a transformer. Note that currents flowing in the insulation of other energized bushings and windings return to the high-voltage source via a grounded-guard circuit, and are not included in the measurement.

The current, watts, and capacitance are recorded in the conventional manner, and the power factor is calculated and corrected for temperature. For a bushing in a power or distribution transformer, use a multiplier corresponding to the average of the transformer top-oil and ambient air temperatures; for bushings mounted in oil circuit breakers the C_1 power factor is corrected using the air temperature. For additional comments refer to ”Analysis of Test Results” – ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

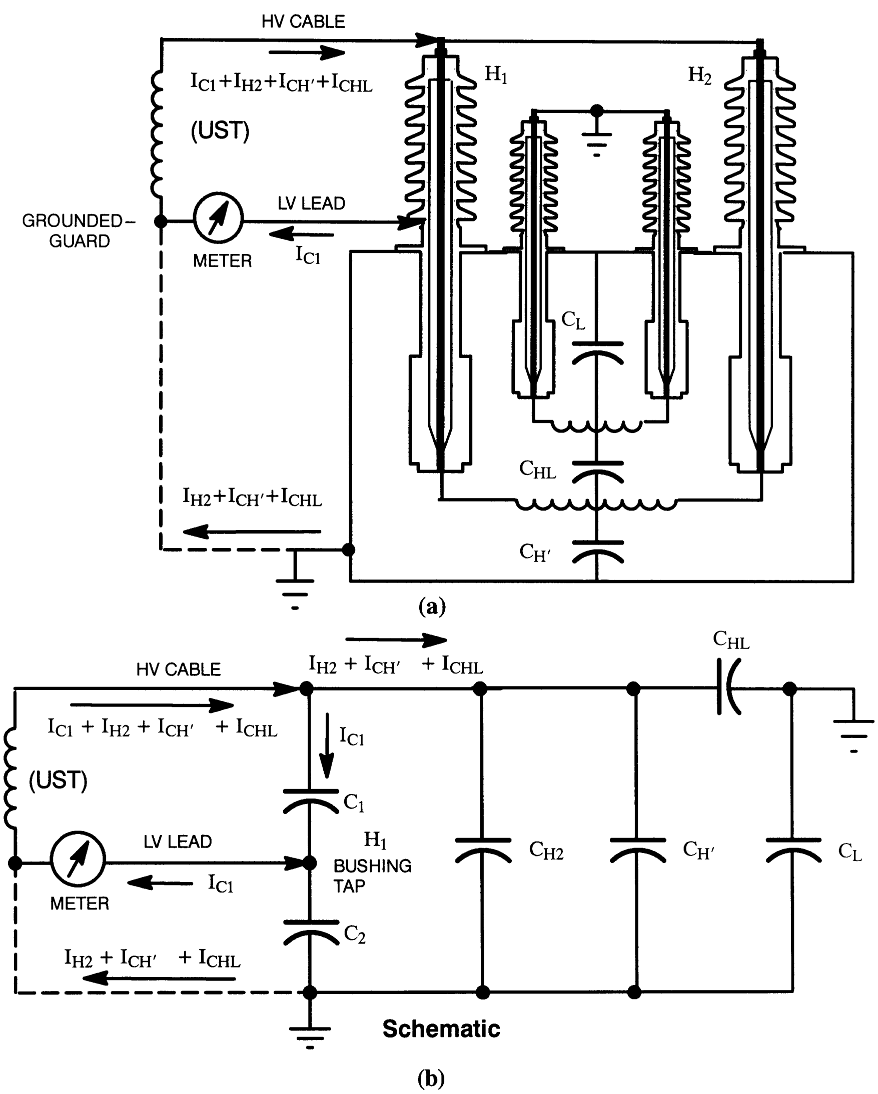


Figure 3.7 C_1 Insulation Test by UST Method of Bushing in Transformer

CAUTION

When making UST measurements on bushings in transformers, all terminals of the windings to which the bushings are connected must be tied together electrically. Otherwise, higher than normal losses may be recorded due to the influence of the winding inductance. Also, for S-A-F-E-T-Y, the bushings associated with all windings not energized should be grounded and not left floating. (Note: voltage can be induced in floating windings by electrostatic coupling.)

Inverted UST (Tap to Center Conductor, C_1)

The Inverted UST is applicable to bushings with capacitance or power-factor test taps, and permits measurements on the same insulation as the conventional UST, however, the inverted measurement is generally not performed except to investigate otherwise abnormal data by the standard UST method. There may be some instances where the Inverted UST measurement does not correlate exactly with the standard UST method – after taking into account possible differences in test potential. For example, this may occur when there is a relatively low impedance connected between the UST connection and ground. The Inverted UST method is illustrated in Figure 3.8.

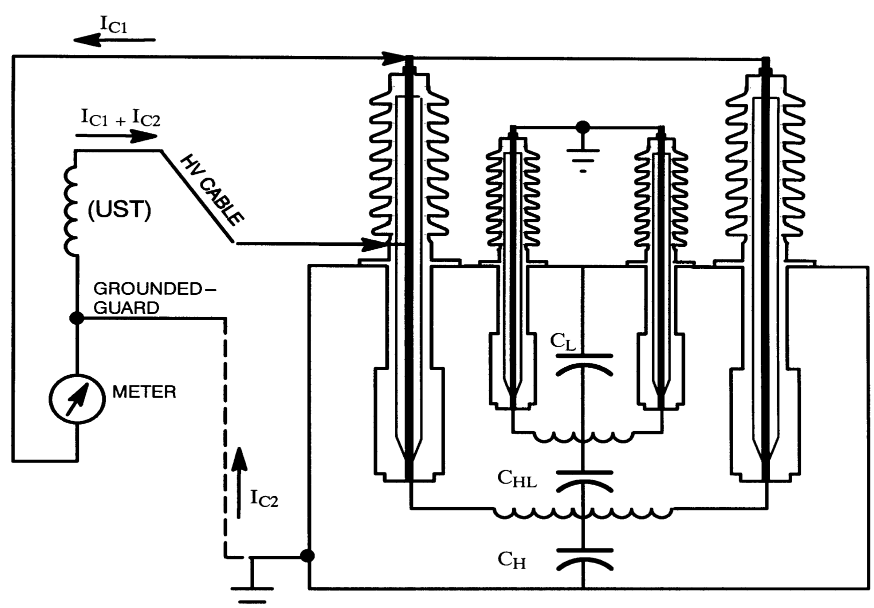


Figure 3.8 C_1 Insulation Test by Inverted UST

The test potential which may be applied to the tap depends upon the bushing type and voltage rating, and must not exceed the tap rating; refer to ”Tap-Insulation Test (Tap to Flange, C2)” on page 3-17. For further details, also refer to the *Doble Bushing Field-Test Guide.*

When applying the Inverted UST to a transformer bushing, the windings must be short-circuited, as in the conventional UST method.

The current, watts, and capacitance are recorded in the conventional manner, and the power factor is calculated and corrected for temperature as described for the standard UST. For additional comments refer to ”Analysis of Test Results” – ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25 in this section.

Ungrounded- Specimen Test, Isolated Flange Bushings (Center Conductor to Flange)

An Overall bushing measurement between the center conductor and flange may be performed by the UST method, provided that the flange can be insulated from ground by about 50,000 ohms or more. The most common application of this technique is in the case of bushings in transformers which are not equipped with test taps, and in which the winding cannot be disconnected conveniently from the bushing conductor. Some bushings have so-called isolating flanges which may be ungrounded by simply removing a short link. In the case of conventional two-terminal bushings, the metal flange bolts must be removed in order to isolate the flange from ground. Before attempting to unground the support flange of a conventional two-terminal bushing in a transformer, certain precautions should be taken, as follows:

1. If the bushing is in a conservator-type transformer, the valve to the raised conservator oil tank should be closed. The valve must be reopened before the transformer is placed back in service. Similar precautions should be taken on constant gas pressure type transformers; that is, the valve to the gas bottle should be closed for the tests, and reopened before the transformer is returned to service.

2. As each metal bolt is removed, an insulated bolt should be installed in its place. If, after the metal bolts are replaced, a low-resistance path remains between the flange and ground, use a sharp edged tool in an effort to break off conducting flakes of metal or paint between the flange and ground.

WARNING

Care must be taken not to disturb the bushing mounting in any way, since oil may leak out if the bushing is installed on a conservator-type transformer, and gasketing may be destroyed.

3. All terminals of the windings, to which the bushings are connected, should be tied together electrically for these tests.

4. When returning the metal bolts, be certain that they are tightened evenly, and to the prescribed torque.

The Overall test technique, using the UST method to the isolated (ungrounded) flange, is illustrated in Figure 3.9. The current, watts, and capacitance are recorded in the conventional manner, and the power factor is calculated and corrected for a temperature based on the average of the transformer top oil and ambient air temperatures. For further comments, refer to ”Analysis of Test Results” – ”Condenser Bushings Without Potential Taps or Power-Factor Test Electrodes” on page 3-26 or to ”Noncondenser Bushings With Split or Isolated Flanges” on page 3-26.

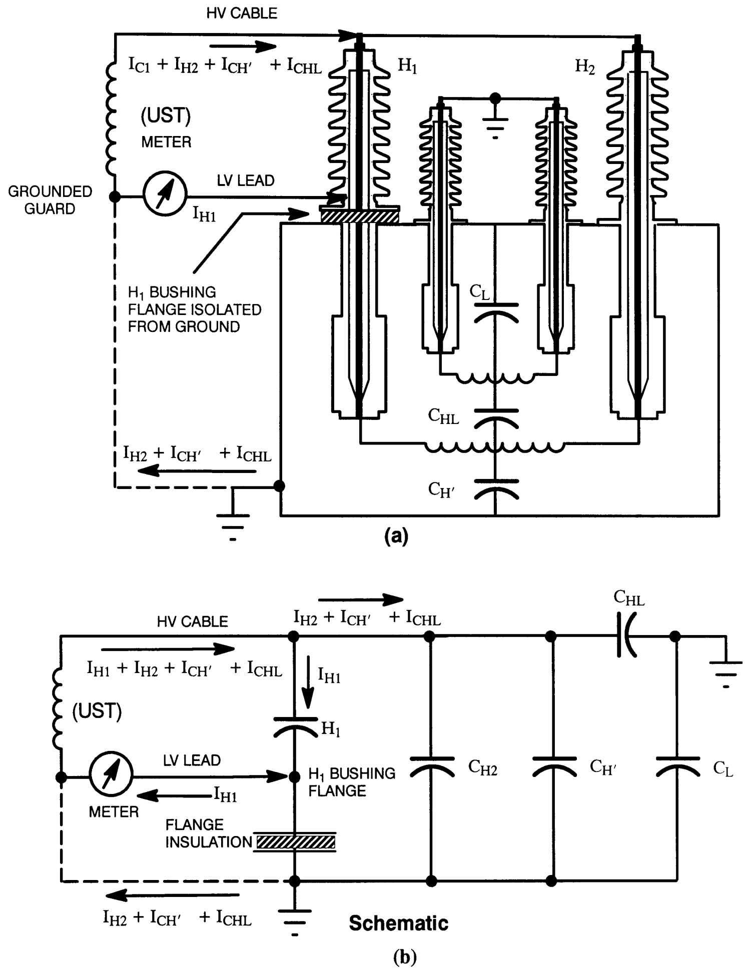
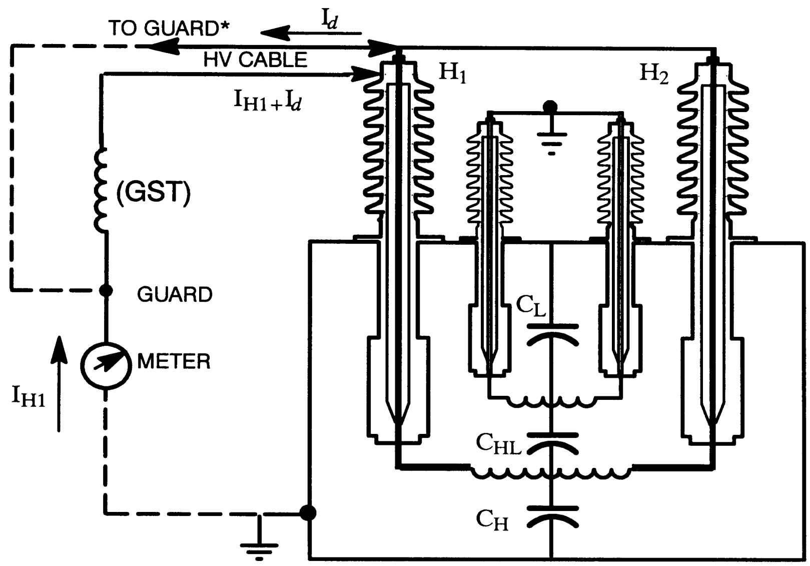


Figure 3.9 Overall Test (Conductor to Flange) by UST Measurement on Bushing in Transformer with Bushing Flange Isolated from Ground

Cold-Guard Test (Center Conductor to Flange)

Some transformer bushings are designed to permit isolation of the transformer lead from the bushing center conductor (these bushings are variously referred to as draw-lead, shielded-layer, or insulated-head). It may be possible to obtain a measurement of the overall condition of these bushings by using the test-set guard circuit as illustrated in Figure 3.10.



* Connect either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to the LV Lead in the GUARD mode.

Figure 3.10 Overall test on Draw-Lead Type Bushings by GST (Cold-Guard Method)

In the Cold-Guard method, the bushing center conductor is energized while guarding the draw lead, so that the lead must be isolated from the center conductor where it comes out of the bushing for the test. The full test voltage appears across the shield-layer, insulated-head, or the insulation separating the bushing center conductor from the draw-lead conductor. This insulation draws current I_∂ in Figure 3.10. Since the insulation between the bushing conductor and the draw-lead conductor may not be too great, the test voltage should not exceed 500 volts. In some cases, it may be necessary to twist and vary the position of the draw lead in order to isolate a defective layer of draw-lead insulation from the conducting tube of the bushing.

As in the case of isolated flanges, precautions should be taken to prevent the loss of gas when making an Overall test on a draw-lead bushing by the Cold-Guard method in a gas-blanketed transformer. Test personnel should also be aware of the oil level when preparing these bushings for test in a conservator-type transformer, making certain that the oil valve between the main transformer and conservator is closed for tests, and reopened before returning the transformer to service.

The current, watts, and capacitance are recorded in the conventional manner, and the power factor is calculated and corrected for temperature using the average of the transformer top-oil and ambient temperatures. Refer to ”Analysis of Test Results” – ”Condenser Bushings Without Potential Taps or Power-Factor Test Electrodes” or to ”Noncondenser Bushings With Draw-Leads, Shielded-Layers, or Insulated-Heads” on page 3-27 for further comments.

Tap-Insulation Test (Tap to Flange, C_2)

Most modern high-voltage condenser-type bushings are equipped with potential or power-factor test taps. There are two general classes of taps: (1) potential (or capacitance) taps, which are used generally on bushings rated above 69 kV, and (2) power-factor taps, used generally on bushings rated 69 kV and below.

Potential taps are designed for possible use with a bushing potential device. These are capable of withstanding fairly high voltages. Conveniently, potential taps also serve the additional purpose of permitting UST measurements on the main insulation (C_1) of a bushing without the need to isolate the upper and lower terminals from the associated apparatus and connected de-energized bus. Power-factor taps are not designed to withstand high potential since their purpose is solely to provide an electrode for making a UST measurement on the bushing C_1 insulation.

The test engineer must carefully consider the test potential before proceeding with a tap-insulation test. For bushings with potential taps, up to 5 kV may be applied. The test engineer should be careful that the test potential applied does not exceed the tap rating. For bushings with power-factor taps, the maximum permissible test voltage is usually designated by the manufacturer (usually between 500 volts and 2 kV). An up-to-date list of acceptable test potentials for power-factor tap-insulation tests on many different types of bushings is contained in the *Doble Bushing Field-Test Guide.*

Figure 3.11 illustrates a tap-insulation (C_2) test on a bushing.

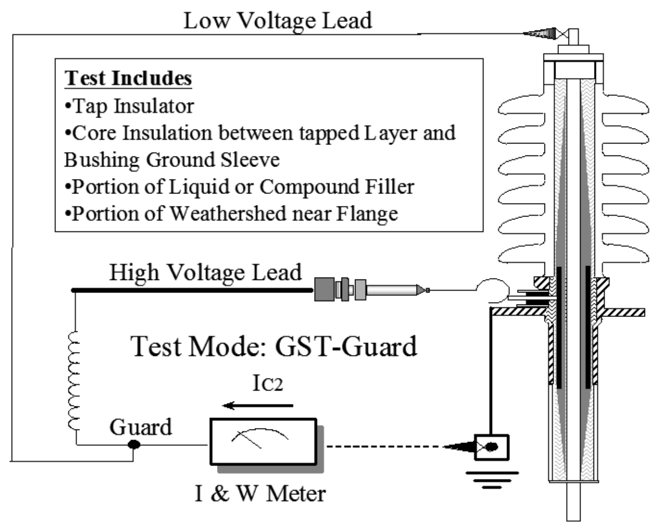


Figure 3.11 Bushing C_2 Tap-Insulation Test

Connect the bushing center conductor either to the Guard terminal on the outboard pothead of the High-Voltage Cable or to a LV Lead in the GUARD mode.

Note in Figure 3.11 that any electrostatic interference current (I_i), which may couple to the bushing conductor, will go to ground through the Low Voltage Lead and the meter. In some cases I_i may be quite appreciable, but will not bother the M4000 test set. While older Doble test sets, such as the M2H and MH, are also capable of coping with electrostatic interference, it may be more convenient in the case of the tap-insulation test to alter the test procedure slightly so as to reduce the overall effect of electrostatic interference. An alternative method of performing the tap-insulation test is given in Figure 3.12, whereby the bushing center conductor is grounded. C_1 and C_2 are both measured in this instance. The user then subtracts the watts and current readings of the C1 test to obtain the resultant C2 values.

NOTE **Alternative methods are not required for M4000 tests performed using the line frequency modulation technique.**

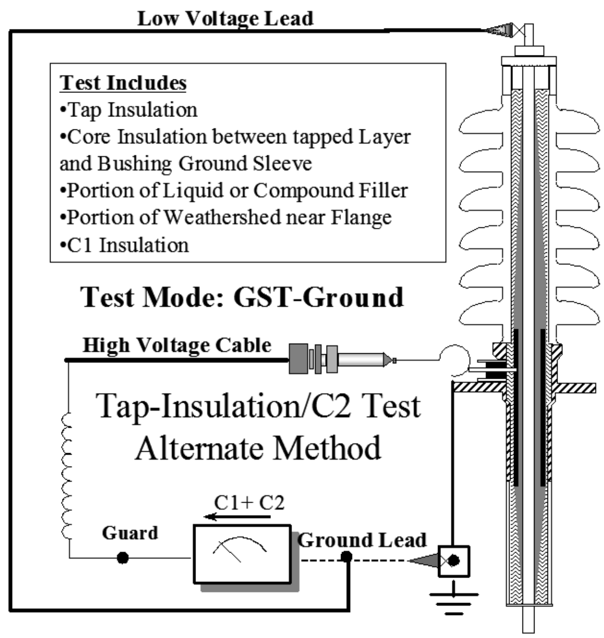


Figure 3.12 Alternative Technique for Tap-Insulation Test (Bushing C_1 and C_2 Insulations in Parallel by GST)

Collar Tests

It is a well established fact that a characteristic fault of compound-filled bushings has been one which develops from leaks in the top end of the bushing, which in turn allows moisture to enter the compound chamber. As a result, leakage paths may be established which may lead to failure of the bushing. The Collar Test is easily applied to this type of bushing. By application of increased voltage stress in the upper region of the bushing, moisture or deterioration is detected in the early stages, before it has progressed sufficiently to be detected by overall tests.

The Collar Test was originally designed to detect defects in compound chambers of compound filled bushings. They are currently used in dry-type solid-porcelain bushings, oil-filled bushings, and cable potheads. The Collar Test is useful for detecting low levels of insulating oil or compound in bushings and potheads. For example, the performance of magnetic-type liquid-level gauges of oil-filled bushings may be checked using this technique. Bushings and potheads with neither liquid-level indicators or sight glass also may be checked periodically for low liquid level. Tests are applied in the GST mode as standard, in the UST mode under some conditions and applications, and may be applied using either single or multiple collars.

The collar material may be conducting rubber (Figure 3.13) or metallic (foil, braid, etc.). In any case, care must be taken that the collars are drawn tightly around the bushing to ensure intimate contact with the surface. Poor contact or gaps may produce erratic or unreliable results, and only reasonable care is required to avoid this difficulty. For consistency, especially in reading the current:

- The collar should have very little slack or overhang.
- The position of the High-Voltage Cable should be approximately 90° to the axis of the bushing under test.
- The same width size collar needs to be utilized for any follow-up tests.

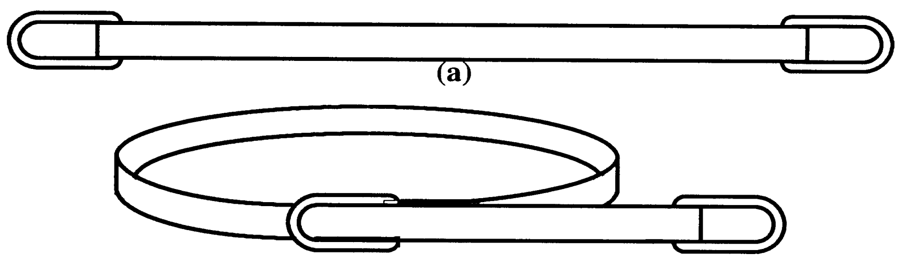


Figure 3.13 Standard Doble Collar (Conducting Rubber) with Elongated "D" Rings

The Single Hot-Collar test consists of a measurement between an externally applied collar and the bushing center conductor. The collar is generally placed below the top petticoat of the bushing, or in some other region of interest. The collar is energized by the test set (thus the term "Hot" Collar), while the center conductor is grounded. Refer to Figure 3.14 and Figure 3.15.

Single Hot-Collar Test on Bushings - GST Test Mode

In the GST mode (Figure 3.14) the Hot-Collar test includes measurement of all currents passing between the energized collar and ground. This includes surface-leakage currents, and illustrates why atmospheric humidity and bushing surface conditions must be taken into consideration. (Refer to section on "Surface Leakage" on page 1-27.) Also, electrostatic currents resulting from external voltages coupled at the bushing terminal have a direct path to ground without passing through the measuring circuit.

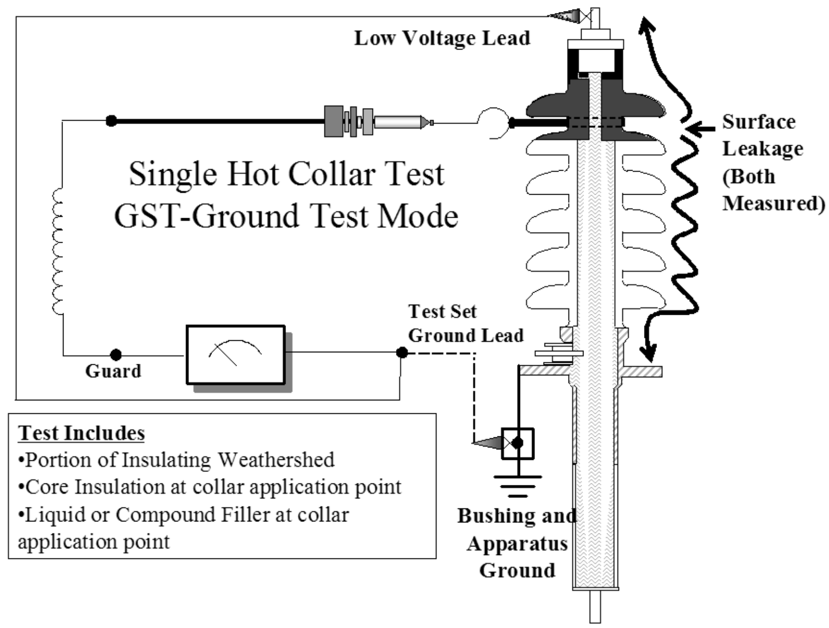


Figure 3.14 Bushing Hot-Collar Test, GST Test Mode

Single Hot-Collar Test on Bushings - UST Test Mode

In the UST mode (Figure 3.15), the Hot-Collar test includes measurement of all currents passing between the energized collar and the bushing center conductor. Surface-leakage currents up over the top petticoat are measured, but surface currents down to the grounded mounting flange are not. The UST mode may be less affected by surface leakages.

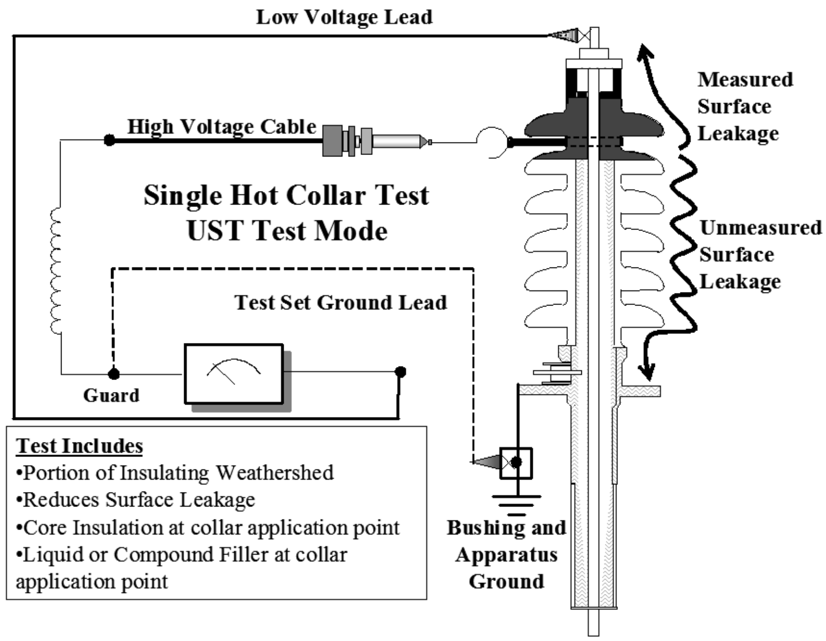


Figure 3.15 Bushing Hot-Collar Test, UST Test Mode

Cold-Collar Tests on Bushings

A variation of the Collar test used in the past is the Cold-Collar test. In this test the collar is connected to ground GST or to the UST circuit in the latter mode. The bushing conductor is energized as in the Overall test.

In the case of a Cold-Collar test in the GST mode, the test results include the Overall currents and losses (current and watts) for the bushing. The latter must be determined by a separate Overall test and subtracted from the combined Cold-Collar test results to determine the current and losses between the center conductor and collar(s). This may involve subtraction of relatively large values to arrive at relatively small values for the collar area, with the possibility of significant error.

In the case of a Cold-Collar test in the UST mode, the test results are confined to the current and losses between the center conductor and collar(s).

Note that the Cold-Collar test necessitates energizing the bushing conductor and any parts or windings connected to it, as in an Overall test. Only the collar is energized in a Hot-Collar Test. In general, there appears to be no advantage in the Cold-Collar technique, and the Hot-Collar approach is recommended.

For Single Hot-Collar tests, the collar is energized at 10 kV, as shown in Figure 3.14 and Figure 3.15 (in the case of short bushings, and, whenever the physical spacing to ground is very small, then the test voltage should be reduced). The bushing or pothead center conductor is connected either to ground (Figure 3.14) or to UST (Figure 3.15), and measurements of current and watts are recorded in the conventional manner.

Data is analyzed on the basis of relative magnitudes of current and watts, recorded for similar bushings or for periodic tests on the same bushing. (See ”Analysis of Test Results” – ”Single Hot-Collar Test” on page 3-29). Power factor is not calculated, except in some instances of Multiple Hot-Collar Tests. No attempt is made to correct for the effects of temperature.

Multiple Hot-Collar Tests

Multiple Hot-Collar tests are useful supplements to Single-Collar tests on bushings not equipped to permit Overall tests by the UST, Cold-Guard, or Hot-Guard methods. Multiple Collar tests give indications of the general condition of insulation of the upper region of a bushing, and may be relatively insensitive to condition in insulation below the mounting flange. Refer to Figure 3.16.

Multiple-Collar tests are performed in the same manner as Single-Collar tests (GST or UST), but with two or more collars placed in alternate grooves along the bushing outer surface. The collars are connected and energized together. The advantages of GST and UST modes are the same as for Single Hot-Collar tests.

The current and watts are recorded in the conventional manner, and data is analyzed on the basis of relative magnitudes of current and watts, among similar bushings or between periodic tests. Power factor may be calculated if a sufficient number of collars are installed so as to produce currents approaching Overall test values.

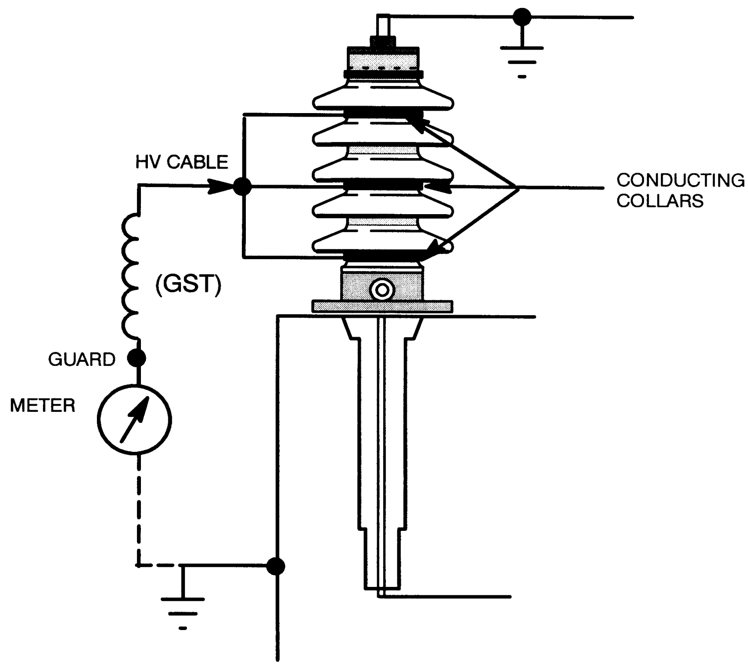


Figure 3.16 Multiple Hot-Collar Test on Bushing

Hot-Collar Tests on Cable Potheads

Hot-Collar tests are made on cable potheads in the same general manner as described for bushings. Tests are generally performed in the GST mode. The test does not require energizing of the cable conductor, which may be beyond the current capability of the test set, particularly on long cable lengths.

Hot-Collar tests are extremely effective in detecting contamination and voids in compound-filled potheads. Single and Multiple Hot-Collar tests are also performed on oil-filled potheads not designed for UST tests (that is, potheads not equipped with power-factor test electrodes).

Analysis of Test Results

General

Bushing insulation should be graded on the basis of one or more of the following parameters, depending upon the bushing design:

Power factor obtained by:

- Standard Overall test on an isolated or spare bushing.
- Ungrounded-Specimen Test (UST) on bushings equipped with potential taps or power-factor test electrodes (C_1).

- Cold-Guard test on bushings equipped with draw-leads, shielded-layers or insulated-heads.
- Tap-insulation test on potential taps or power-factor test taps (C_2).

Capacitance or current:

Short-circuited condenser layers or sections of a bushing result in increased capacitance and charging current. Open circuits or discontinuities, such as a break in the band between the ground sleeve and mounting flange, result in decreased capacitance and charging current.

Hot-Collar Test Results:

Increased losses (watts) indicate contamination of the bushing insulation; decreased current indicate voids, or low compound or liquid levels.

The following comments deal with the application of various test methods to several basic bushing designs, and the significance of the test results recorded.

Condenser Bushings With Potential Tap or Power-Factor Test Electrodes

Bushings of this design are tested by the Overall test method (GST) if they are isolated from other parts of apparatus in which they may be mounted (generally not practical), or by the UST method. The latter is a test on C_1, the conductor to tap insulation.

The power factor and capacitance recorded are compared with one or more of the following:

- Nameplate data.
- Results of prior tests on the same bushing.
- Results of similar tests on similar bushings.

Power factors for modern condenser bushings are generally on the order of 0.5% after correction to 20° C. More detailed information on power factors for specific makes and designs is contained in the *Doble Test-Data Reference Book* and in the *Doble Bushing Field-Test Guide*.

Capacitances should be within 5 to 10% of nameplate value, depending upon the total number of condenser layers. Increased power factors indicate contamination or deterioration of insulation. Increased capacitance indicates the possibility of short-circuited condenser layers. Decreased capacitance indicates the possibility of a floating ground sleeve, or open or poor test tap connection.

Negative power factors accompanied by small reductions in capacitance or charging current are experienced occasionally, and may result from unusual conditions of external surface leakage or internal leakages resulting from carbon tracks. For further information on this subject, refer to the 1960 Doble Client Conference paper, “Application and Significance of Ungrounded-Specimen Tests,” 27AC60/Sec. 3-201. This paper is contained in the General section of the *Doble Test-Data Reference Book*.

On bushings equipped with taps, the UST measurement on C_1 is supplemented by a Tap-Insulation test on C_2. Test potential may have to be reduced from 2.5 kV depending upon the tap rating. Power factors recorded for tap insulation are generally on the order of 1%. Results should be compared with those of earlier tests or with results of tests on similar bushings.

Capacitances recorded for tests on potential taps should also be checked against nameplate values, if available. Decreased capacitance indicates the possibility of a floating ground sleeve, or poor test tap connection.

Overall or UST measurements are supplemented by Single Hot-Collar tests on the upper porcelain, particularly on compound-filled bushings, and on oil-filled bushings without oil-level gauges. See analysis of test results for ”Single Hot-Collar Test” on page 3-29, in this section.

Condenser Bushings Without Potential Taps or Power-Factor Test Electrodes

Bushings of this design are tested by the Overall test method (GST) if they are isolated from other parts of apparatus in which they may be mounted (may not be practical), or by Cold-Guard or Hot-Guard test methods if they are equipped with draw-leads, shielded-layers, or insulated-heads. If none of the foregoing tests are applicable, Single and/or Multiple Hot-Collar tests are performed. Single Hot-Collar tests are of particular importance in the case of compound-filled bushings, and oil-filled bushings without oil-level gauges.

Test results are analyzed and rated as described under the discussion of ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

Noncondenser Bushings With Split or Isolated Flanges

Bushings of this design are tested by the Overall test method (GST) if they are isolated from other parts of apparatus in which they may be mounted (may not be practical), or by the UST method, utilizing an isolated or split flange which is isolated from the grounded mounting flange. The bushing conductor is energized and the UST circuit is connected to the isolated or split flange, and measurements are made in the conventional manner.

The UST measurements are supplemented by Single Hot-Collar tests on the upper porcelain, particularly on compound-filled bushings, and oil-filled bushings without oil-level gauges.

Test results are analyzed and rated as described under the discussion of ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

Noncondenser Bushings With Draw-Leads, Shielded-Layers, or Insulated-Heads

Bushings of this design are tested by the Overall test method (GST) if they are isolated from other parts of apparatus in which they may be mounted (may not be practical), or by the Cold-Guard test method. Any of the foregoing should be supplemented by Single Hot-Collar tests on the upper porcelain, particularly on compound-filled bushings, and oil-filled bushings without oil-level gauges.

Test results are analyzed and rated as described under the discussion of ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

Noncondenser Bushings Without Special Test Facilities

Tests on bushings without potential taps, power-factor test electrodes, split or isolated flanges or draw-leads, shielded-layers, or insulated-heads can only be tested by the Overall (GST) method, provided that they can be isolated from other parts of apparatus in which they may be mounted. Otherwise, the only test applicable is the Multiple Hot-Collar method, with collars installed in alternate grooves on the porcelain surface. This test is supplemented by a Single Hot-Collar test on the upper porcelain, particularly on compound-filled bushings, and oil-filled bushings without oil-level gauges.

Test results are analyzed and rated as described under the discussion of ”Condenser Bushings With Potential Tap or Power-Factor Test Electrodes” on page 3-25.

Dry-Type Porcelain Bushings

Bushings of this design may be used in circuit breakers or transformers, or as roof or wall bushings. They are not equipped with special test electrodes or facilities, so that the only Doble test applicable is the Overall method, conductor to mounting flange. This may be either in the GST or UST mode, if the bushing is a spare bushing out of apparatus, or in the GST mode in apparatus. The latter requires that the center conductor be isolated from other parts of the apparatus in which the bushing is mounted. Otherwise, the only test applicable in apparatus is by the Hot-Collar method.

When some designs of porcelain bushings are removed from transformers, there may be no center conductor remaining in the bushing. The conductor must be replaced by a metal rod which is bonded to the bushing cap to serve as a test electrode. The conductor must be of sufficient diameter to essentially fill the center bore of the porcelain.

The test results are analyzed and graded on the basis of comparison of results among similar bushings and with results recorded for previous tests. Abnormally high losses and power factor result from:

- Cracked porcelain.
- Porous porcelain, which has absorbed moisture (not common in modern porcelain).
- Losses in the secondary insulations, such as varnished cambric, which may be wrapped around the center conductor.
- Corona around the center conductor.
- Conducting paths over the insulation surfaces to ground.
- Improper use or bonding of resistance coatings or glazings on internal porcelain surfaces.

The most serious cause of high losses and power factors in this type of bushing is conducting paths over the surface, and cracked porcelain, especially at points near the grounded mounting flange. Cracks in porcelain can develop from mechanical stresses resulting from rigid copper connections to a bushing, settlement of apparatus foundations, etc. The advantages of flexible connections are apparent.

Cable-Type Bushings

Bushings of the cable type can only be tested by the Overall (GST) method if they can be isolated from other parts of the apparatus in which they are mounted. Otherwise, the only test applicable is the Hot-Collar test, single or multiple, depending upon the number of petticoats or grooves in the porcelain rainshed.

The main insulation of this type of bushing is a cable, generally insulated with varnished cambric. The top half or weather end of the bushing is protected by a porcelain weathershed. The space between the cable and inner porcelain surface may be compound filled.

Overall power factor and Hot-Collar losses are relatively high because of inherently high losses in the cambric insulation. Test results should be compared among similar bushings and with those recorded for previous tests. Abnormally high losses can result from moisture entering the top of the bushing and contaminating cambric and compound, migration of oil into the compound through a bottom seal, cracked porcelain, etc.

Single Hot-Collar Test

This test is usually made with the collar wrapped around the porcelain rainshed of the bushing under the top petticoat. The losses recorded should be less than 0.10 watts. If the current or watts-loss is appreciably higher than normal, a second test is made after moving the collar down one petticoat. This procedure can be followed as far down the bushing as necessary to determine how far down the fault has progressed.

With specific reference to compound-filled bushings, as a guide it is suggested that a bushing showing a loss by the Hot-Collar test of less than 0.10 watts should be given a “G” insulation rating provided that it does not show high power factor by the standard test. The losses should be compared between similar bushings tested at the same time and under similar atmospheric conditions.

When the loss is between 0.11 and 0.30 watts, the bushing should be given an Investigate (“I”) rating. The bushing cap should be removed and an examination made to determine whether moisture is present in the top of the compound chamber. A new cap gasket should be installed when the cap is reassembled.

When the loss is between 0.31 and 0.50 watt, and the loss with the collar under the second petticoat drops down to a normal value, the bushing cap should be removed and an examination made for moisture in the top of the compound chamber and in the compound itself. If a hot rod is inserted into the compound, a sputtering sound will indicate that there is moisture present in the compound. Bushings of this type have been successfully reconditioned. The compound is melted out and new compound installed. A new gasket is also installed when the bushing cap is reassembled.

When the loss is above 0.50 watt with the collar under the top petticoat, and normal or nearly normal with the collar under the second or lower petticoats, it is possible that there is a defect in the porcelain rainshed. If so, either the bushing should be discarded, or else a new porcelain rainshed should be installed. In the event of the latter, the compound chamber should be filled with new compound and a new cap gasket should be installed.

If the loss with the collar under the top petticoat is above 0.30 watt and high losses are also obtained for additional collar tests made with the collar under the second and third petticoats, etc., there is evidence that the fault is distributed throughout the compound chamber. In such cases, the bushing should be disassembled and reconditioned if practical, or discarded.

Abnormally high charging current readings, obtained when surface conditions are favorable, would indicate an increase in capacitance due to defective porcelain or to moisture inside the compound chamber.

Since air has a lower dielectric constant than insulating oil or compound, a Collar test made on a bushing or pothead, in which air has displaced the oil or compound in the area where the collar is placed, may result in a lower than normal charging current. For Single Hot-Collar Tests performed on similar bushings and potheads, tested at the same time using the same sized collar, a 10% lower than average current reading could be an indication of low oil or compound level. The accuracy of this technique depends most importantly on positioning the collar in exactly the same manner on each of the similar bushings tested (with as little collar slack as possible in order to reduce current variations). The UST mode is normally employed, since stray currents to ground are not measured in UST. Whenever a lower than average current value is recorded, additional Single Hot-Collar tests are performed by moving the collar down successive skirts. The point at which the current value for a suspect bushing or pothead compares favorably with other similar units indicates how far the liquid level has dropped. Low current values recorded along the entire length of bushing or pothead may be an indication of the complete absence of oil or compound.

When tests are made on solid porcelain bushings, a comparison of the test results should be made, and a bushing showing a watts-loss by the Collar Test that is appreciably higher than that obtained for other similar bushings should be investigated.

NOTE **The previous comments refer only to the results of Collar tests. A different diagnosis might be made if an Overall test indicated deterioration of the bushing.**

Multiple Hot-CollarTest

Readings of current and watts are recorded, and the results are evaluated by comparison with those obtained for similar bushings tested under favorable weather conditions. Refer to foregoing comments on ”Single Hot-Collar Test” on page 3-29.

Hot-Collar Tests on Cable Potheads

The resulting current and watts are compared with those for potheads of the same type and tested under the same conditions. Refer to foregoing comments on ”Single Hot-Collar Test” on page 3-29.

4. Circuit Breakers and Reclosers

Oil Circuit Breakers

Introduction

The common oil circuit breaker consists of one or more single-pole switches arranged to operate simultaneously. The contacts of the switch are located inside a tank of oil, and connections are made to them through two insulating bushings. The primary object of any insulation test is to determine the condition of these bushings because, from an insulation point of view, they are the most vulnerable part of the breaker.

When the power-factor testing of oil circuit breaker bushings in the field was first begun, many people were skeptical about its success. It was felt that, since the internal insulation of the circuit breaker would be included in the tests, the losses in this auxiliary insulation, connected insulators, etc., would so obscure the losses in the bushing that it would be very difficult to determine whether the bushings were in good condition.

Early tests in the field showed that this auxiliary insulation had considerable effect on the tests. At first the interpretation of such tests presented a difficult problem. As the Doble Engineering Company, with the cooperation of its clients, continued to collect and interpret data, it was discovered that the inclusion of such insulation in the tests, instead of being a handicap, was actually an asset. The test results, properly interpreted, indicated not only the condition of the bushings, but also the condition of the auxiliary insulating members.

Most bulk-type dead-tank oil circuit breakers have a basic similarity of construction, regardless of the manufacturer or type. Most units have one grounded tank per phase (i.e., a total of three tanks), although some designs have all three phases housed in a single tank. Whether single-tank or triple-tank, the test procedure and analysis of test results are on a per-phase basis.

An oil circuit breaker may be described, in simplified terms, to include the following:

- Two-bushings (per phase) mounted in an oil-filled, grounded tank.
- A contact assembly (interrupter) mounted on the bottom terminal of each bushing.

- An insulated operating rod (wood, fiberglass, etc.) which may move up and down, or in a rotary motion, in order to close and open the breaker contacts.
- An insulated guide assembly to keep the operating rod in proper alignment.
- A volume of oil.

Some breakers are designed with tank liners, shunt resistors across the interrupters, and other auxiliary components. Test data recorded for the large majority of oil circuit breakers can be analyzed with respect to the parts listed above in Items 1 through 5.

Test Voltages

Oil circuit breakers rated 15 kV insulation class (e.g., 14.4 kV), and above, are routinely tested at 10 kV. Oil circuit breakers rated below 15 kV insulation class are tested at a convenient whole number voltage at or below the nameplate voltage rating.

Table 4.1 Recommended Doble Test Voltages for Oil Circuit Breakers

Breaker Voltage Ratings	Test Voltage (kV)
15 kV Class and Above	10
7.2 and 7.5 kV	5
5 kV Class and Below	2

WARNING

Whenever investigating oil circuit breakers with the oil removed or lowered below the bushing ground sleeves, do not apply test voltages to any bushings or internal components before first determining (by direct measurement) that the air space and residual liquid inside the breaker tank contain safe combustible gas levels for testing as prescribed by your company. <u>This precaution is especially important in cases where a breaker has failed internally or recently interrupted a fault.</u> If there are any questions regarding the combustible gas levels in the tank(s), the air space must be purged with dry air or nitrogen before any test voltage is applied.

Test Procedure

Nine overall tests are routinely performed on a three-phase oil circuit breaker, three overall tests per phase as outlined in the following:

Table 4.2 Overall Test Procedure for Oil Circuit Breakers

Test No.	Breaker Position	Test Mode	Bushing* Energized	Bushing* Floating
1	Open	GST	1	2
2	Open	GST	2	1
3	Open	GST	3	4
4	Open	GST	4	3
5	Open	GST	5	6
6	Open	GST	6	5
7	Closed	GST	1 & 2	—
8	Closed	GST	3 & 4	—
9	Closed	GST	5 & 6	—

* For most conventional breakers, the bushings are numbered left-to-right starting at the breaker control cabinet.

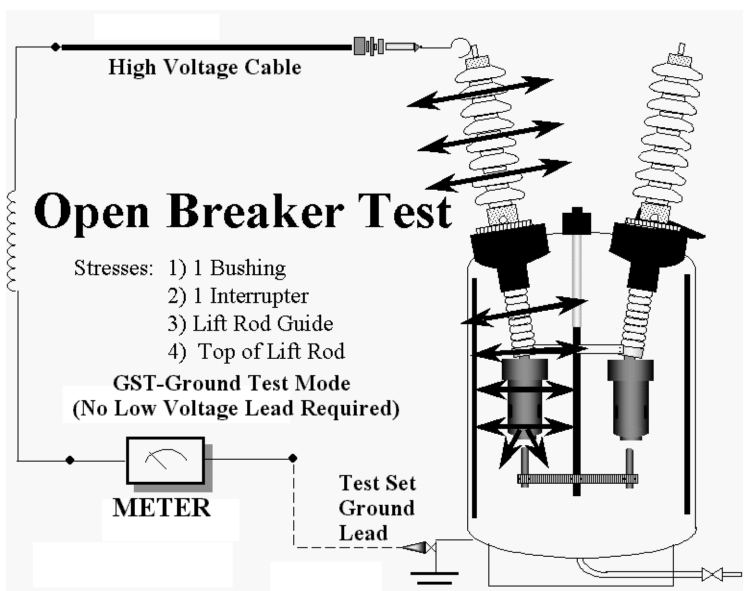


Figure 4.1 Oil Circuit Breaker Open-Breaker Test

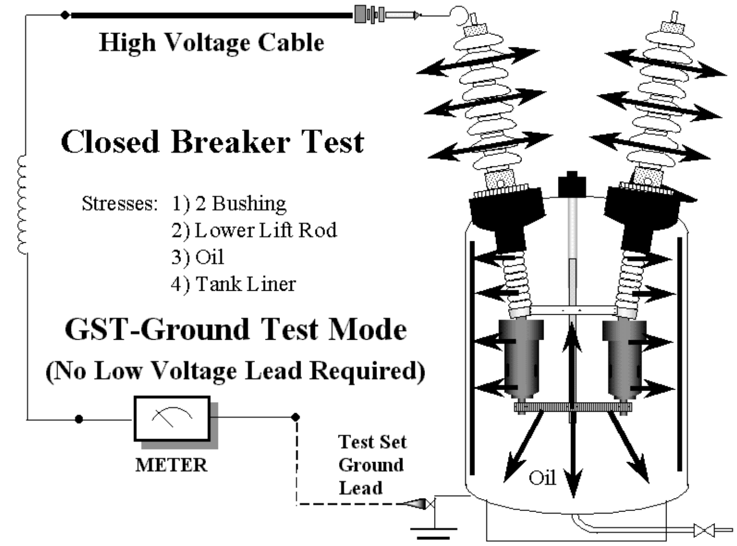


Figure 4.2 Oil Circuit Breaker Closed Breaker Test

For all tests, the breaker tank must be properly grounded. It is advisable to connect the test set ground directly to the breaker ground.

A Low-Voltage (LV) Lead is not required for the Overall tests, and the test set must be in the GST-GROUND (R,B) position. All bus and insulators should be disconnected from the bushings so that the test results are confined to the breaker alone.

NOTE

Overall tests on circuit breakers are always supplemented by separate tests on bushings (UST on the main insulation C_1, GST on the tap insulation C_2, and/or Hot-Collar) and on oil samples from each tank.

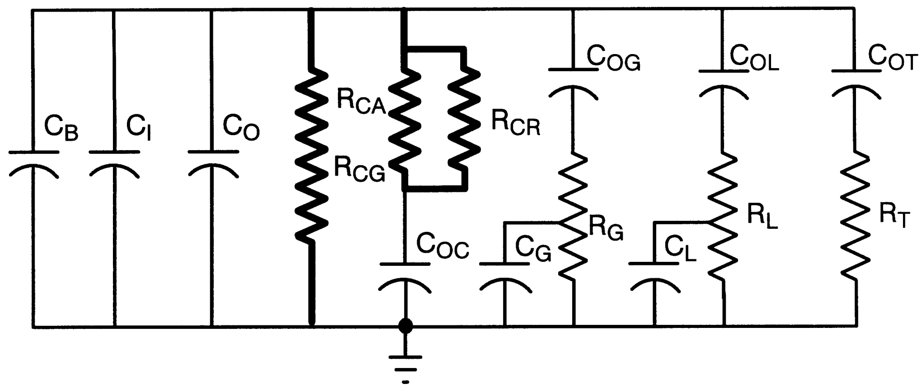
For each of the tests, current and watts readings are recorded and power factors are calculated. The latter are corrected for temperature (ambient) on the basis of bushing type, not the breaker type.

General Considerations

Connecting the test cable to a bushing for Overall tests on an oil circuit breaker and applying voltage, establishes an electric field between the center conductor of the bushing and the grounded parts of the breaker. The losses in any insulation which is in an electric field are dependent upon the potential gradient (voltage per unit distance) at the location of the insulation. In an oil circuit breaker, at a fixed test voltage, the potential gradient is dependent upon the shape and size of the electrodes and upon their distance apart. The gradient is higher near the smaller electrode (the center conductor of the bushing) than it is near the large electrode (the tank or the ground sleeve of the bushing). At a given test voltage, these gradients are generally greater in low-voltage small-tank breakers than in higher voltage large-tank breakers.

The bushing insulation and the oil are located between the center conductor of a bushing and ground. In the oil are various auxiliary insulating members. Since the ground sleeve of the bushing is much closer to the center conductor of the bushing than is the tank, the gradient in the bushing insulation is much higher than the gradient in the oil. The gradient in the auxiliary insulations is lower than the gradient in the bushing insulation. The tests, therefore, are primarily on the bushing, and the amount of loss measured in the auxiliary insulations is dependent upon their condition and their location in the electric field.

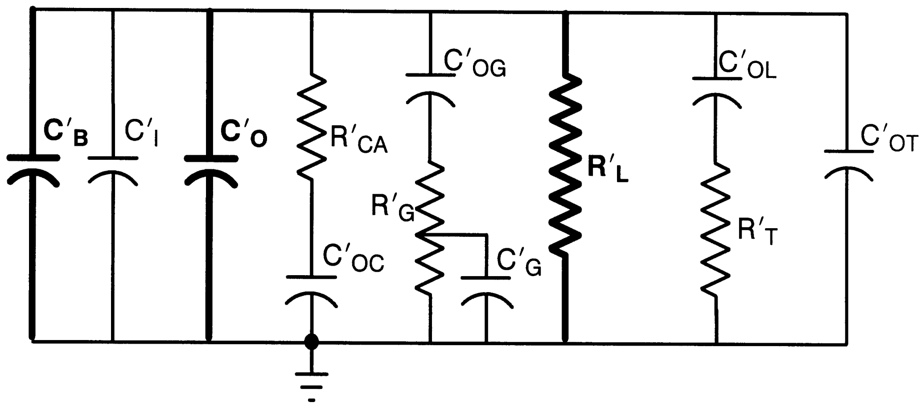
A convenient method for studying the results of Overall tests is to construct a schematic diagram of the breaker dielectric circuit. The actual dielectric circuits to which the High-Voltage Test Cable is connected are fairly complex. The simplified circuit of Figure 4.3 is adequate for the condition when one bushing is tested with the breaker open, and analysis of it leads to the same conclusions as analysis of the exact but more complex circuit. Closing the breaker results in the different dielectric circuit of Figure 4.4. In both figures, for the sake of simplicity, the insulations are shown as either capacitances or resistances. Actually the capacitances have resistive components, and the resistances have distributed capacitances.



C_B	=	Bushing insulation
C_1	=	External bus insulators (should be disconnected)
C_O	=	Oil between bushing conductor and ground
R_{CG}	=	Cross-guide assembly (as opposed to "V" or box guide – see R_C)
R_{CA}	=	Contact assembly
R_{CR}	=	Contact assembly grading resistor or resistance paint
C_{OC}	=	Oil between contact assembly and ground
C_{OG}	=	Oil between bushing conductor and operating (lift)-rod guide (except for cross guide, R_{CG})
R_C	=	Operating (lift)-rod guide (except for cross guide, R_{CG})
C_G	=	Distributed capacitance between the operating (lift)-rod guide and ground
C_{OL}	=	Oil between bushing conductor and operating (lift) rod
R_L	=	Operating (lift) rod
C_L	=	Distributed capacitances between operating (lift) rod and ground
C_{OT}	=	Oil between bushing conductor and tank liner
R_T	=	Tank liner

Figure 4.3 Oil Circuit Breaker

Simplified Dielectric Circuit Between
One Energized Bushing and Ground, with Breaker OPEN



C'_B	=	Both bushings
C'_I	=	External bus insulation (should be disconnected)
C'_O	=	Oil between energized conductors and ground
R'_{CA}	=	Contact assemblies connected to both bushings
C'_{OC}	=	Oil between both contact assemblies and ground
C'_{OG}	=	Oil between energized conductors and operating (lift)-rod guide
R'_G	=	Operating(1ift)-rod guide
C'_G	=	Distributed capacitance between operating (lift)-rod guide and ground
R'_L	=	Operating (lift) rod
C'_{OT}	=	Oil between energized conductors and tank liner
R'_T	=	Tank liner
C'_A	=	Auxiliary-contact support insulators

Figure 4.4 Oil Circuit Breaker

Simplified Dielectric Circuit Between Energized Bushings, Conductors (Crosshead and Contacts) and Ground, with Breaker CLOSED

Analysis And Interpretations

NOTE **If using DTA software, proper analysis cannot be completed unless bushing manufacturer and type are entered in the nameplate panel. This is due to the dominance of the influence of the bushings.**

Bushings and Tank Members

A single Open-Breaker test includes the insulation of one bushing (C_B in Figure 4.3) and any connected bus insulators (C_1). When the breaker is closed, the insulation of both bushings (C'_B in Figure 4.4) and the bus insulators (C'_I) is included. The electric fields in all these insulations are essentially the same for both tests. Therefore, due to these insulations alone, the watts-loss recorded for the Closed-Breaker test should be equal to the sum of the watts-loss recorded for the two Open-Breaker tests. If it is not, then any difference must be due to losses in the auxiliary insulations, which are not stressed the same for both test conditions. The amount of such a difference can be used as a criterion of the condition of the auxiliary insulation, and is referred to as the Tank-Loss Index (TLI):

TLI = (Closed-Breaker watts) – (Sum of Two Open-Breaker watts)

In the above algebraic formula, the TLI assumes a positive value when the Closed-Breaker watts is larger than the Sum of the Two Open-Breaker watts, and is negative when the Sum of the Two Open-Breaker watts exceeds the Closed-Breaker watts.

The TLI is not corrected for temperature. The TLIs for a given breaker are compared between phases, with previous test results (if any), with results recorded for similar breakers on the system, and with data tabulated in the Circuit Breaker section of the *Doble Test-Data Reference Book*. The following table offers helpful guides in the investigation of abnormal TLI results. Most oil circuit breakers typically have normal TLIs in the range of –0.10 W to +0.05 W.

Table 4.3 Guidelines for Investigating Abnormal Oil Circuit Breaker Tank-Loss Indexes

Tank-Loss Index (TLI)
Watts (W)

Below –0.20W	Between –0.10W and –0.20W	–0.10W to +0.05W	Between +0.05W and +0.10W	Above +0.10W
Investigate immediately	Retest on a more frequent basis	Normal for most breaker types. Place on a normal routine test schedule	Retest on a more frequent basis	Investigate immediately
Lift-rod guide assembly, contact assembly (interrupter), and upper portion of lift-rod			Lift-rod, tank oil, tank liner, and auxiliary contact support insulation	

* The range of data and recommendations given in this table should be taken as general information. Certain makes and types of breakers may have normal TLIs which differ from the range given in the table. Therefore, it is imperative to compare TLI values between tanks of a given breaker, and with results recorded for other similar breakers. Whenever breakers have TLI(s) only slightly above the expected normal range, the condition should be monitored by making tests on a more frequent basis in order to keep abreast of further developments. When the TLI(s) are well beyond the normal range, an investigation, including separate tests on internal breaker members, should be performed immediately.

Oil

For the Open-Breaker test on either bushing, the portion of the oil (C_O in Figure 4.3) between the bushing center conductor and the tank will be included in the test. Deteriorated oil will cause the watts-loss for both Open-Breaker tests to be increased. When the breaker is closed (Figure 4.4), the oil between each bushing and the tank will be included substantially as in each Open-Breaker test. In addition, the portion of the oil between the energized crosshead and the tank will be included. If the oil is in good condition, the loss in it will be small and its effect on Tank-Loss Index will likewise be small, but in the positive TLI direction. If the oil is considerably deteriorated, then the effect on Tank-Loss Index will still be positive, but greater. In practice, when the oil is deteriorated, the condition of other insulating members is considerably more deteriorated and would have more effect on the measured tank losses than the oil.

Guide Assemblies

Cross Guide Types – R_{CG}

Some types of oil circuit breakers have, connected between the bottom ends of the two bushings, a wood member for guiding the operating rod. This guide is represented by R_{CG} in Figure 4.3. In an Open-Breaker test, the end of the guide connected to the energized bushing will be at the test potential. The end connected to the unenergized bushing will be at practically ground potential, as shown in Figure 4.3, since the impedance of this unenergized bushing will be much smaller than the resistance of the guide. Each of the Open-Breaker tests will include the loss in the guide.

In the Closed-Breaker test, the loss in this guide will be eliminated, as both bushings are connected by the crosshead. R_{CG} is therefore not shown in Figure 4.4. Losses in the crossguide will cause the Tank-Loss Index to be negative.

As the wood cross-guide merely connects the two bushings, and is always insulated from ground by them, it might appear that deterioration in it is of small consequence. While more deterioration is permissible than in the case of a bushing, extreme deterioration could possibly prevent the breaker from interrupting the circuit by offering a conducting path between the two bushings.

Other Types of Guides – R_G/R'_G

In other types of breakers instead of cross-guide, a “V”, box, or other shaped guide is employed. Although it is not in contact with any energized conductors, it is in an electric field due to the capacitance between it and the energized conductor, and the capacitance between it and ground, as well as its resistance to ground.

Since the unenergized bushing is effectively at ground potential, the capacitance from the guide to ground is relatively large, and the potential gradient in the guide relatively high. If the guide is deteriorated, there will be losses in it which will be measured in each of the Open-Breaker tests.

When the breaker is closed, the electric field in the guide assembly (R'_G) is considerably changed from that in the Open-Breaker test (R_G). The capacitance to the energized parts is increased, but the capacitance to ground is considerably reduced because of the shielding effect created by the energized crosshead and the other bushing. The resulting change in the electric field causes the Tank-Loss Index to be negative. If the guide is in good condition the effect on Tank-Loss Index will be small. If the guide is deteriorated, the losses obtained for both Open- and Closed-Breaker tests will be high but the Tank-Loss Index will be negative and also high.

Contact Assembly lnsulation (Interrupters) – R_{CA}/R'_{CA}

High-voltage breakers may be equipped with interrupter or contact assemblies mounted on the bottom of each bushing conductor. The insulating members of these contact assemblies affect the tests in a manner similar to the guide assemblies.

The contact-assembly (interrupter) insulation is included in Open-Breaker tests by virtue of its presence in the electric field established between the energized bushing and the unenergized bushing and grounded tank. In the Open-Breaker test, the unenergized bushing is practically at ground potential and the average voltage gradient in the contact assembly insulation is relatively high.

In the Closed-Breaker test, due to the shielding effect of the other bushing and the crosshead, the capacitance to ground is reduced and the average gradient and losses in the contact assembly insulation will be reduced.

Deteriorated or contaminated contact assembly insulation will cause both Open- and Closed Breaker watts to be high (the latter to a lesser extent), and the Tank-Loss Index will be negative and also high.

As in the case of “V” or box guides, the interrupters do not have direct paths to ground, and it might appear that deterioration in them is of little importance. High losses which develop in these members may indicate that moisture is entering the tank and may deteriorate other more vital insulation. Excessive moisture may cause warping or deformation of interrupter parts and lead to malfunction. High losses in these members may also tend to mask faults in the bushings themselves.

Some types of oil circuit breakers have a form of resistance grading associated with each interrupter to distribute the voltage across the opening contacts more equally. This resistance, R_{CR} in Figure 4.3, is in series with the capacitance C_{OC} from the lowest contact through the oil to the tank. Such a construction usually causes relatively high losses to be obtained for the Open Breaker tests, even though the circuit breaker is in good condition. During the Closed-Breaker tests, such resistance is short-circuited and will not affect the tests. In such cases the Tank-Loss Index is negative and high without indicating any deterioration.

Operating Rod (Lift Rod) – R_L /R'_L

In the Open-Breaker test there is a capacitance between the operating rod (R_L)and the energized bushing, as well as resistance and distributed capacitance to ground. Since the operating rod is in the lowered position, the center section will be closest to the bushing conductor and will have a higher potential gradient than the top and bottom sections.

In the Closed-Breaker test the operating rod is connected directly between the live crosshead and ground (R'_L) The voltage gradient in most of the operating rod is markedly increased from the Open-Breaker tests. Deterioration or contamination of the operating rod should cause the Tank-Loss Index to be positive and large.

Stresses in the operating rod in the Closed-Breaker test are quite different from those during the Open-Breaker tests. The bottom and center sections are stressed to a greater extent, while the top section has the stress reduced. The top part of the operating rod, which extends up into the mechanism housing, is entirely removed from the electric field. If moisture from the mechanism housing has entered the top section of the operating rod, and has not progressed very far into the rod, then this might lead to suspecting deteriorated operating rod guides or interrupter or contact insulation. The moist part of the rod would be in the electric field during the Open-Breaker tests, but during the Closed-Breaker tests it would either be removed from the electric field or the stress would be reduced. Such a condition would cause the Tank-Loss Index to be negative. Usually, deterioration in an operating rod is more general, and the Tank-Loss Index will be positive.

Tank Liners – R_T/R'_T

In order to prevent any possibility of conducting particles in the oil lining up and causing a direct path to ground from the lower ends of the bushings, the tanks of an oil circuit breaker may be lined with insulating material, usually a processed fiber or paper. The liner is not in direct contact with the energized parts but is in the electric field due to the capacitance from it through the oil to the bushings. Because of its location, the voltage gradient in it is low, but nevertheless a deteriorated liner will have losses which can be measured. The losses in the tank liner affect the Open- and Closed-Breaker tests in a manner similar to those in the oil.

For the Open-Breaker test on one bushing, Figure 4.3 shows that a portion of the tank liner (R_T) will be in the electric field of the bushing. With the other bushing energized, a different portion of the tank liner (R'_T) will be in its electric field. With the breaker closed, both of these portions of the liner will be in substantially the same strength field as in the Open-Breaker tests and, in addition, other parts of the liner which for the Open-Breaker tests had little or no voltage gradient in them are now in the relatively strong field produced by the crosshead being energized. As with deteriorated oil, a deteriorated liner will tend to have a greater overall influence on the Closed-Breaker test, and thus cause the Tank-Loss Index to be in the positive direction.

Auxiliary Contact Support Insulators – C'_A

Some types of oil circuit breakers have multibreak features. The auxiliary contacts are supported by insulation such as a porcelain third leg, which in the Open-Breaker tests is at most in a very weak electric field. For this reason deterioration in such insulation will have practically no effect on the Open-Breaker test and is not shown in Figure 4.3.

In the Closed-Breaker tests, such insulation (C'_A in Figure 4.4) is directly between the energized parts and ground and will be in a relatively strong electric field. Any contamination or deterioration will cause the Tank-Loss Index to be positive and high.

Investigations

Sometimes it is useful to investigate abnormal results by making a series of tests at several voltages, to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV in the case of tests normally performed at 10 kV.

In most instances when abnormally high losses or power factors are obtained, it is not possible to state definitely that any particular insulation – and it alone – is deteriorated. For example, if high losses or power factors are obtained for both bushings in the Open- and Closed-Breaker tests and the Tank-Loss Index appears low, there may be a combination of faults. Both bushings, or the insulators connected to both bushings, may be faulty. Another possibility is that both the guide members or the contact-assembly insulation and operating rod, oil, or tank liner, etc., are faulty. The decrease in the losses in the guide assemblies, etc., in the Closed-Breaker tests is offset by the increased losses in the operating rod, etc.

Before finally condemning any part of the circuit breaker insulation, further investigating tests should be made. Obviously, anything that can be done externally should be done first. Bus insulators may be disconnected and the bushing porcelain cleaned. A sample of oil from the suspected tank should be tested. In some cases certain auxiliary tests may be used to confirm the analysis of the standard tests. For example, if the tests indicate that both the operating rod and a guide assembly of the cross type have high losses, the cross guide may be eliminated, and operating-rod losses minimized, by connecting the two bushings together externally and testing the combination with the breaker open. This same test will also cause the losses in the contact assembly insulation or in a “V”, or box guide, to be slightly reduced. An operating rod which is deteriorated only in the upper section may also be indicated in this test by bringing the breaker to the nearly closed position and noting whether the losses are reduced. In a breaker equipped with the cross type of guide, the actual loss in the guide alone can be determined with the breaker open by energizing one bushing with the other bushing connected to UST.

Such external tests, while helpful in analysis, may not yield positive information that certain insulations, and they alone, are deteriorated. Separate tests on the suspected members alone should be made. These tests necessitate lowering the tank, or in the case of fixed tanks, pumping out the oil.

Removing the oil does not fundamentally change the arrangement of the dielectric circuit of Figure 4.3 and Figure 4.4, but does alter the relative proportions of the constants. Air will be substituted for the oil, and since it has a lower dielectric constant than oil, any losses in guide assemblies, tank liners, etc., will be lowered, since the stress in them will be decreased. If the breaker design permits the tank to be lowered, then doing so will affect the dielectric circuit even more. Not only is air (a lower dielectric-constant material) being substituted for the oil, but in addition, the capacitance is reduced further by the removal of the grounded tank. For example, the tank liner is removed almost entirely from the electric field. Removal of the oil also causes a washing effect, which may redistribute any carbon or other surface contaminant which is causing surface leakage. In general, the losses in auxiliary insulation will be decreased when the oil is removed.

In some cases, abnormal losses may have been obtained due merely to carbon deposits which can be quite readily removed. For example, removing and cleaning a bushing arc shield and the lower end of the bushing may reduce the losses to normal.

If an internal investigation is required, the wood members may be tested separately by the Three-Electrode method as described under ”Wood and Other Insulating Members” on page 13-1. Often, abnormally high negative Tank-Loss Indexes are due to wet interrupters, which also may be tested separately by the Three-Electrode method. Another method for testing interrupters individually is shown in Figure 4.5.

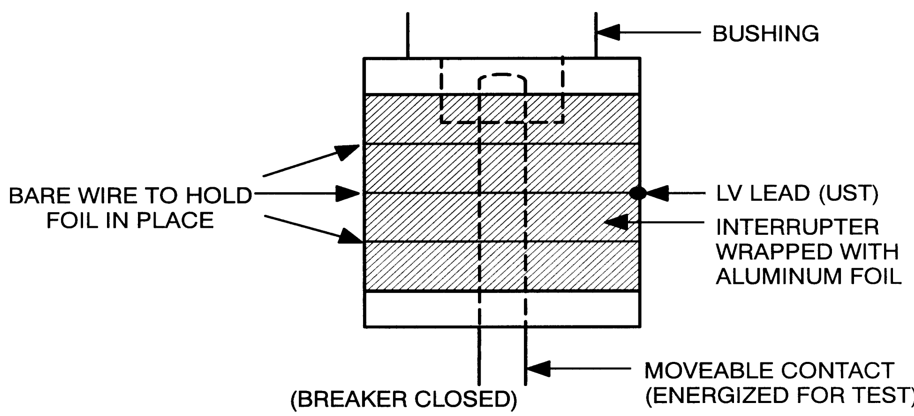


Figure 4.5 Separate UST Measurement on Interrupter

In Figure 4.5, the cross-hatched area represents metallic foil (e.g., ordinary household aluminum foil), which is placed snugly around the interrupter surface and held in place with bare wire. There should be adequate clearance between the foil and the top and bottom edges of the interrupter to prevent spark-over during the test. The breaker is closed and the low-voltage (LV) lead is connected to the foil with the LV SWITCH of the test set in the UST mode; thus, the bushing and other losses to ground will not be measured.

NOTE ☝ **The test technique shown in Figure 4.5 may not be applicable if the interrupters have grading resistors or semiconducting paint across them.**

Interrupters, by their nature, normally have relatively high power factor (10-20% is not uncommon). The materials used in the construction of interrupters have an affinity for moisture. Also, a certain amount of moisture is desirable to preserve mechanical strength. Too much moisture may cause swelling and subsequent overstressing of the clamping bolts. On the other hand, interrupters should not be overdried, since a large reduction in water content may cause the plate structure to weaken mechanically, become loose, warp out of shape, and thus reduce the effectiveness of the interrupter both mechanically and electrically.

The following examples should assist the test engineer in interpreting the data:

Example 1

			% Power Factor		
Test No.	**I(mA)**	**Watts**	**Measured**	**Corrected**	
1 (Open)	1150	0.07	0.61	0.6	
2 (Open)	1150	0.07	0.61	0.6	TLI
7 (Closed)	2300	0.11	0.48	0.5	–0.03 W

Comment: Test results are normal.

Example 2

Test No.	I(mA)	Watts	% Power Factor Measured	% Power Factor Corrected	
1 (Open)	1150	0.07	0.61	0.6	
2 (Open)	1200	0.22	1.83	1.8	TLI
7 (Closed)	2300	0.13	0.56	0.6	–0.16 W

Comments: The high negative Tank-Loss Index may be due to a “wet” interrupter on Bushing No. 2. Bushing No. 2 itself may be considered good, even though the power factor for Test 2 is high. If Bushing No. 2 did, in fact, have a high power factor, it would also have contributed high losses to Test 7. If applicable, a supplementary UST measurement on Bushing No. 2 and/or UST measurement on interrupter No. 2 (see Figure 4.5) would provide additional helpful information. See also Example 3.

Example 3

Test No.	I(mA)	Watts	% Power Factor Measured	% Power Factor Corrected	
1 (Open)	1150	0.07	0.61	0.6	
2 (Open)	1200	0.22	1.83	1.8	TLI
7 (Closed)	2350	0.26	1.11	1.1	–0.03 W

Comments: In view of the “normal” Tank-Loss Index, the high power factor for Test 2 must be due to Bushing No. 2 (or connected insulators, if any). Note that the Closed-Breaker power factor is an approximate average of the two Open-Breaker power factors, provided that the Tank-Loss Index is relatively low. If applicable, a supplementary UST measurement on Bushing No. 2 would provide additional helpful information.

Example 4

Test No.	I(mA)	Watts	% Power Factor Measured	% Power Factor Corrected	
1 (Open)	1200	0.15	1.25	1.3	
2 (Open)	1200	0.15	1.25	1.3	TLI
7 (Closed)	2300	0.11	0.48	0.5	–0.19 W

Comments: The low Closed-Breaker power factor indicates that the bushings are satisfactory. However, the high negative Tank-Loss Index, which is reflecting the high Open-Breaker losses for Tests 1 and 2 (and their resultant calculated power factors), may be due to a deteriorated operating-rod guide or upper portion of the (lift) rod, both of which would affect the Open-Breaker test. It is also possible that both interrupters are contaminated.

Example 5

Test No.	I(mA)	Watts	% Power Factor Measured	% Power Factor Corrected	
1 (Open)	1150	0.07	0.61	0.6	
2 (Open)	1150	0.07	0.61	0.6	TLI
7 (Closed)	2400	0.25	1.04	1.0	+0.11 W

Comments: The relatively low Open-Breaker losses and power factor indicate that the bushings are satisfactory. The high Closed-Breaker losses (resulting in a high positive Tank-Loss Index) indicate an internal problem, perhaps a deteriorated operating rod, a contaminated tank liner or, possibly, abnormally high contact resistance.

Example 6

Test No.	I(mA)	Watts	% Power Factor Measured	% Power Factor Corrected	
1 (Open)	1200	0.18	1.50	1.5	
2 (Open)	1200	0.18	1.50	1.5	TLI
7 (Closed)	2400	0.40	1.67	1.7	+0.04 W

Comments: The Open-Breaker and Closed-Breaker power factors in this example are high, and the Tank-Loss Index is only slightly high in the positive direction. While it is possible that the bushings themselves may have high losses, high power factor oil will also cause both the Open- and Closed-Breaker power factors to be high and would tend to make the Tank-Loss Index positive. Supplementary tests on oil and bushings would provide helpful information. The pattern of data shown by this example is often indicative of a condition of general internal contamination. Flushing of the tank and internal members with clean oil, cleaning and reassembly of internal parts (such as the interrupter structure), and replacing or reconditioning the oil are generally required to restore the breaker to good condition.

Grounded-Tank SF_6 Circuit Breakers

Test Voltage

Grounded-tank SF_6 circuit breakers are generally rated above 15 kV class and all Overall tests are performed at 10 kV.

Breakers of this type, which are rated 15 kV class and below are tested initially and routinely at the following voltages:

Table 4.4 Recommended Doble Test Voltage For Grounded Tank SF_6 Circuit Breakers (Rated 15 Kv Class and Below)

Initial Test	Routine Follow-Up Tests
1. Some low voltage below corona inception (e.g., 2 kV test voltage for 15 kV class breakers)	————
2. Rated operating line-to-ground voltage (e.g., 8 kV test voltage for a 13.8 kV breaker)	————
3. 10% to 25% above rated operating line-to-ground voltage (e.g., 8.8 kV to 10 kV test voltage for a 13.8 kV breaker)	**1.** 10% to 25% above rated operating line-to-ground voltage (e.g., 8.8 kV to 10 kV test voltage for a 13.8 kV breaker)

For grounded-tank SF_6 breakers rated 15 kV class and below, once a proper benchmark has been established at several test voltages (i.e., whereby no appreciable increase in watts-loss or power factor is observed initially to indicate the presence of corona), routine tests thereafter are generally performed only at the maximum voltage selected for the initial test.

Test Procedure

Multiple Tests

DTA can perform multiple tests to speed things up. In the procedure described below, multiple tests require that you place a low voltage lead on the opposite bushing to that being energized, on the same phase (the bushing in the column labeled “Bushing Floating”). Instead of floating, that bushing will then be guarded. Multiple tests are available only on tests 1, 3, and 5. The results are as follows:

1. When running test 1, choosing a multiple test causes the M4000 to perform tests 1 and 7.
2. When running test 3, the multiple tests choice gives you tests 3 and 8.
3. When running test 5, it yields tests 5 and 9.

NOTE

Since multiple tests require that tests 1, 3, and 5 be Guard tests and not Ground tests, the test results for those three tests will differ from those obtained when using single tests. Therefore, test results for multiple tests cannot be properly compared to test results when using single tests!

The Overall test procedure for grounded-tank SF_6 circuit breakers is outlined below:

Table 4.5 Overall Test Procedure from Grounded-Tank SF_6 Circuit Breakers

Test No.	Breaker Position	Test Mode	Bushing* Energized	Bushing* Floating	Bushing* UST
1	Open	GST	1	2	—
2	Open	GST	2	1	—
3	Open	GST	3	4	—
4	Open	GST	4	3	—
5	Open	GST	5	6	—
6	Open	GST	6	5	—
7	Open	UST	1	—	2
8	Open	UST	3	—	4
9	Open	UST	5	—	6

* Bushings of the phases not under test are left floating.

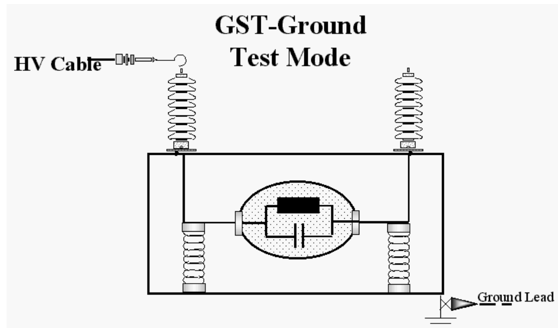


Figure 4.6 Tests 1-6, Dead Tank SF6 Circuit Breaker. For performing multiple tests as described above, connect as in Figure 4.7 below.

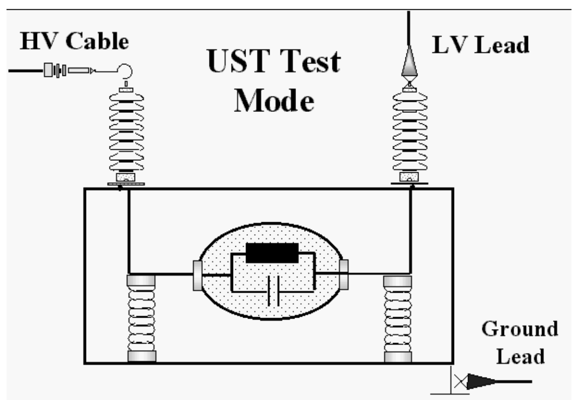


Figure 4.7 Tests 7-9, Dead Tank SF6 Circuit Breaker

Several designs of multi-contact grounded-tank SF_6 circuit breakers contain internal support insulators in each tank to provide support for other internal members and may also house operating rods and high-pressure feed tubes. Some of these designs include:

Brown Boveri/Gould/I-T-E	Types GA/GB
High Voltage Breakers, Inc.	SF_6 Puffers
Westinghouse Electric Corp.	Type SFV (two interrupters/phase)

For this type of design, the internal insulator column is not stressed directly with the breaker in the open position. Therefore, for these breakers, Tests 1 through 9 are supplemented by Closed-Breaker GST measurements on each phase as outlined below:

Table 4.6 Supplimentary Tests on Grounded Tank SF_6 Circuit Breakers

Test No.	Breaker Position	Test Mode	Bushing* Energized	Bushing* Floating	Bushing* UST
10	Closed	GST	1 & 2	—	—
11	Closed	GST	3 & 4	—	—
12	Closed	GST	5 & 6	—	—

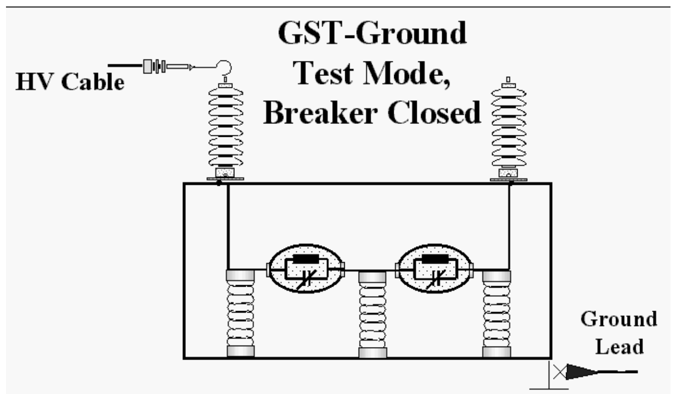


Figure 4.8 Alternate Test For Internal Support Insulators

Analysis Of Test Results

The Open(GST)-Breaker tests are rated on the basis of current, watts, and power factor. For comparison data, refer to the Circuit Breaker section of the Doble *Test-Data Reference Book.* If the charging current is relatively small, then more emphasis should be given to watts-loss rather than the power factor. In some cases, these breakers are equipped with line-to-ground capacitors on the line and/or load side. When applicable, the power factor and capacitance are recorded and analyzed.

For breakers with grading capacitors across the contacts, UST measurements (Tests 7, 8, and 9) are of particular significance. The results of such tests are analyzed on the basis of a comparison of capacitances and power factors (or watts-losses in the case of relatively low capacitance values). Abnormally high capacitances can be indicative of short-circuited sections in one or more of the grading-capacitor assemblies. For comparison data, refer to the Circuit Breaker section of the *Test-Data Reference Book.*

The Closed-Breaker tests, where applicable, are rated on the basis of current, watts, and power factor. The data are compared between phases, with previous test results (if any), with results recorded for similar breakers on the system, and with data tabulated in the Circuit Breaker section of the *Test-Data Reference Book.*

High losses and power factor for Tests 1 through 6 (all designs), and for Tests 10-12, could be the result of excessive moisture or by-products of arced SF_6 which have condensed or deposited on internal insulating members. Operating the breaker several times may improve the high results, if caused by moisture. Suspicion of moisture may be confirmed by dew point or moisture-content measurements on the SF_6 gas.

Supplementary UST and tap-insulation tests are performed on those bushings equipped with potential or power-factor test taps.

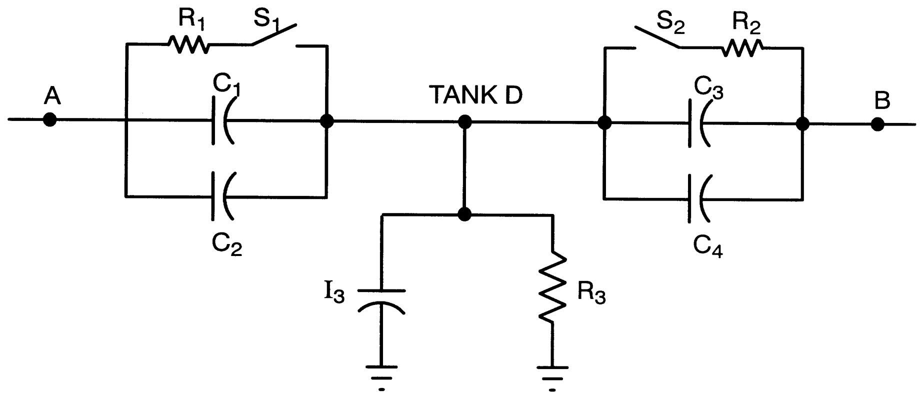
For breakers equipped with gas-filled bushings, supplementary Hot-Collar tests are performed to detect internal contamination along the inner weathershed wall, cracks, and other problems in the vicinity of the collar(s). Single or Multiple Hot-Collar tests may be performed (see ”Bushings” on page 3-1). On large bushings, at least three Single Hot-Collar Tests are performed or, instead, one Multiple Hot-Collar Test is made with collars placed at the top, middle, and bottom of the bushing (more collars may be used, depending on the bushing size). The Hot-Collar losses are compared between similar bushings tested under similar atmospheric conditions, between bushing sections in the case of Single Hot-Collar tests performed at various locations of a given bushing, and with previous results (if any). Under favorable atmospheric conditions, the loss for a Single Hot-Collar test on a gas-filled porcelain bushing is expected to be 0.010 watt or less. Comparatively high losses obtained for Multiple Hot-Collar tests are investigated by performing a series of Single Hot-Collar Tests along various sections of the bushing, in order to determine if the high losses are localized or are general.

Sometimes it is useful to investigate abnormal results by making a series of tests at several voltages, to determine if the condition causing the abnormal results is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV in the case of tests normally performed at 10 kV.

Live-Tank Breakers (Air, SF_6 Or Minimum Oil Types)

“T” and “Y” Module - General

High voltage and extra-high voltage (EHV) breakers may be of the modular design in which two interrupters are mounted in a “live tank”, which itself is mounted atop a vertical insulator column of varying height, depending upon the kV rating of the breaker. A number of such modules may be connected in series for higher voltage ratings and increased interrupting capabilities. A variation of this design has each arm of the “T” or “Y” containing a single interrupter mounted in a large porcelain housing. In this design, contact grading capacitors and preinsertion resistors and their switches are mounted in separate porcelains connected across each interrupter section. Dielectrically, each type described above is the same as shown in Figure 4.9. Breakers of this type of lower voltage ratings may have only one interrupter mounted atop a vertical insulator column, and are commonly called “Candlestick” breakers. Test procedure for this type of breaker is described under”Candlestick Breakers (One Break Per Phase)” on page 4-30.



C_1 and C_3 =	Entrance bushings
C_2 and C_4 =	Grading capacitors (across the interrupter contacts)
S_1 and S_2 =	Preinsertion resistor switches
R_1 and R_2 =	Preinsertion resistors
I_3 =	Vertical insulator column (one or more sections)
R_3 =	Gas or air-supply tube, operating rod, and other column insulation

Figure 4.9 Dielectric Schematic of "T" or "Y" Module Breaker

Test Voltages

Live-tank "T" and "Y" module breakers are typically designed for high voltage and extra-high voltage (EHV) application. All routine Doble tests are performed at 10 kV. Sometimes it is useful to investigate abnormal results by making a series of tests at several voltages to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV.

Test Procedure

Multiple Tests

DTA can run multiple tests to save time. If running test 1, selecting multiple tests will result in all 3 of the tests described in the procedure below. When using the multiple test function:

1. DTA will ask you at which point on the breaker the Red and Blue Low Voltage Leads have been placed (see the Layout drawing if unsure by selecting *Layout* from the *View* menu).

2. DTA will display a Setup window where you may select Multiple Tests. Make sure the test kV and circuits are correct. An example is given beneath the test procedures below.
3. For breakers with multiple columns per phase, each set of 2 interrupters and their supporting column are tested as another multiple test of 3.

The Overall test technique for each module of a high-voltage “T” and “Y” module “live-tank” breaker is outlined below:

Table 4.7 Test Procedure for Each Module “T” And “Y” Module Live-Tank Breakers (Breakers Open for All Tests)

Perform All Routine Tests at 10 kV

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	UST	D	B	—	A	C_1+C_2+ (R_1+S_1)
2	UST	D	A	—	B	C_3+C_4+ (R_2+S_2)
3	GST	D	—	A, B	—	I_3+R_3

The dual Low-Voltage (LV) Test Lead arrangement of the M4000 set greatly facilitates testing of “T” and “Y” module live-tank breakers. By making only one set of test connections, Tests 1, 2, and 3 on a given module are performed by simply selecting the circuit description for each test. To illustrate, assume the following connections (refer toFigure 4.10):

High-Voltage Test Cable connect to Point D

LV Lead (Red, R) connect to Point A

LV Lead (Blue, B) connect to Point B

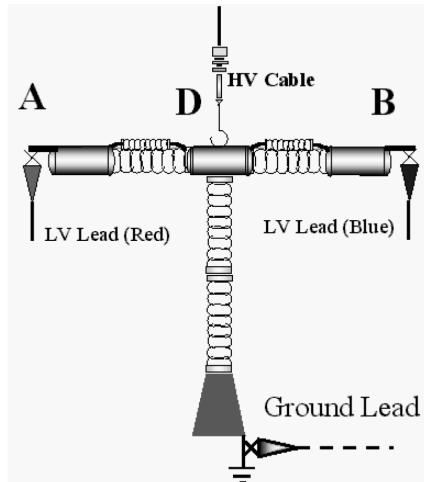


Figure 4.10 Single Module Live Tank Breaker Test

Tests Nos. 1, 2, and 3 are then performed using the following circuit descriptions:

Test No.	Energize	Ground	Guard	UST	Circuit Description
1	D	B*	—	A	UST-R
2	D	A*	—	B	UST-B
3	D	—	A, B	—	GAR-RB

* For UST, Guard and Ground are the same.

Analysis Of Results

The entrance bushing/grading capacitor combinations are rated on the basis of capacitance and power-factor test results.

NOTE **While preinsertion resistors and their associated switches are shown as being included in Tests 1 and 2, resistors R_1/R_2 are usually of low ohmic value, and switches S_1/S_2 have very low capacitance relative to the bushings and grading capacitors. Thus, the influence of R_1R_2 and S_1/S_2 on tests 1 and 2 are practically negligible.**

In some breakers, the capacitance and/or power factors are to be corrected for temperature based on information provided by the manufacturers. Data to assist in temperature correction and in analysis of test results is included in the Circuit Breaker section of the Doble *Test-Data Reference Book.* The results are also compared between modules of a given breaker, with previous test results (if any), and with results recorded for similar breakers on the system.

High losses and power factor for the entrance bushing/grading capacitor combinations generally indicate deteriorated or contaminated grading capacitors, but may also be the result of surface leakage (external or internal) on the bushing. Higher than normal capacitance may indicate short-circuited sections of the grading capacitor assembly. Unacceptable results for Tests 1 or 2 warrant separate tests to be performed on the associated bushings and grading capacitors.

High losses along the “T” or “Y” column indicate the possibility of surface leakage (internal or external) along the column, or moisture which may have condensed on internal tubes and rods. In the event of the latter, operating the breaker several times may improve the results.

Investigation of abnormal results should include supplementary tests at several voltages (see discussion herein under “General” – ”Test Voltages” on page 1-11.

The current transformers (CTs) associated with these breakers are also tested. These CTs are usually of the “free standing” design, but in some cases may be incorporated as part of the interrupter support column of the module. In either case, an overall measurement is performed (primary winding to ground), and the power factor is calculated and corrected for temperature. The power factors are compared for similar CTs associated with the same breaker, with previous test results (if any), with results recorded for similar CTs on the system, and with the data tabulated in the Instrument Transformer section of the Doble *Test-Data Reference Book.*

Some free-standing CTs are equipped with potential or power-factor test taps which permit, in addition to the Overall test, supplementary UST and tap-insulation measurements. For further comments, refer to ”Current Transformers” on page 5-32 in this section.

Candlestick Breakers (One Break Per Phase)

One phase of a three-phase candlestick breaker, having one interrupter per phase, is illustrated in Figure 4.11. Breakers of this type with multiple interrupters are described earlier in this chapter under ”Live-Tank Breakers (Air, SF6 Or Minimum Oil Types)” on page 4-25.

C_1 = Interrupter chamber

R = Operating rod and support insulator

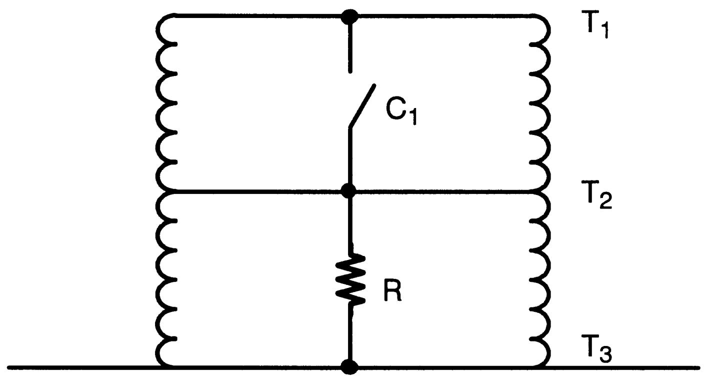


Figure 4.11 Candlestick Breaker

Test Voltages

Candlestick breakers of 15 kV insulation class and above are tested at 10 kV. Breakers of this type rated below 15 kV class are tested at a convenient voltage at or below the nameplate rating.

Multiple Tests

If using DTA, multiple tests can speed up testing. In the test procedure described below, tests 1 and 2 could be performed in one multiple tests:

1. DTA first asks the user which test lines to include in the multiple test. The user should select the lines for interrupter C1 and its support column S1 (or C2 and S2, C3 and S3).
2. DTA asks which test circuits to use. For the test procedure shown below, the circuit for test 1 would be UST measure Red, and for test 2 GST Guard Red Blue (a low voltage lead is connected to T1).

Test Procedure

If using DTA, choose Layout #7. The test procedure for each phase of this type of breaker is as follows:

Table 4.8 Test Procedure for Candlestick Breakers

Test No.	Breaker Position	Test Mode	Energize	Ground	Guard	UST	Measure
1	Open	UST	T_2	T_3	—	T_1	C_1
2	Open	GST	T_2	T_3	T_1	—	R*

* The same as S1 in DTA

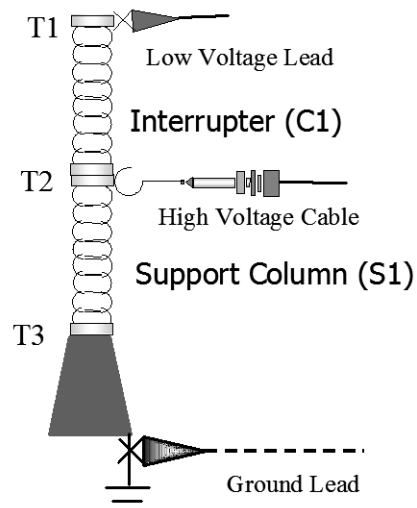


Figure 4.12 Candlestick Breaker Or Switcher Test

In the presence of strong electrostatic fields, and if testing with an instrument other than the M4000, the effects of interference on these relatively low-capacitance measurements may be minimized by a simple alteration in the standard test procedure as follows:

Table 4.9 Alternative Test Procedure for Low Oil Volume Breakers

Test No.	Breaker Position	Test Mode	Energize	Ground	Guard	UST	Measure
1A	Open	UST	T_1	T_3	—	T_2	C_1
2A	Closed	GST	T_1&T_2	T_3	—	—	R*

* The same as S1 in DTA.

With reference to the alternative test procedure, note that Test 2A may be performed quite easily after Test 1A by removing the Low Voltage Lead from T_2 and closing the breaker.

Analysis Of Results

Because of the relatively low current and watts-loss expected for tests on this type of breaker, the upper and lower porcelains should be clean and dry. If higher than normal losses are obtained after cleaning the surface, the use of surface guard collars should be considered, as discussed under "General" – "Surface Leakage" on page 1-27.

The current and watts are recorded for each test, although, in view of the low charging current expected, the power factor is not calculated. Instead, a comparison is made of the individual current and watts readings obtained between phases, with previous test results (if any), and with results recorded for similar breakers on the system. Under ideal conditions the losses for Tests 1(1A) and 2(2A) are expected to be of the order of 0.010 watt.

Tests Made Possible By The M4000

Testing Live Tank Breakers Without Removing Attached CT's Or Switches

With the advent of the M4000 and its ability to eliminate the effect of electrostatic interference, it may not be necessary to disconnect attached CT's or Disconnect Switches. When testing an interrupter with another apparatus attached to its outboard side, the UST test will measure only up to the interrupter and the attached CT or switch will be disregarded.

Testing A Live Tank Breaker With A Ground On An Interrupter's Outboard End

Some utilities require that one particular end of a live tank breaker be grounded during test. In this case, the test circuit used to test that interrupter (grounded on its outboard side) will not be the usual UST test, but will have to be a GST test. Since the test involves energizing the breaker head and measuring to the outboard (grounded) side of that interrupter, one must assure he is not also including the grounded support column in the test. To do this, attach a Low Voltage Lead between two sections of the column's porcelain units, and test with a GST-Guard circuit.

Air-Magnetic Breakers

Test Voltages

Air-magnetic circuit breakers generally are rated 15 kV insulation class and below, and are tested initially and routinely at the following voltages:

Table 4.10 Recommended Doble Test Voltages for Air-Magnetic Circuit Breakers

Initial Test	Routine Tests
1. Some low voltage below corona inception (2 kV for 15 kV class)	————
2. Rated operating line-to-ground voltage (8 kV for breakers used on 13.8 kV system)	————
3. 10% to 25% above rated operating line-to-ground voltage (8.8 kV to 10 kV for breakers used on 13.8 kV systems)	**1.** 10% to 25% above rated operating line-to-ground voltage (8.8 kV to 10 kV for breakers used on 13.8 kV systems)

For 15 kV insulation class low-voltage air-magnetic breakers operating at 13.8 kV, the initial series of tests would be performed at 2, 8, and 8.8 to 10 kV. Once a proper benchmark has been established at several voltages (i.e., whereby no appreciable increase in watts-loss or power factor with voltage is observed initially to indicate the presence of corona), routine follow-up tests then would be performed, only at the highest voltage selected for the initial test. Abnormal results obtained during routine tests should be investigated by performing additional tests at the lower voltages selected for the initial tests for which benchmark data has been obtained. The test results at several voltages will help determine if the abnormal condition is voltage sensitive.

Multiple Tests

DTA can run multiple tests for tests 1, 3, and 5 to speed things up. Here are the tests that are run:

1. When running a multiple test on test 1, tests 1 and 7 are obtained.
2. When running a multiple test on test 3, tests 3 and 8 are obtained.
3. When running a multiple test on test 5, tests 5 and 9 are obtained.

Test Procedure

The standard test technique for air-magnetic breakers is outlined below: The High Voltage Cable is placed on one bushing, and the Low Voltage Lead is placed on the opposite bushing of the same phase. This applies for all nine tests listed below.

Table 4.11 Test Procedure for Air-Magnetic Circuit Breakers

Breakers Open for All Tests

Test No.	Test Mode	Bushing Energized	Bushing Guarded	Bushing* UST
1	GST	1	2	—
2	GST	2	1	—
3	GST	3	4	—
4	GST	4	3	—
5	GST	5	6	—
6	GST	6	5	—
7	UST	1	—	2
8	UST	3	—	4
9	UST	5	—	6

The breaker frame must be properly grounded in order to obtain correct data.

Ordinarily, air-magnetic breakers are tested with the arc-chutes in place. In order to eliminate the influence of the arc-chutes on the bushing and other ground insulation, it is preferable to make Tests 1 through 6 with the arc-chutes raised or removed. This is recommended as a routine procedure for breaker types on which it is feasible. If questionable, Doble test results are obtained for Bushing Tests 1 through 6 with the arc-chutes in place, then an investigation is performed by repeating these measurements with the chutes raised or removed.

Analysis Of Results

If the charging current for Tests 1 through 6 is relatively small, then these tests should be analyzed on the basis of the watts-loss, not power factor. The results of the UST measurements are analyzed on the basis of the watts. The results of Tests 1, 3, and 5 should be compared with each other. Likewise, compare Tests 2, 4, and 6, and also compare the three UST measurements. These results should be compared with previous tests (if any), with results recorded for other similar breakers on the system, and against data tabulated in the Circuit Breaker section of the *Doble Test-Data Reference Book*.

Temperature-correction factors are not applied to air-magnetic breakers.

Low-Voltage Air-Blast Breakers

Test Voltages

Low-voltage air-blast circuit breakers generally are rated 15 kV insulation class and below, and are tested initially and routinely at the following voltages:

Table 4.12 Recommended Doble Test Voltages for Low-Voltage Air-Blast Circuit

Rated 15 kV Class and Below	
Test Units Rated Above 15 kV Class at 10 kV	
Initial Test	**Routine Tests**
1. Some low voltage below corona inception (2 kV for 15 kV class)	————
2. Rated operating line-to-ground voltage (8 kV for breakers used on 13.8 kV system)	————
3. 10% to 25% above rated operating line-to-ground voltage (8.8 kV to 10 kV for breakers used on 13.8 kV systems)	**1.** 10% to 25% above rated operating line-to-ground voltage (8.8 kV to 10 kV for breakers used on 13.8 kV systems)

For 15 kV insulation class low-voltage air-blast breakers operating at 13.8 kV, the initial series of tests would be performed at 2, 8, and 8.8 to 10 kV. Once a proper benchmark has been established at several voltages (i.e., whereby no appreciable increase in watts-loss or power factor with voltage is observed initially to indicate the presence of corona), routine follow-up tests then would be performed only at the highest voltage selected for the initial test. Abnormal results obtained during routine tests should be investigated by performing additional tests at the lower voltages selected for the initial tests for which benchmark data has been obtained. The test results at several voltages will help determine if the abnormal condition is voltage sensitive.

Test Procedure

The test procedure recommended for breakers of this type is outlined below. The High Voltage Cable is placed on one bushing at a time, and all other bushings float. No Low Voltage Lead is needed. The breaker and test set are both grounded to the same point.

Table 4.13 Test Procedure for Low-Voltage Air-Blast Breakers

Test No.	Breaker Position	Test Mode	Bushing* Energized	Bushing* Floating
1	Open	GST	1	2
2	Open	GST	2	1
3	Open	GST	3	4
4	Open	GST	4	3
5	Open	GST	5	6
6	Open	GST	6	5
7	Closed	GST	1 & 2	—
8	Closed	GST	3 & 4	—
9	Closed	GST	5 & 6	—

* Bushings of the phases not under test are left floating.

Analysis Of Results

In the event of questionable test results, the test procedure for air-magnetic breakers may be used to obtain additional information in order to assist in pinpointing the location and cause of abnormal values.

Reference data for use in analyzing the results of tests on various makes and types of these breakers is tabulated in the Circuit Breaker section of the *Doble Test-Data Reference Book*. Comparisons are also made between the three phases of a given breaker, with previous test results (if any), and with the results obtained for other similar breakers on the system. Data is analyzed on the basis of watts-loss and power factor, with particular significance on the watts in the event of relatively low capacitance and charging current.

Test results for this type of equipment are not corrected for the effects of temperature.

Oil Circuit Reclosers

Test Voltages

Oil circuit reclosers of 15 kV insulation class (e.g., units rated 14.4 kV) and above are tested at 10 kV. Oil circuit reclosers rated below 15 kV class are tested at a convenient voltage at or below the nameplate rating. For example, a 2.4 kV unit may be tested at 2 kV.

Test Procedure

Oil circuit reclosers are tested by the conventional Open- and Closed-Breaker test technique outlined for oil circuit breakers. One bushing at a time is energized with the High Voltage Cable, and all other bushings float. No Low Voltage Lead is necessary.

Table 4.14 Test Procedure for Oil Circuit Reclosers

Test No.	Recloser Position	Test Mode	Bushing Energized	Bushing* Floating
1	Open	GST	1	2
2	Open	GST	2	1
3	Open	GST	3**	4
4	Open	GST	4	3
5	Open	GST	5**	6
6	Open	GST	6	5
7	Closed	GST	1 & 2	—
8	Closed	GST	3 & 4**	—
9	Closed	GST	5 & 6**	—

* Bushings of the phases not under test are left floating.
* * Remove any closing solenoid.

Analysis Of Results

The current and watts are recorded for all tests, and the Tank-Loss Index (TLI) is computed. For the Open-Breaker tests, the power factors are usually not calculated because of the relatively low current. These tests are analyzed primarily by comparing the watts results recorded for the six bushings, with the results of previous tests (if any), with the results recorded for other similar reclosers on the system, and with results tabulated in the Circuit Breaker section of the *Doble Test-Data Reference Book*.

The power-factor value is computed for the three Closed-Breaker tests, but these are not corrected for temperature. These three measurements include both bushings in each phase and the losses associated with the operating rod and other tank insulation.

The analysis of test results is based on the same approach as outlined under ”Oil Circuit Breakers” on page 4-1. In general, a high TLI is indicative of internal contamination and/or deterioration. A high open-breaker loss, with relatively high closed-breaker power factor and normal TLI for the tank in question, indicates a possible bushing problem.

Supplementary Hot-Collar tests may be performed on the bushings whenever high open-breaker watts-loss results are recorded.

Some reclosers may be designed with an interrupter/resistor assembly connected between the lower bushing terminals. One such design is the Westinghouse Electric Corporation Type PRC. The resistors especially influence the standard Open-Recloser tests, making proper analysis of the data difficult. For units of the design, the following alternative method should be utilized. For each test, the High Voltage Cable is placed on a bushing, and the Low Voltage Lead is placed on the opposite bushing of the same phase.

Table 4.15 Alternative Test Procedure for Oil Circuit Reclosers

Westinghouse Type PRCs or other Similar Designs

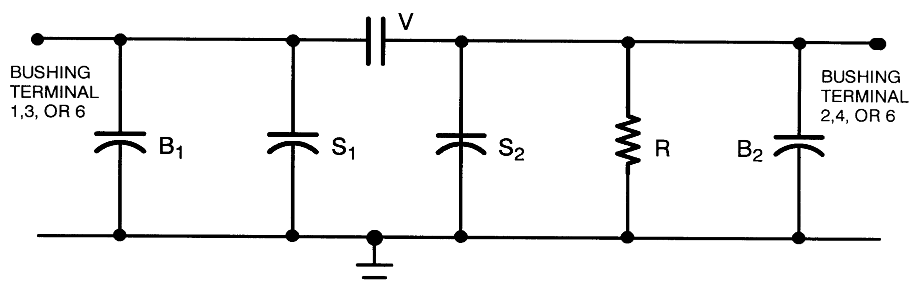
Test No.	Breaker Position	Test Mode	Bushing* Energized	Bushing* Guarded	Bushing* UST
1	Open	GST	1	2	—
2	Open	GST	2	1	—
3	Open	GST	3	4	—
4	Open	GST	4	3	—
5	Open	GST	5	6	—
6	Open	GST	6	5	—
7	Open	UST	1	—	2
8	Open	UST	3	—	4
9	Open	UST	5	—	6
10	Closed	GST	1 & 2	—	—
11	Closed	GST	3 & 4	—	—
12	Closed	GST	5 & 6	—	—

*Bushings of the phases not under test are left floating.

Tests 1 through 6 are primarily a measurement of the bushing losses (the power factor is not calculated). The guard technique effectively eliminates the influence of the interrupter/resistor assembly. Tests 7, 8, and 9 are a direct measurement of the losses associated with the interrupter/resistor assembly, although the power factor is not calculated. Tests 10, 11, and 12 test both bushings in each phase, and include losses associated with the operating rod and other tank insulation.

Vacuum Breakers and Reclosers

Some types of vacuum breakers and reclosers consist of three phases (six bushings) mounted in a single-grounded tank. The dielectric circuit of each phase of this type of vacuum breaker/recloser may be represented schematically as shown in Figure 4.13:



B_1 and B_2	=	Entrance bushings
S_1 and S_2	=	Internal standoff insulators (if any)
R	=	Insulated operating rod
V	=	Vacuum interrupter and housing

Figure 4.13 Dielectric Circuit for Conventional Vacuum Breakers/Reclosers

Test Voltages

Vacuum breakers and reclosers rated above 15 kV insulation class are tested at 10 kV. Vacuum breakers/reclosers rated 15 kV and below are tested initially and routinely at the following voltages:

Table 4.16 Recommended Doble Test Voltages for Vacuum Breakers and Reclosers (Rated 15 Kv Class And Below)

Test Units Rated Above 15 kV Insulation Class at 10 kV

Initial Test for Dry Type	Routine Tests for Dry Type and Initial and Routine Test for Oil-Filled
1. Some low voltage below corona inception (2 kV for 15 kV class)	————
2. Rated operating line-to-ground voltage (8 kV for breakers used on 13.8 kV system)	————
3. 10% to 25% above rated operating line-to-ground voltage (8.8 kV to 10 kV for breakers used on 13.8 kV systems)	**1.** 10% to 25% above rated operating line-to-ground voltage (8.8 kV to 10 kV for breakers used on 13.8 kV systems)

For 15 kV insulation class vacuum breakers and reclosers operating at 13.8 kV, the initial series of tests would be performed at 2, 8, and 8.8 to 10 kV. Once a proper benchmark has been established at several voltages (i.e., whereby no appreciable increase in watts-loss or power factor with voltage is observed initially to indicate the presence of corona), routine follow-up tests then would be performed only at the highest voltage selected for the initial test. Abnormal results obtained during routine tests should be investigated by performing additional tests at the lower voltages selected for the initial tests for which benchmark data has been obtained. The test results at several voltages will help determine if the abnormal condition is voltage sensitive.

Test Procedure

Multiple Tests

DTA can run multiple tests for tests 1, 3, and 5 to speed things up. Here are the tests that are run:

1. When running a multiple test on test 1, tests 1 and 7 are obtained.

2. When running a multiple test on test 3, tests 3 and 8 are obtained.

3. When running a multiple test on test 5, tests 5 and 9 are obtained.

- If you prefer multiple tests on bushings 1, 3, and 5, energize one bushing at a time with the High Voltage Cable, and place the Low Voltage Lead on the opposite bushing of the same phase (it will be guarded). Single tests must still be run on bushings 2, 4, and 6, as shown in the table below. Run the first six tests below. Test 7 will be included when you run test 1, 8 with test 3, and 9 with test 5.

NOTE

Since multiple tests require that tests 1, 3, and 5 be Guard tests and not Ground tests, the test results for those three tests will differ from those obtained when using single tests. Therefore, test results for multiple tests cannot be properly compared to test results when using single tests!

- If you prefer single tests, there is no need to use the Low Voltage Lead for tests 1-6, and all but the energized bushing float. Choosing "Single" for tests 1, 3, and 5 then requires that you run tests 7-9 singly, and for those three tests you must place the Low Voltage Lead on the opposite bushing from that being energized, on the same phase. The overall test technique for vacuum breakers/reclosers is as follows (single tests):

Table 4.17 Test Procedure for Conventional Vacuum Breakers/Reclosers (All Tests with Breakers/Reclosers in the Open Position)

Test No.	Test Mode	Bushing Energized	Bushing Floating	Bushing* UST
1	GST	1	2	—
2	GST	2	1	—
3	GST	3	4	—
4	GST	4	3	—
5	GST	5	6	—
6	GST	6	5	—
7	UST	1	—	2
8	UST	3	—	4
9	UST	5	—	6

Analysis Of Results

Tests 1, 3, and 5 include entrance bushings and the associated internal insulators which support one end of the vacuum bottles. Tests 2, 4, and 6 do likewise and, in addition, include the losses associated with the operating rod. Tests 7, 8, and 9 are direct measurements on the vacuum interrupter bottle.

The charging currents for all tests are expected to be very small. The power factors are not calculated and no temperature correction is applied to these tests. The current and watts for Tests 1 through 6 are compared with each other, with the results of previous tests (if any), and with results recorded for other similar breakers/reclosers on the system. The watts-loss is further compared with data in the Circuit Breaker section of the Doble *Test-Data Reference Book.*

Vacuum bottles tested under dry ambient conditions should have dielectric losses approaching zero, and therefore, the watts-loss for Tests 7, 8, and 9 is expected to be extremely small and should be compared between phases, with results of previous tests (if any), with results recorded for other similar breakers/reclosers on the system, and with data tabulated for similar units in the *Test-Data Reference Book*. High UST losses for a vacuum interrupter may be due to a defective bottle which has allowed moisture to enter, or may be due to external surface losses across the vacuum housing. The latter may be confirmed by one or a combination of several retests after: (1) cleaning the surface of the vacuum bottle; (2) applying heat to the surface of the bottle; and (3) application of guard collar. Refer to comments under “General” – ”Surface Leakage” on page 1-27.

Excessive surface leakage on vacuum bottles may be an indication of insufficient heat or defective heaters in the breaker/recloser housing. This condition warrants appropriate attention to ensure that the ambient air around the vacuum bottles is clean and dry under service conditions.

In investigating abnormal results, Hot-Collar tests on the bushings are helpful in locating cracks and confirming the existence of surface losses, both above and below the bushing mounting flange. Hot-Collar tests may also be applied to support insulators and the Three-Electrode Test Technique is applicable to the operating rod. Refer to discussion under “Miscellaneous” – ”Wood and Other Insulating Members” on page 13-1.

5. Transformers, Reactors, and Regulators

Power and Distribution Transformers

Introduction

The Doble dielectric-loss and power-factor test, as applied to transformers (units rated 500 kVA or less are classified as distribution transformers and those rated 501 kVA and higher are classified as power transformers), is a most comprehensive test for moisture, carbonization, and other forms of contamination of winding, bushing, and liquid insulation in power and distribution transformers (Winding distortions are revealed by change of capacitance; capacitance is measured during the power-factor test. Short-circuited and partially short-circuited turns are made manifest by an abnormally high current value obtained for the excitation-current test. Refer to the section entitled ”Transformer Excitation-Current Tests” on page 5-44). A test that is even more sensitive to winding distortion is the Leakage Reactance test (see ”Leakage Reactance Testing” on page 5-71). Deterioration developing in winding, bushing, and liquid insulation can be localized by separate tests on these components, utilizing a technique which does not require physical disconnection of the transformer network. This technique also makes possible segregation of the dielectric circuit into major winding-to-ground and interwinding components for more effective analysis of test results.

Power and distribution transformers may be either single-phase or three-phase, and may be either dry-type (air, gas), or oil-, askarel-, or synthetic liquid-filled. Three general types are considered here:

- Two-winding transformer.
- Autotransformer (with or without a tertiary winding).
- Three-winding transformer.

For test purposes, the procedure utilized depends on the number of separate windings which are accessible. Thus, the power-factor test procedure for an autotransformer (with accessible tertiary winding) is the same as for a two-winding transformer. The only difference is in the nomenclature used to identify the windings.

When testing transformers, the following conditions should be observed:

1. The transformer must be de-energized and completely isolated from the power system.

2. The transformer housing must be properly grounded. This is especially noteworthy in the case of spare units.
3. All terminals of each winding, including neutrals, must be connected together. The object is to short-circuit each winding to eliminate any effect of winding inductance on the insulation measurements. Neutrals must be ungrounded.
4. If the unit is equipped with a Load-Tap Changer (LTC), it should be set to some position off neutral. Some transformer designs have arrester-type elements associated with the LTC which are not effectively short-circuited with the LTC in the neutral position, even when the terminals of the transformer winding are short-circuited externally.

Test Voltages

Liquid-Filled Power and Distribution Transformers

In considering the power-factor test voltages for liquid-filled power and distribution transformers, it is instructive to refer to the following standards:

- ANSI/IEEE C57.12.00-1987, *American National Standard, General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.*
- ANSI/IEEE C57.12.90-1987,American *National Standard, Test Code for Liquid -Immersed Distribution, Power, and Regulating Transformers (Part I) and Guide for Short-Circuit Testing of Distribution and Power Transformers (Part II).*

ANSI/IEEE C57.12.90 recommends that, for insulation power-factor tests, the voltage not exceed one-half the low-frequency test voltage given in ANSI/IEEE C57.12.00. The lowest BIL (Basic Lightning Impulse Insulation Level) given in C57.12.00, is 30 kV, which applies down to and including 120 volt windings, and winding neutrals. The low-frequency test voltage, corresponding to 30 kV BIL, is 10 kV. Therefore, in accordance with ANSI/IEEE, an insulation power factor test voltage of 5 kV could conceivably be applied to 120 volt windings. Doble recommends the following test voltages for making power-factor tests on liquid-filled power and distribution transformers.

Table 5.1 Recommended Doble Power-factor Test Voltages for Liquid-filled Power and Distribution Transformers

Transformer Winding Rating (L to L kV)	Test Voltage (L to G kV)
12 and Above	10
5.04 to 8.72	5
2.4 to 4.8	2
Below 2.4	1

Sometimes it is useful to investigate abnormal results by making a series of tests at several voltages, to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage beyond the norm. For example, going to 12 kV in the case of windings normally tested at 10 kV.

Refer also to the discussion in “General” – ”Test Voltages” on page 1-11.

Liquid-Filled Power and Distribution Transformers Tested in the Absence of the Insulating Liquid

Doble tests can be performed on liquid-filled power and distribution transformers in the absence of the insulating liquid or with a reduction in the amount of the insulating liquid. In general, the test voltage should be limited to 10% of the voltage recommended for transformer insulation power-factor tests in ANSI/IEEE C57.12.00-1993 (or latest revision) tables 3, 4, and 5 and C57.12.90-1993 (or latest revision) paragraph 10.10.3. The recommended test voltages listed in this section meet this requirement. This test technique may be used to assess the insulation drying process when the core and coil is in its own tank or in a drying chamber. This technique is also applicable when the core and coil assembly is required to be tested out of its own tank.

WARNING

In the presence of oxygen, oil vapors and combustible gases can be ignited by an energy source such as an electric arc or spark. Accordingly:

- **Whenever the insulating liquid in a transformer is removed or lowered, do not apply test voltage before determining - by direct measurement - that the gas space and liquid contain safe combustible gas levels for testing as prescribed by your company**. To minimize the risk of ignition associated with the presence of oxygen in the tank of a transformer that has an unknown condition, dry nitrogen may be purged through the tank to reduce the oxygen level in the gas below 2%. An effective method to minimize the level of oxygen in the transformer is to fill the gas space with dry nitrogen as the insulating liquid is drained. An effective way to removed combustible gasses is to draw a vacuum on the transformer, which has been drained of oil, and then break the vacuum with dry nitrogen. The tank must be designed to withstand the vacuum applied. **This precaution is especially important in the cases of suspected faulty transformers. It may be prudent not to test a transformer that has likely sustained damage due to an electrical fault**.

- **Never apply Doble test voltage to a transformer whose windings are under vacuum**. The tank pressure must be equal to or greater than the outside tank pressure (one atmosphere or greater absolute pressure which is the same as zero or greater gauge pressure). The level of vacuum attainable within a transformer does not assure sufficient dielectric strength to perform testing.
- **Do not to apply voltages that exceed those recommended herein for transformers with the insulating liquid removed**. For suspected faulty transformers, always perform the first test at the lowest possible voltage, then in the absence of adverse signs, gradually increase to the maximum allowable voltage.
- **Low test voltage is sufficient to assess the general level of dryness of a transformer insulation system**.
- **When testing with some or all of the transformer leads, core, and coils out of the liquid, maintain adequate clearance between all energized, floating, and grounded conductors**.

Doble suggests the following test voltages when windings of ordinarily liquid-filled transformers are tested in the absence of the insulating liquid:

Table 5.2 Recommended Doble Power-Factor Test Voltages for Liquid-Filled Type Power and Distribution Transformers Tested in the Absence of Insulating Liquid and Under Atmospheric Or Greater Absolute Pressure (Strict Accordance To The Preceding Warnings Is Required).

Transformer Winding Rating (L to L kV)	Test Voltage (L to G kV)
Delta and Ungrounded Wye Windings	
161 and Above	10
115 to 138	5
34 to 69	2
12 to 25	1
Below 12	0.5
Grounded Wye Windings and Single-Phase with Neutral	
12 and Above	1
Below 12	0.5

Tests may be performed under atmospheric, or higher, air or nitrogen pressure.

Dry-Type Power and Distribution Transformers

The following are Doble recommended test voltages for dry-type power and distribution transformers:

Table 5.3 Recommended Doble Power-Factor Test Voltages For Dry-Type Power and Distribution Transformers

Transformer Winding Rating (L to L kV)	Test Voltage (L to G kV)
Delta and Ungrounded Wye Windings	
Above 14.4	2 and 10
12 to 14.4	2, *, and 10
5.04 to 8.72	2 and 5
2.4 to 4.8	2
Below 2.4	1
*Operating Line-to-Ground Voltage	
Grounded Wye Windings and Single-Phase with Neutral	
2.4 and Above	2
Below 2.4	1
Possible graded insulation system.	

Two-Winding Transformers

Multiple Tests

DTA can perform multiple tests to save time. Just two multiple tests are needed to complete power factor tests:

1. When starting with test one in the table below, the multiple tests are one, two, and three.
2. When starting with test five, the multiple tests are five, six, and seven.

NOTE

All terminals of each winding, including neutrals, must be connected together. The object is to short-circuit each winding to eliminate any effect of winding inductance on the insulation measurements. Neutrals must be ungrounded.

Test Procedure

The standard Doble test procedure for two-winding transformers is outlined in Figure 5.1 and Figure 5.2. In the table below, the high voltage cable is placed on the winding in the **Energize** column, and the low voltage lead is placed on the opposite winding.

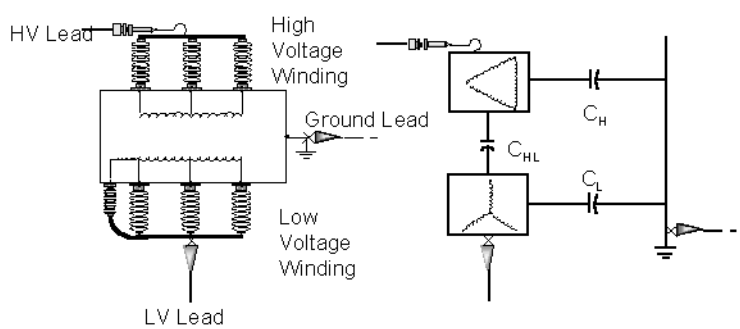


Figure 5.1 Two Winding Transformer Connections For Tests 1, 2, 3

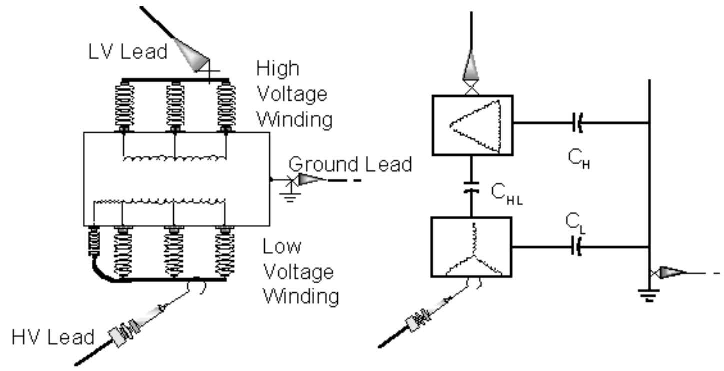


Figure 5.2 Two Winding Transformer Connections For Tests 5, 6, 7

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	GST	High	Low	—	—	C_H+C_{HL}
2	GST	High	—	Low	—	C_H
3	UST	High	—	—	Low	C_{HL}
4	Test 1 minus Test 2 (calculated)					C_{HL}
5	GST	Low	High	—	—	C_L+C_{HL}
6	GST	Low	—	High	—	C_L
7	UST	Low	—	—	High	C_{HL}
8	Test 5 minus Test 6 (calculated)					C_{HL}

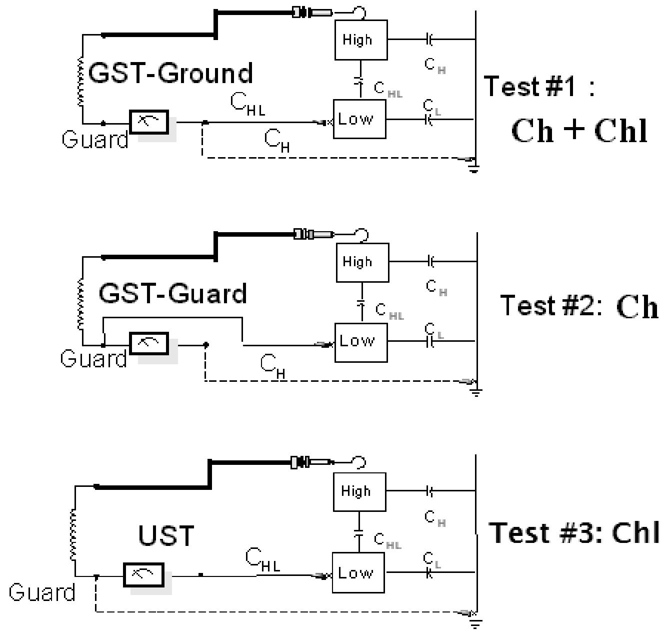


Figure 5.3 Measured Currents, Tests 1, 2, 3

It should be noted (Figure 5.3) that Test 1 includes the parallel combination C_H and C_{HL} (C_H measured via the test ground lead, C_{HL} via the Low Voltage Lead), while Test 2 includes only C_H (the Low Voltage Lead is guarded). The differences between the two sets of readings are attributable to C_{HL}. The magnitudes of current and watts for C_{HL} are obtained by subtraction of current (mA) and watts values recorded for Tests 1 and 2 (Test 1 minus Test 2), and by direct measurement (Test 3) for comparison. Power factors for C_{HL} are calculated in the normal manner ([Watts X 10]/mA), utilizing the results of the subtraction. A second set of comparable data for C_{HL} is obtained by subtraction of current and watts values recorded for Tests 5 and 6 (Test 5 minus Test 6) and also again by direct measurement (Test 7).

It is apparent that the current and watts recorded for Test 1 must be greater in magnitude than those recorded for Test 2. Test 5 must be greater than Test 6. If this is not the case, test connections should be checked and tests repeated, as indicated.

The Two-Winding test procedure described was specially developed by Doble and has the advantage of providing a cross check. For example, the two sets of current and watts calculated for C_{HL} should agree.

Power factors are calculated in the normal manner for C_H, C_L, and C_{HL}. The calculated values are corrected for top-oil temperature, using instructions and multipliers included in “General” – ”Variation Of Power Factor with Temperature” on page 1-14.

Analysis of Test Results

Modern oil-filled power transformers should have insulation power factors of 0.5% or less at 20°C. There should be reasonable justification by the manufacturer for higher values, and assurance that they are not the result of incomplete drying. If a higher power factor is caused by use of materials having inherently higher power factors, consideration should be given to their replacement with available materials which meet all of the electrical, mechanical, thermal, and compatibility requirements of transformer design, and have low power factors.

Older power transformers, oil-filled distribution transformers, and other liquid-filled or dry-type power and distribution transformers may have power factors in excess of 0.5%. Data should be analyzed on the basis of prior tests on the same unit, comparison with test results on similar units, and reference to tabulation of data in the Doble *Test-Data Reference Book.*

The capacitance (charging current) of C_H, C_L, and C_{HL} should be compared with factory data, with previous test results (if any), and with test results on sister units. Capacitance is a function of winding geometry, and is expected to be stable with temperature and age. Change of capacitance is an indication of winding movement such as might occur as a result of a through fault. The C_L, and C_{HL} insulations are where these changes are likely to occur.

Abnormal power factors (high or low/negative) are occasionally recorded for interwinding insulations of two-winding transformers. These may be the result of improper (high-resistance) grounding of the transformer tank, or the use of grounded electrostatic shielding between transformer windings. In the latter case, as a result of the ground shield, the interwinding capacitance is practically non-existent except for stray capacitances between bushing leads. The relatively low values of current and watts, which result from subtraction of relatively large meter readings, are subject to error, are of no practical significance, and should be disregarded once the existence of a shield has been verified.

Investigation of abnormal results should include supplementary tests at several voltages (see discussion under “General” – ”Test Voltages” on page 1-11.

Bushing Tests

Although bushings are included in C_H and C_L, the effect of a single bushing on the overall C_H or C_L measurement may be small, depending upon the relative capacitance of the bushing and the overall C_H or C_L component. The smaller the bushing capacitance with respect to the overall capacitance, the less its effect on the overall power factor. It is possible, therefore, that a defective bushing may go undetected in an overall test because of the masking effect of the winding capacitance. It is imperative, therefore, that separate tests be performed on all transformer bushings.

WARNING

The transformer windings must remain short-circuited for all bushing tests and all bushings associated with all unenergized windings should be grounded for safety.

Bushings with potential or power-factor taps may be tested separately by the UST method; bushings with draw-leads, shielded-layers, or insulated-heads may be tested by the Cold Guard method; bushings without such test facilities may be tested by the Hot-Collar technique. Refer to ”Bushings” on page 3-1.

Excitation-Current Tests

Tests on the windings and bushings in power and distribution transformers are supplemented by excitation-current measurements. Refer to ”Transformer Excitation-Current Tests” on page 5-44 in this section.

Liquid -Insulation Test

Samples of the insulating liquid are drawn from each separate transformer tank compartment (main tank, LTC compartment, etc.) and checked for power factor. Refer to ”Liquid Insulation” on page 10-1.

Leakage Reactance Test

A transformer winding may be displaced or distorted by the forces of a system disturbance, without burning or short-circuiting any turns. In this case, the best test that can be used to detect such a movement may be the Leakage Reactance test (see ”Leakage Reactance Testing” on page 5-71).

Autotransformers

For test purposes, an autotransformer is considered the same as a two-winding transformer with the following differences and special considerations:

- The high-voltage winding is in fact the combination of the high- and low-voltage windings (H and X), which cannot be separated physically. To short-circuit the high-voltage wincing, all seven bushings (three bushings for a single-phase unit) are connected together for test: H_1, H_2, H_3, X_1, X_2, X_3, and H_0X_0.
- With respect to the test procedure outlined in Figure 5.1 and Figure 5.2, the tertiary insulation (C_T) of an autotransformer is analogous to the low-voltage winding (C_L) of a conventional two-winding transformer.

- If only one leg of a three-phase tertiary winding is brought out through a bushing, the transformer may still be tested as a two-winding unit provided that the high-voltage winding is properly short-circuited. In this case, it is acceptable to make connections to the tertiary through the single (Y_1) bushing.
- If an autotransformer does not have a tertiary, or if no tertiary terminals are accessible, then only one Overall test to ground is performed.

Power factors are calculated in the normal manner for C_H, C_T, and C_{HT}. The calculated values are corrected for top-oil temperature using instructions and multipliers under “General” – ”Variation Of Power Factor with Temperature” on page 1-14. The analysis of winding-to-ground and interwinding test results is the same as described for ”Two-Winding Transformers” on page 5-7.

Separate tests should be performed on the bushings and oil, and excitation-current measurements should be performed on the windings, as outlined for a Wye-connected transformer for three-phase units, or the single-phase technique for single-phase units.

Three-Winding Transformer

Multiple Tests

DTA can perform multiple tests to save time. Just three multiple tests and one single test are needed to complete the overall insulation tests on a three winding transformer:

1. When starting with test one in the table below, the multiple tests are test one, test two, and test three.
2. When starting with test five, the multiple tests are test five, test six, and test seven.
3. When starting with test nine, the multiple tests are test nine, test ten, and test eleven.

Test Procedure

The standard Doble test procedure for three-winding transformers is outlined in Figure 5.4, Figure 5.5, and Figure 5.6. In the table below, the high voltage cable is placed on the winding in the Energize column. Both the red and the blue low voltage leads are used; one is placed on each of the other two windings not being energized. For an example, see the three smaller tables associated with each figure below.

If using DTA, you will be asked, for each series of multiple tests (1-3, 5-7, 9-11) on which winding you have placed the Red Low Voltage Lead, and on which winding you have placed the Blue Low Voltage Lead. An example follows below.

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	GAR	High	Low	Tert.	—	C_H+C_{HL}
2	GAR	High	—	Low, Tert.	—	C_H
3	UST	High	Tert.	—	Low	C_{HL}
4	Test 1 minus Test 2 (calculated)					C_{HL}
5	GAR	Low	Tert.	High	—	C_L+C_{LT}
6	GAR	Low	—	Tert., High	—	C_L
7	UST	Low	High	—	Tert.	C_{LT}
8	Test 5 minus Test 6 (calculated)					C_{LT}
9	GAR	Tert.	High	Low	—	C_T+C_{HT}
10	GAR	Tert.	—	High, Low	—	C_T
11	UST	Tert.	Low	—	High	C_{HT}
12	Test 9 minus Test 10 (calculated)					C_{HT}
13	GND	High, Low, Tert.	—	—	—	C_H+$C_{L+}$$C_T$

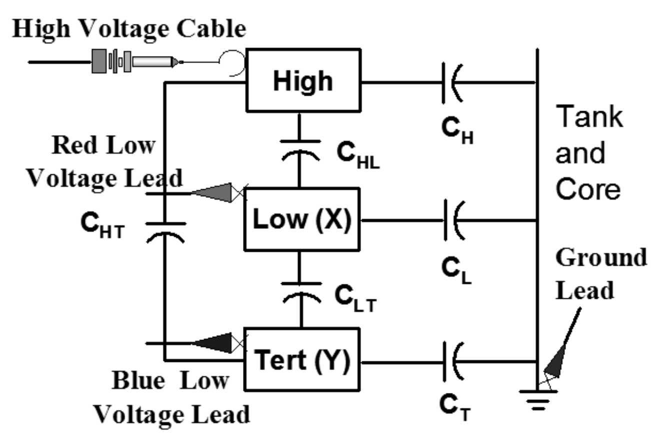


Figure 5.4 Three-Winding Transformer Connections, Tests 1, 2, 3

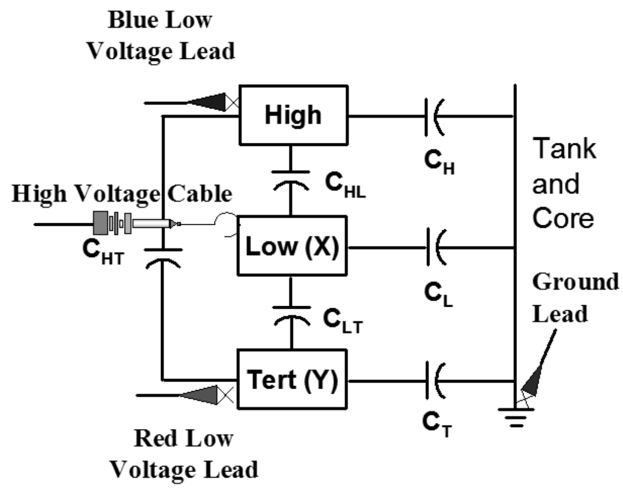


Figure 5.5 Three Winding Transformer Connections, Tests 5, 6, 7

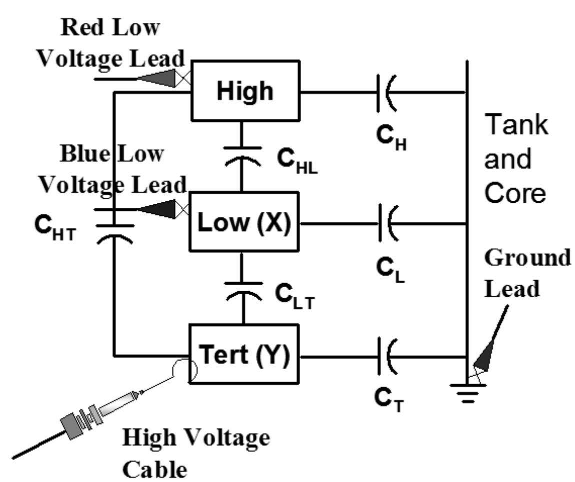


Figure 5.6 Three Winding Transformer Test Connections, Tests 9, 10, 11

The test technique for a three-winding transformer is an extension of the two-winding transformer test procedure. The following points should be noted:

1. The leads are rotated after every set of three tests, except for test 13.

2. Refer to Figure 5.4. Three-winding transformers are most conveniently tested using both Low-Voltage (LV) Leads (Red, R and Blue, B), although one LV Lead may be used in conjunction with the Guard and Ground terminals of the outboard pothead of the High-Voltage (HV) Test Cable. To illustrate the convenience of using two LV Leads for making the Overall tests on three-winding transformers, consider the Circuits chosen for tests 1, 2, and 3:

HV Cable connect to the High-Voltage Winding

LV Lead (Red) connect to the Low-Voltage (X) Winding

LV Lead (Blue) connect to the Tertiary (Y) Winding

Test No.	Energize	Ground	Guard	UST	Circuit Description
1	High	Low	Tert.	—	GAR-B
2	High	—	Low, Tert.	—	GAR-RB
3	High	Tert.*	—	Low	UST-R

* For UST, Guard and Ground are the same.

For the following table, refer to lead placement in Figure 5.5.

Test No.	Energize	Ground	Guard	UST	Circuit Description
5	Low (X)	Tert (Y)	High.	—	GAR-B
6	Low (X)	—	Tert, High	—	GAR-RB
7	Low (X)	High*	—	Tert (Y)	UST-R

* For UST, Guard and Ground are the same.

For the following table, refer to lead placement in Figure 5.6.

Test No.	Energize	Ground	Guard	UST	Circuit Description
9	Tert (Y)	High	Low (X)	—	GAR-B
10	Tert (Y)	—	High, Low	—	GAR-RB
11	Tert (Y)	Low*	—	High	UST-R

* For UST, Guard and Ground are the same.

3. Values of current (mA) and watts for C_{HL}, C_{LT}, and C_{HT} are calculated by subtraction: Test 1 minus Test 2, Test 5 minus Test 6, and Test 9 minus Test 10, respectively. These results are compared with the direct UST measurements for C_{HL}, C_{LT}, and C_{HT}, respectively (Tests Nos. 3, 7, and 11).
4. As a cross check on the winding-to-ground measurements, Test 13 includes the parallel combination of C_H, C_L, and C_T, in which all three windings are connected together, and energized together, making one measurement to ground for the three.

NOTE **Do not exceed the allowed test voltage for the lowest voltage winding included in Test 13.**

5. Power factors are calculated in the normal manner for the winding-to-ground and interwinding insulations. The calculated values are corrected for top-oil temperature, using instructions and multipliers included under “General” – ”Variation Of Power Factor with Temperature” on page 1-14.
6. In some cases a Three-Winding Transformer is so constructed that one of the interwinding capacitances is practically non-existent. This condition may be the result of a grounded electrostatic shield between two windings, or of a concentric-winding arrangement which places one winding between two others. The effect of the grounded shield of the sandwiched winding is to effectively eliminate the interwinding capacitance except for stray capacitances between bushing leads. The relatively low values of current and watts which result are determined by subtraction of relatively large meter readings, are subject to considerable error, are of no practical significance, and should be disregarded once the existence of a shield or a concentric-winding arrangement is verified.

Analysis Of Results

The analysis of the test results is the same as described for ”Two-Winding Transformers” – ”Analysis of Test Results” on page 5-10.

Separate power-factor tests are performed on bushings and oil, and excitation-current measurements performed on the windings as outlined under ”Transformer Excitation-Current Tests” on page 5-44 in this section.

For additional information on transformer maintenance and testing, refer to Doble Indexes of Minutes for a listing of papers in *Doble Client Conference Minutes*. Also refer to the *Doble Transformer Maintenance and Test Guide.*

Shunt Reactors

Oil-filled shunt reactors are employed on HV and EHV systems to limit over-voltage surges associated with long transmission lines. Each phase may be contained in its own separate tank, or all three phases may be contained in a common tank. In the latter type, each phase may have its own neutral bushing, or the phases may be inseparable and all be connected to a common neutral (H_{01}, H_{02}, and H_{03} would be replaced by one common neutral, H_0. Refer to Figure 5.7.

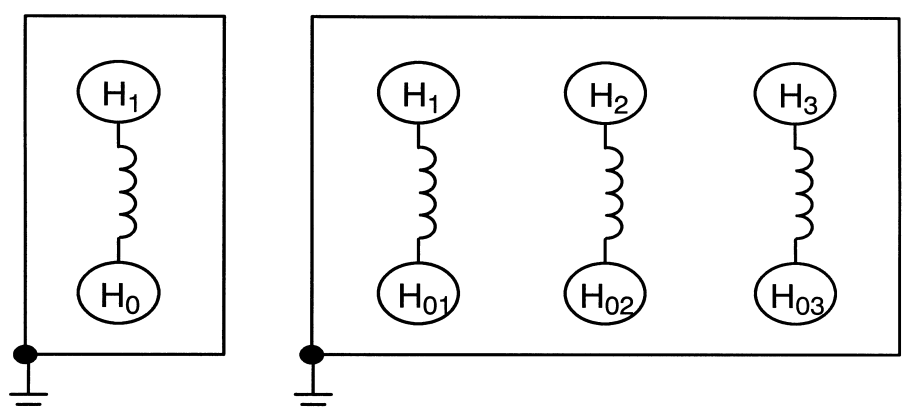


Figure 5.7 Shunt Reactors

Test Procedure

For a single-phase unit, only one Overall measurement is made, by short-circuiting H_1 and H_0 and making a GST measurement to ground (high voltage cable energizes the winding, current returns through test set test ground lead).

If using DTA, the user must select *Configuration* on the Reactor ID panel (Separable or Inseparable phases). The test procedure for a three-phase unit is as follows:

Common Neutral

If the phases are all connected to a common neutral bushing and are inseparable:

1. The neutral is isolated from ground.
2. All bushings are connected together and energized.
3. The measurement is made to ground using a GST-Ground circuit as with the single phase unit above.

Separable Phases, Neutrals Not Common

The test procedure is similar to that for a three winding transformer. The high voltage cable is placed on the phase in the **Energize** column, and the red and blue low voltage leads are each placed on one of the other phases. If using DTA, follow the prompts as described under test procedures for three winding transformers. Multiple tests are performed as with three winding transformers.

Table 5.4 Test Procedure for Three-Phase Shunt Reactors Corresponding Line and Neutral Bushings of Each Phase are Short-Circuited

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	Guard	H_1H_{01}	H_2H_{02}	H_3H_{03}	—	$C_1 + C_{12}$
2	Guard	H_1H_{01}		H_2H_{02} H_3H_{03}		C_1
3	UST	H_1H_{01}	H_3H_{03}	—	H_2H_{02}	C_{12}
4	Guard	H_2H_{02}	H_3H_{03}	H_1H_{01}	—	$C_2 + C_{23}$
5	Guard	H_2H_{02}	—	H_1H_{01} H_3H_{03}	—	C_2
6	UST	H_2H_{02}	H_1H_{01}		H_3H_{03}	C_{23}
7	Guard	H_3H_{03}	H_1H_{01}	H_2H_{02}		$C_3 + C_{31}$
8	Guard	H_3H_{03}	—	H_1H_{01} H_2H_{02}		C_3
9	UST	H_3H_{03}	H_2H_{02}	—	H_1H_{01}	C_{31}
10	Ground	H_3H_{03} H_2H_{02} H_1H_{01}	—	—	—	$C_1 + C_2 + C_3$ (All)

The overall winding power factors should be corrected for top oil temperature, using the Doble curve labeled *Oil-Filled Power Transformers (Sealed, Gas-Blanketed, and Modern Conservator Types Rated 210 kV and Up, Above 750 kV BIL).* Winding power factors are analyzed in the same manner as power transformers.

Overall test results are supplemented by tests on the bushings by UST, Hot-Collar, or other applicable methods, by tests on oil samples, and by excitation-current measurements on the individual phases (H_1 to H_{01}, etc.).

NOTE **For all tests on the windings and bushings (except for the excitation-current tests), the winding(s) must be short-circuited.**

Sometimes it is advantageous to investigate abnormal results by making a series of tests at several voltages to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV.

Compared with power transformers, the windings of shunt reactors have very low AC impedance. In some cases, it may be possible to perform the excitation-current measurements at a reduced test voltage, perhaps in the range of 500 volts or 1 kV.

Potential Transformers

Introduction

Potential transformers (PTs) find widespread use on high-voltage power systems for voltage indication in applications involving metering and relaying. Doble tests are performed routinely on bushing and winding insulation of this equipment. Because of the low-voltage rating of PT secondaries, Doble tests on this equipment are generally confined to the primary side.

In order to make Doble tests on a potential transformer, the unit is de-energized and the line terminal(s) are grounded before any attempt is made to isolate any terminals. Since the secondaries of two or more PTs may be paralleled, voltage can be back-fed through the secondaries to produce a high voltage across the primary winding on a seemingly de-energized unit. In addition to isolating and grounding line terminal(s) of the primary winding, secondary fuses and other leads should be removed to isolate the unit from the system completely and effectively.

Test Voltage

For PTs designed for line-to-line operation, the test voltage is determined on the basis of the operating voltage which normally exists between the line terminals and ground.

For PTs designed for line-to-ground operation, the test voltage is generally limited by the voltage rating of the neutral terminal. The neutral may be rated 5 kV, and perhaps less. It is preferable to perform the various tests on each PT at the same voltage. For the Cross-Check test with the neutral bushing connected to guard, a higher test voltage may be applied, since the neutral is essentially at ground potential for these measurements.

The two exciting current tests must be made at the same voltage for purposes of comparison. In the case of line-to-ground PTs, this test voltage is limited by the rating of the neutral bushing, usually 5 kV or less.

Liquid-Filled Line-to-Ground PTs

For all kV ratings, a complete series of tests (as outlined later in this section for the appropriate PT type) is performed at the voltage permitted by the neutral-terminal rating. Usually, this is 5 kV or less. In addition, the Cross-Check test with the line terminal(s) energized, and H_0 guarded, is made at 10 kV, or at the rated transformer line-to-ground voltage, whichever is lower.

Liquid-Filled Line-to-Line PTs

For units rated 15 kV insulation class (e.g., 14.4 kV units) and above, perform the complete series of tests (as outlined later in this section for the appropriate PT type) at 10kV.

For units rated below 15 kV insulation class (i.e. units below 12 kV nameplate rating), select a convenient test voltage which is equal to or below the nameplate voltage rating.

Table 5.5 Recommended Doble Test Voltages for Liquid-Filled Line-to-line PTs

Line-to-line PTs Rated Below 15 Kv Insulation Class	
PT Voltage Rating (kV)	**Test Voltage (kV)**
7.2 to 8.7	5.0
4.2 to 5.0	2.5
2.4	2.0

Sometimes it is useful to investigate abnormal results on these units (all ratings) by making a series of tests at several voltages, to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV in the case of units normally tested at 10 kV.

Dry-Type Line-to-Ground PTs

For all kV ratings, a complete series of tests (as outlined later in this section for the appropriate PT type) is performed at the same voltage. The voltage selected must not exceed the rating of the neutral terminal. Usually, this is 5 kV or less. In addition, the Cross-Check test with H_1 energized and H_0 guarded is repeated at 10 kV or at the transformer rated line-to-ground voltage, whichever is lower.

Dry-Type Line-to-LinePTs

For units rated above 15 kV insulation class, the complete series of tests (as outlined later in this section for the appropriate PT type) is performed at 2 kV and 10 kV.

For units rated 15 kV insulation class and below, the various tests (as outlined later in this section for the appropriate PT type) should be performed at the following test voltages:

Table 5.6 Recommended Doble Power-factor Test Voltages For Dry-Type Line-to-Line PTs (Rated 15 Kv Insulation Class and Below)

Test Designation	Test Voltages
Overall	a. 2 kV
	b. Line-to-Ground Operating Voltage
	c. 10% to 25% Above Line-to-Ground Operating Voltage
Cross-Check	a. 2 kV
	b. Line-to-Ground Operating Voltage
Exciting Current	Line-to-Ground Operating Voltage

Single-Phase Potential Transformers

Test Procedure

A single-phase potential transformer is shown in Figure 5.8.

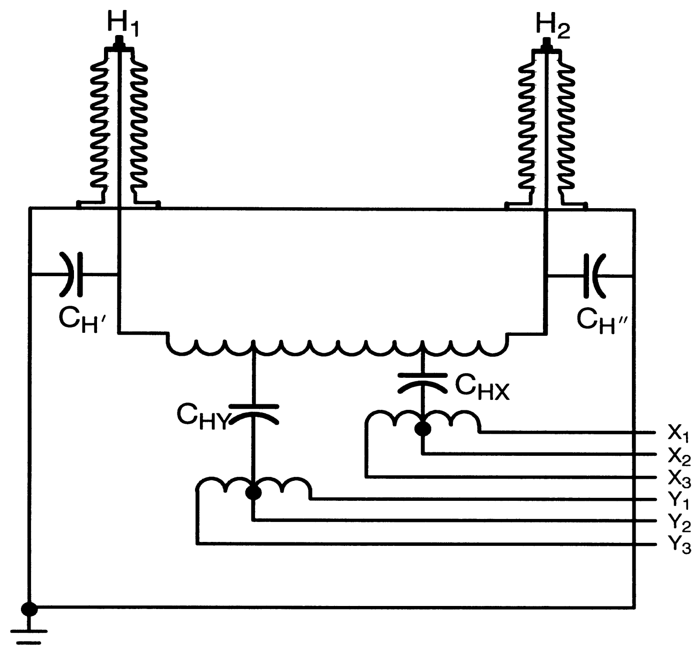


Figure 5.8 Single-Phase Potential Transformer

Multiple Tests

DTA can perform multiple tests at once to save time:

1. For test one, the second test of a multiple test is a repeat of test one at 2 kV; if testing at 2 kV to begin with, select Single Test for test one.
2. For test two, the multiple tests are test two and test four as shown in the procedure below.
3. For test three, the multiple tests are test three and test five.
4. If multiple tests are selected, then all test voltages must be limited by the rating of the neutral bushing. If you wish to run test 2 at a higher voltage, then select “Single” test for this test, and run tests 2 and 4 separately.

The Doble test procedure for single-phase potential transformers is outlined below. For test 1, the high voltage cable energizes the PT primary which has been short-circuited. For tests 2 to 5, the shorting jumper cable is removed, and the high voltage cable is placed on the bushing in the **Energize** column, while a low voltage lead is placed on the bushing in the **Guard** or the **UST** column. The two exciting current tests, tests 4 and 5, must be made at the same test voltage to enable comparison of results.

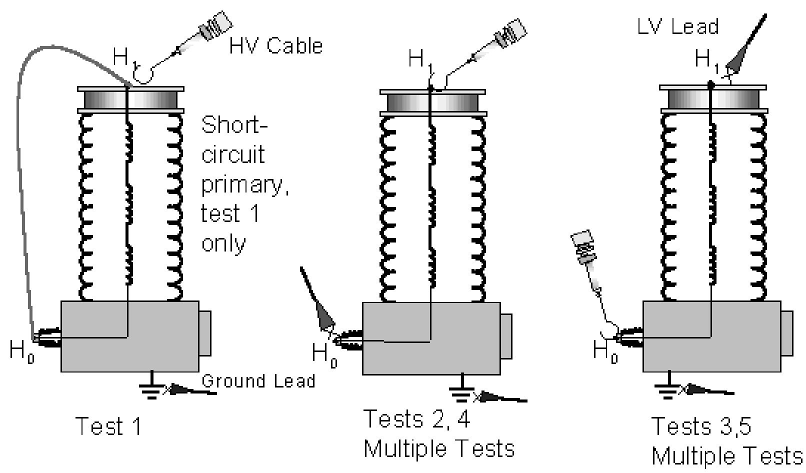


Figure 5.9 PT Test Connections

Table 5.7 Test Procedure for Single-Phase Potential Transformers

Test No.	Test Mode	Energize	Ground	Guard	UST	Test Description
$1^{(5)}$	GST	$H_1H_2^{(2)}$	X_1Y_1	—	—	Overall
2	GST	H_1	X_1Y_1	$H_2^{(2)}$	—	H_1 Cross-Check$^{(3)}$
3	GST	$H_2^{(2)}$	X_1Y_1	H_1	—	H_2 Cross-Check$^{(3)}$
4	UST	H_1	X_1Y_1	—	H_2 H_{02}	Excitation H_1 to H_2
5	UST	$H_2^{(2)}$	X_1Y_1	—	H_3 H_{03}	Excitation H_2 to H_1
6	Supplementary Hot-Collar tests on the primary line-terminal buildings[4]					

NOTE

(1) All secondary leads not indicated are isolated at the secondary terminal box of the PT and left floating (i.e., ground only one leg of each secondary winding, and let the other secondary terminals float). Also, if the unit under test is a spare, or is otherwise not installed in service position, then apply an external ground to the device housing.

(2) Some manufacturers may designate the H_2 bushing as H_0, especially if it is a neutral bushing on a line-to-ground PT.

(3) For the Cross-Check tests the test potential is graded along the winding, from full test potential on the energized bushing to approximately zero voltage on the guarded bushing and winding end.

(4) Supplementary Hot-Collar tests are regularly performed on the primary line-terminal bushings if these bushings are solid porcelain, compound-filled, and bushings of molded-type PTs. Hot-Collar tests may be performed on other bushing types when investigating abnormal Overall and Cross-Check results. Refer to 3."Bushings" – "Hot-Collar Tests" on page 3-5.

(5) An alternate test can be used when bushing positioning doesn't allow short-circuiting the primary winding for test 1, under "Cascade Potential Transformers" on page 5-29.

To perform Test 1, short-circuit the primary winding, ground the secondaries, then connect the High-Voltage Test Cable to the primary and energize. The circuit description is GND-RB. A Low-Voltage (LV) Lead is not used in Test 1, but is used for Tests 2 through 5. To perform Test 2, remove the short-circuit jumper from across the primary winding, then connect the HV Cable to H_1 and the LV Lead to H_2, with the test set circuit description set to GAR-RB. Then, set the circuit description to UST-RB and perform Test 4, one of two of the excitation-current measurements. After completing Tests 2 and 4, de-energize the test set and move the HV Cable to H_2 and the LV Lead to H_1. Perform Tests 3 and 5 in the manner described above for Tests 2 and 4.

WARNING

The ground terminal H_0 must be reconnected to ground before returning the Single Phase Metering Outfit to service.

The current and watts are recorded for Tests 1, 2, and 3, and the power factors are calculated. The current (i.e., the excitation current) only is recorded for Tests 4 and 5. If the unit is oil-filled, then the calculated power factors are corrected for ambient temperature using the curve labeled: *Oil-Filled lnstrument Transformers*. The power factors of askarel-filled PTs are corrected for temperature using the curve labeled: *Askarel and Askarel-Filled Transformers*. Refer to the discussion under “General” – ”Variation Of Power Factor with Temperature” on page 1-14. The measured Overall and Cross-Check power factors of dry-type PTs are not corrected for temperature.

Analysis of Results

The corrected Overall power factor should be compared with the results of previous tests (if any), with results recorded for other similar units on the system, and with data tabulated in the Instrument Transformer section of the *Test-Data Reference Book.*

For most PTs, both Cross-Check power factors compare closely with the Overall power factor. In some units it is normal for one Cross-Check power factor to be higher than the Overall. This is exemplified somewhat by the data shown for a *Typical Good Unit* under the discussion later of ”Cascade Potential Transformers” on page 5-29. This pattern may also occur in non-cascade PTs; for example, General Electric Company Type ES.

The Cross-Check tests provide useful supplementary data, particularly when the Overall test results are questionable. For example, if the Overall power factor is higher than expected, then the Cross-Check tests will help to differentiate between a general condition or one localized in a bushing or one end of a winding. Note the following example:

Table 5.8 Test Results on Single-Phase Potential Transformers

Normal Units

Test No.	mA	Watts	% Power Factor
1 (Overall)	2.540	0.104	0.41
2 (H_1 Cross-Check)	1.256	0.056	0.45
3 (H_2 Cross-Check)	1.248	0.046	0.37

Suspect Units

Test No.	mA	Watts	% Power Factor
1 (Overall)	2.650	0.350	1.32
2 (H_1 Cross-Check)	1.356	0.313	2.31
3 (H_2 Cross-Check)	1.248	0.055	0.44

The results on the Suspect Unit above indicate a problem with the H_1 bushing itself or, possibly, deterioration or contamination in an area of the primary winding relatively close to the H_1 terminal.

In the examples above, note that the sum of the two Cross-Check current (mA) and watts values (not power factor) approximately equal the Overall values. Failure of the results to agree may be the result of internal winding problems (open circuits) or poor connections at bushing terminals.

Thus, this technique is not only effective in determining the location of insulation or winding problems, but is also helpful in verifying that the Overall and Cross-Check tests were performed correctly, and that the various readings were properly calculated and recorded.

Supplementary Tests

While conventional Overall and Cross-Check tests often provide complete information, other supplementary tests (below) may occasionally be used to further pinpoint the source of abnormally high losses and power factor.

Table 5.9 Supplementary Tests for Single-Phase Potential Transformers

Test No.	Test Mode	Energize	Ground	Guard	UST	Test Description
6	UST	$H_{1,}H_2$	Y_1	—	X_1	C_{HX}
7	UST	$H_{1,}H_2$	X_1	—	Y_1	C_{HY}
8	GST	H_1	—	$H_2X_1Y_1$	—	Bushing H_1
9	GST	H_2	—	$H_1X_1Y_1$	—	Bushing H_2

For Tests 6, 7, 8, and 9, the current and watts are recorded, and the power factors are calculated and corrected for temperature, if applicable. Tests 6 and 7 are direct measurements of the interwinding insulations. Tests 8 and 9 are similar to Tests 2 and 3, respectively, except for the elimination of interwinding insulation losses, thus making these measurements more sensitive to the condition of the primary bushings alone. Tests 8 and 9 would not be performed if conventional UST measurements are made on the H_1 and H_2 bushings with taps.

Hot Collar Tests

Single and/or Multiple Hot-Collar tests are regularly performed on the primary line-temminal bushings if the bushings are solid porcelain, compound-filled, and of molded-type PTs. Hot-Collar tests may be performed on other bushing types when investigating abnormal Overall and Cross-Check results. Refer to 3.”Bushings” – ”Hot-Collar Tests” on page 3-5.

Excitation-Current Tests

The excitation-currents obtained for Tests 4 and 5 should compare with each other. This measurement detects internal winding and core problems as described under ”Transformer Excitation-Current Tests” on page 5-44.

Liquid Insulation Tests

Investigation of abnormal results on liquid-filled PTs may include separate power factor and other screen tests on a representative sample of the insulating liquid. Drawing of liquid samples may not be feasible, and must take into account the total liquid volume of the unit, which may be small.

Investigation of abnormal test results on PTs generally should include supplementary tests at several voltages (see discussions under “General” – ”Test Voltages” on page 1-11).

Single-Phase Potential Transformer With Internal Primary Ground

In some single-phase PTs, the neutral of the primary winding is grounded internally (Figure 5.10).

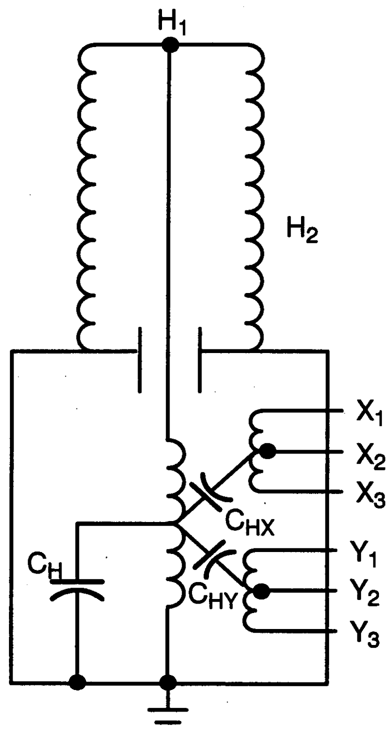


Figure 5.10 Single-Phase PT with Internally. Grounded Neutral

Test Procedure

A standard Overall power-factor test is not possible on the PT shown in Figure 5.10. Power-factor and excitation-current tests can be performed as outlined below:

Table 5.10 Modified Test Procedure For Single-Phase PTs

With Internally Grounded Primary Neutral

Test No.	Test Mode	Energize	Ground	Guard	UST	Test Description
1	UST	H_1	H_0	—	X_1, Y_1	Line-end interwinding insulation
2	GST	H_1	H_0	X_1, Y_1	–	Excitation current

Cascade Potential Transformers

In cascade potential transformers, the primary winding consists of a number of winding sections connected in series, in which the secondary winding is inductively coupled only to the last or bottom-most section of the primary as shown in Figure 5.11.

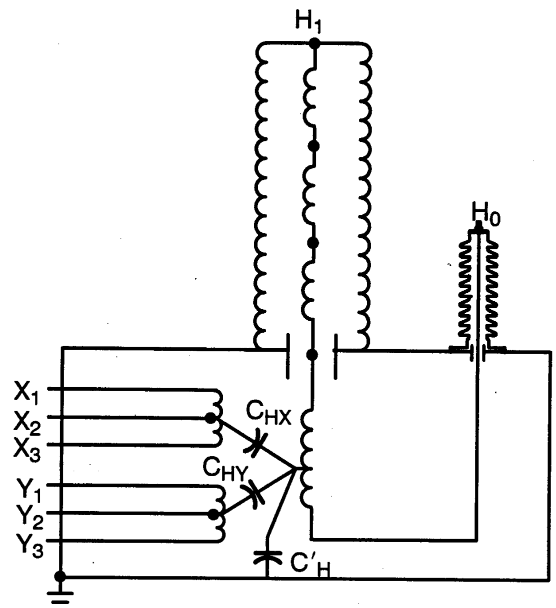


Figure 5.11 Cascade Potential Transformer

Test Procedure

The standard test technique and analysis of results for cascade (line-to-ground) potential transformers is the same as for conventional units. In some cascade PTs it may be difficult to short-circuit H_1 and H_0 for the Overall test. An alternative procedure for performing the Overall test on this type of unit is outlined below:

Table 5.11 Cascade Potential Transformers

Alternative Method for Performing Overall Tests

Test No.	Test Mode	Energize	Ground	Floating	Test Description
1A	GST	H_0	X1, X3 Y1, Y3	H_1	Overall

The secondaries must be short-circuited and grounded for this test only!
Tests 2 through 5 same as for conventional PT (see page 5-21).

The alternative Overall technique outlined above requires that the secondaries be short-circuited and grounded. The short-circuited secondaries cause the primary to be effectively short-circuited by transformer action, thereby allowing a proper test result to be obtained.

WARNING

The ground terminal H_0 must be reconnected to ground before returning the Single Phase Metering Outfit to service.

Analysis Of Results

In a cascade PT, the capacitance to ground at the H_1 end is often substantially lower than the capacitance to ground at the H_0 end. Because of the low capacitance and losses normally associated with the H_1 Cross-Check test, this measurement may be influenced by surface leakage, thereby producing a pattern whereby the Overall and H_2 Cross-Check power factors are acceptably low, but where the H_1 Cross-Check power factor is seemingly high, as shown in the following example:

Table 5.12 Test Results on Cascade Potential Transformers

Good Units

Test No.	mA	Watts	% Power Factor
1 (Overall)	3.040	0.152	0.50
2 (H_1 Cross-Check)	0.278	0.0312	1.12
3 (H_2 Cross-Check)	2.810	0.128	0.46

Questionable Units

Test No.	mA	Watts	% Power Factor
1 (Overall)	3.080	0.181	0.58
2 (H_1 Cross-Check)	0.311	0.0682	2.19
3 (H_2 Cross-Check)	2.810	0.128	0.46

With one exception, the analysis of Doble test data for cascade potential transformers is the same as for conventional units. Because of the relatively low current usually recorded for Test 2 as illustrated above for a *Typical Good Unit*, the results recorded for this measurement should be analyzed on the basis of watts. That is, the watts-loss recorded for Test 2 is compared with previous tests (if any), and with the watts recorded for other similar units on the system. Thus, for cascade PTs, it is misleading to compare the H_1 Cross-Check power factor with the corresponding Overall power factor or with the data tabulated in the Instrument Transformer section of the *Test-Data Reference Book*, which is based solely on Overall power factors.

In the example above for the *Questionable Unit*, a retest should be performed after cleaning and drying the H1 porcelain surface. Refer to the discussion in the section under “General” – ”Surface Leakage” on page 1-27.

Three-Phase Potential Transformers

Test Procedure

The test procedure for a three-phase potential transformer (three line-voltage bushings and one neutral bushing in a single grounded tank) is as follows:

Table 5.13 Test Procedure for Three-Phase Potential Transformers

Test No.	Test Mode	Energize	Ground*	Guard	UST	Test Description
1	GST	H_1, H_2, H_3, H_0	X_1, Y_1	—	—	Overall
2	GST	H_1	X_1, Y_1	H_0, H_2, H_3	—	H_1 Cross-Check
3	GST	H_2	X_1, Y_1	H_0, H_1, H_3	—	H_2 Cross-Check
4	GST	H_3	X_1, Y_1	H_0, H_1, H_2	—	H_3 Cross-Check
5	GST	H_0	X_1, Y_1	H_1, H_2, H_3	—	H_0 Cross-Check
6	UST	H_1	X_1, Y_1	H_2, H_3	H_0	Excitation H_1 to H_0
7	UST	H_2	X_1, Y_1	H_1, H_3	H_0	Excitation H_2 to H_0
8	UST	H_3	X_1, Y_1	H_1, H_2	H_0	Excitation H_3 to H_0
9	Supplementary Hot-Collar tests on the primary bushings					

*Terminals of the secondaries not indicated are left floating for all tests

The power factor is recorded for Tests 1 through 5, and corrected for ambient temperature, whereas only the charging current is recorded for the excitation-current tests (Tests 6, 7, and 8). The analysis of the results for a three-phase potential transformer is similar to a single-phase unit.

NOTE

The sum of the current and watts for the four Cross-Check tests (Tests 2, 3, 4, and 5) should approximate the current and watts obtained for Overall test 1.

In designs where the oil in the line bushings is common with the oil in the main tank, supplementary Hot-Collar tests must be performed on the three line bushings, with particular emphasis on the charging current, to determine that each bushing has the proper level of oil.

Investigation of abnormal results on all liquid-filled PTs may include separate power factor and other screen tests on a representative sample of the insulating liquid.

Current Transformers

Introduction

Current transformers (CTs) vary in voltage rating, up to the highest system voltages now in operation. HV and EHV units are generally of the oil-filled variety. Lower voltage units may be oil-filled, askarel-filled, or dry type. The following discussion deals with all CT designs except for the “donut” type, which is not generally Doble tested.

Test Voltage

Liquid -filled CTs

For units rated 15 kV insulation class, and above, test at 10 kV. Sometimes it is useful to investigate abnormal results on these units by making a series of tests at several voltages to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the voltage to 12 kV.

For units rated below 15 kV insulation class, select a convenient whole number test voltage which is equal to or below the nameplate voltage rating.

Dry-Type CTs

For units rated above *15* kV insulation class, perform tests at 2 and 10 kV.

For units rated 15 kV insulation class and below, perform tests as follows:

Recommended Doble Test Voltages for Dry-Type CTs

Rated 15 kV Insulation Class and Below

1. 2kV
2. Line-to-ground operating voltage
3. 10% to 25% above line-to-ground operating voltage

Test Procedure

Current transformers have a primary high-voltage conductor which may consist of single or multiple turns. The primary should be short-circuited for Doble tests, and all low-voltage secondary windings should be grounded (they may be short-circuited too, but this is not necessary). For CTs tested in storage, the frame must be grounded externally.

For routine tests, the test voltage is applied to the primary and the current and watts-loss to ground are recorded. The power factor is calculated. No low voltage lead is required, since the test set test ground lead is used as the return.

Some HV and EHV CTs are equipped with taps similar to those on bushings. For these units, in addition to the Overall test, supplementary Ungrounded-Specimen Tests (UST) should be performed on the main insulation C_1, along with a test on the tap insulation C_2 (the test potential applied to the tap must not exceed the voltage rating of the tap); refer to ”Bushings” on page 3-1. These CTs often have nameplate values of power factor and capacitance for C_1 and C_2.

For molded-type CTs, the Overall test is supplemented by Hot-Collar tests on the bushings.

Testing A Free-Standing CT Without Disconnecting From Attached Switch Or Breaker

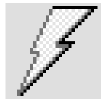
With the advent of the M4000 and its ability to eliminate the effect of electrostatic interference, it may not be necessary to disconnect attached Circuit Breakers or Disconnect Switches. When testing a CT, the standard GST-Ground circuit cannot be used, since the attached apparatus must be guarded out of the measurement circuit. Instead, use the Low Voltage Leads to Guard them, as follows:

1. To guard a T or Y style live tank breaker, attach a Low Voltage Lead to the breaker head on the opposite side of the interrupter attached to the CT.

2. To guard a Candlestick breaker, attach a Low Voltage Lead to the point on the breaker between the interrupter porcelain and the support porcelain.

3. To guard a Disconnect Switch, place a Low Voltage Lead at a point between porcelains in each insulator stack which is attached to the CT. If the porcelain insulators supporting the switch are of only one unit, then use a guard collar, cleaning and drying the porcelain well before applying the collar. Each insulator stack attached to the CT must be guarded.

4. In each case, after placing the necessary Low Voltage Leads, use a GST-Guard circuit to include all leads used.

If using DTA, modify the preset GST-Ground circuit. After starting a test by clicking the  icon, the *Setup* window contains fields for the test kV and circuit. Select a GST-Guard circuit.

Analysis Of Results

The CT power factor is corrected for temperature. Power factors are corrected based on the ambient temperature at the time of test. Oil-filled units use the curve labeled *Oil-Filled Instrument Transformers*, while askarel-filled units are corrected using the curve labeled *Askarel*. Dry-type units are not corrected for temperature.

The corrected power factors should be compared with previous test results (if any), with data recorded for other similar units on the system, against factory or nameplate data (if any), and with the data tabulated for similar units in the Instrument Transformer section of the *Test-Data Reference Book*. Dry-type CTs are further analyzed on the basis of power-factor tip-up.

Investigation of abnormal results on liquid-filled CTs may include separate power factor and other screen tests on a representative sample of the liquid. Drawing of liquid samples may not be feasible, and must take into account the total liquid volume of the unit, which may be small.

Single Phase Metering Outfits

Introduction

Single-phase metering outfits combine a CT and a PT in the same housing. One top terminal of the CT (H_1) is also the top terminal of the PT (P_1). The other top terminal is the second terminal of the CT (H_2). The second terminal of the PT (H_3 or P_0) is a small bushing at the base of the metering outfit (it may be located inside a terminal box) which is grounded in service (connected to the housing via a grounding link or strap) and should be disconnected from ground to perform the tests. Nameplates and instruction manuals should be carefully examined prior to the tests, as the nomenclature varies among the different manufacturers. The following shows a typical arrangement:

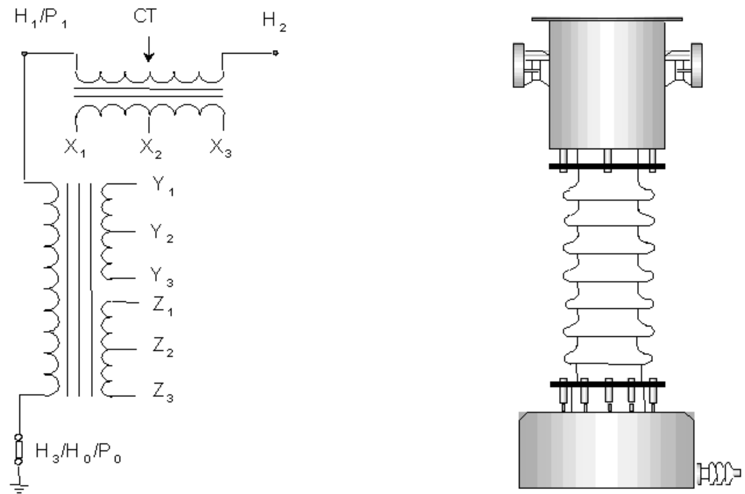


Figure 5.12 Single Phase Metering Outfit

Test Voltages

For tests 1, 3, and 5, the applied test voltage must not exceed the manufacturer's rating for the neutral (H3) terminal, usually 5 kV or less.

Sometimes it is productive to investigate abnormal results on MOs (all ratings) by making a series of tests at several voltages, to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV in the case of units normally tested at 10 kV. Due to limitations of the H3 terminal, the only test on which such voltages may be applied is test 2.

Tests 4 and 5 must be performed at the same voltage in order to have a suitable comparison. The test voltage will be limited by the H3 terminal rating.

Test Procedure

In preparation for testing, one end of the CT secondary, as well as one end of each PT secondary, must be grounded. If using DTA, the form for PT's is used.

Multiple Tests

DTA can perform multiple tests at once to save time:

1. For test one, the second test of a multiple test is a repeat of test one at 2 kV; if testing at 2 kV to begin with, select Single Test for test one.

2. For test two, the multiple tests are test two and test four as shown in the procedure below.
3. For test three, the multiple tests are test three and test five.
4. If multiple tests are selected, then all test voltages must be limited by the rating of the neutral bushing. If you wish to run test 2 at a higher voltage, then select “Single” test for this test, and run tests 2 and 4 separately.

The test procedure for the single phase metering outfit is similar to that of the PT: For test 1, the high voltage cable energizes the Metering Outfit primary which has been short-circuited. For tests 2 to 5, the shorting jumper cable is removed, and the high voltage cable is placed on the bushing in the **Energize** column, while a low voltage lead is placed on the bushing in the **Guard** or **UST** column. The two exciting current tests, tests 4 and 5, must be made at the same test voltage to enable comparison of results. The procedure is as follows:

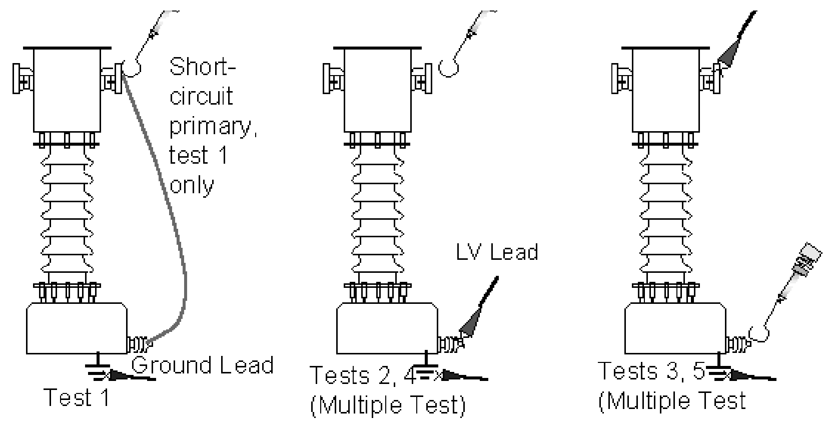


Figure 5.13 Single Phase Metering Outfit Test Connections

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Table 5.14 Test Procedure For Single Phase Metering Outfits

Test Number	Energize	Ground	Guard	UST
1 (Overall)	H1/P1, H2 and H3*	X1, X3 and Y1, Z1	--------	-------
2 (H1/P1 Crosscheck)7	H1/P1	X1, X3 and Y1, Z1	H3	--------
3 (H3 Crosscheck)7	H3*	X1, X3 and Y1, Z1	H1/P1	--------
4 (H1/P1 Excitation)	H1/P1	X1, X3 and Y1, Z1	--------	H3
5 (H3 Excitation)	H3*	X1, X3 and Y1, Z1	--------	H1/P1

6 Hot-Collar tests on bushings, as indicated.

7 Liquid tests, if indicated.

* The H3, or ground terminal, may have a lower voltage rating than the H1 or H2 bushings, and should be tested at 5 kV or less.

In some cases, a by-pass protector (or surge arrester) will be found connected across the primary CT winding. This protector should be disconnected during testing, or the CT primary should be short-circuited.

NOTE

(1) All secondary leads not indicated are isolated at the secondary terminal box of the PT and left floating (i.e., ground only one leg of each secondary winding, and let the other secondary terminals float). Also, if the unit under test is a spare, or is otherwise not installed in service position, then apply an external ground to the device housing.

(2) Some manufacturers may designate the H_2 bushing as H_0, especially if it is a neutral bushing on a line-to-ground PT.

(3) For the Cross-Check tests the test potential is graded along the winding, from full test potential on the energized bushing to approximately zero voltage on the guarded bushing and winding end.

(4) Supplementary Hot-Collar tests are regularly performed on the primary line-terminal bushings if these bushings are solid porcelain, compound-filled, and bushings of molded-type PTs. Hot-Collar tests may be performed on other bushing types when investigating abnormal Overall and Cross-Check results. **Refer to 3.”Bushings” – ”Hot-Collar Tests” on page 3-5.**

(5) An alternate test can be used when bushing positioning doesn't allow short-circuiting the primary winding for test 1, under "Cascade Potential Transformers" on page 5-29.

WARNING

The ground terminal H3 must be reconnected to ground before returning the Single Phase Metering Outfit to service.

Analysis of Results

Analysis for Single Phase Metering Outfits is the same as for the Single Phase PT.

Three-Phase Metering Outfits

Introduction

The high-voltage winding of a three-phase Metering Outfit (MO) usually consists of two current windings and two potential windings, located in a common liquid-filled tank, as shown in Figure 5.14. In addition, there are secondary windings. In view of their relatively low (voltage) rating, tests generally are not performed on the secondaries.

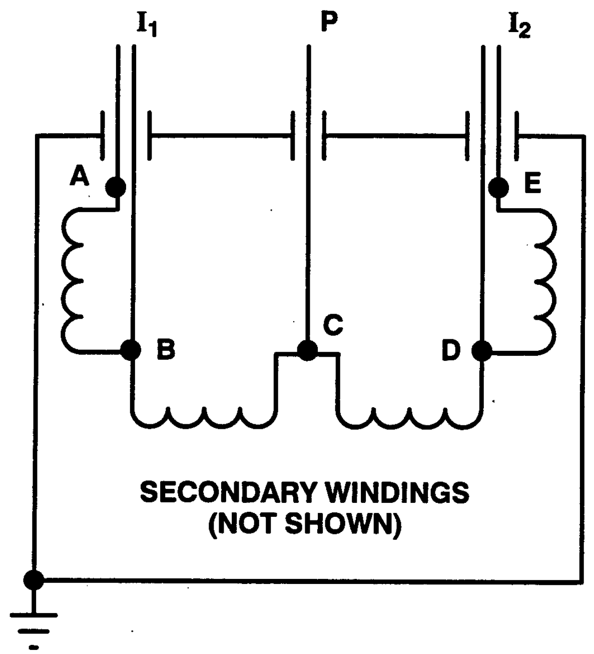


Figure 5.14 Metering Outfit

The two leads from the current winding A-B are brought up through bushing I_1, and the two leads from the current winding D-E are brought up through bushing I_2. One end of each of the potential windings B-C and D-C is connected to the stud of the third bushing P. The other end of each potential winding is connected to the corresponding current winding, and hence to the bushings I_1 and I_2.

The precautions to be observed when testing potential transformers also apply to metering outfits. All terminals of the primary and secondary windings must be completely isolated from the power system. See 5."Transformers, Reactors, and Regulators" – "Potential Transformers" on page 5-19.

Test Voltages

For MOs rated 15 kV insulation class (e.g., 14.4 kV units), and above, perform all tests at 10 kV.

For liquid-filled units rated below 15 kV insulation class (i.e., units below 12 kV nameplate rating), select a convenient test voltage which is equal to, or below, the nameplate voltage rating.

For units which may be dry-type, refer to discussion under ”Current Transformers” – ”Dry-Type CTs” on page 5-32.

Sometimes it is productive to investigate abnormal results on MOs (all ratings) by making a series of tests at several voltages, to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV in the case of units normally tested at 10 kV.

Test Procedure

For testing, both current windings should be short-circuited. This can be accomplished by short-circuiting the winding terminals at the caps of bushings I_1 and I_2. In some cases, four connections are brought up through the bushing. This is done in order that a double winding may be connected either in series or in parallel.

For all tests, one side of each secondary winding is connected to ground, with the other secondary terminals floating.

The test procedure for a three-phase metering outfit is as follows:

Table 5.15 Test Procedure for Three-Phase Metering Outfits

Test No.	Test Mode	Energize	Ground*	Guard	UST	Test Description
1	GST	I_1, P, I_2	X_1, Y_1	—	—	Overall
2	GST	I_1	X_1, Y_1	P, I_2	—	I_1 Cross-Check
3	GST	P	X_1, Y_1	I_1, I_2	—	P Cross-Check
4	GST	I_2	X_1, Y_1	I_1, P	—	I_2 Cross-Check
5	UST	I_1	X_1, Y_1	—	I_2,P	Excitation Test
6	UST	I_2	X_1, Y_1	—	I_1,P	Excitation Test

*On a spare MO tested in storage, the housing must be grounded externally.

Analysis of Results

The current and watts are recorded for Tests 1 through 4, and the power factor is calculated, then corrected for ambient temperature using the correction curve labeled *Oil-Filled Instrument Transformers.*

Test 1 is an Overall measurement of the primary insulation. The corrected power factor for this test is compared with previous test results (if any) against results recorded for other similar units on the system, and with the data tabulated in the Instrument Transformer section of the *Test-Data Reference Book.*

In the three Cross-Check tests, the test potential is graded along the potential winding, from full potential on the energized bushing or winding end to approximately zero voltage on the guarded bushings or winding ends. Thus, each Cross-Check test is confined to the energized bushing, and essentially to that end of the winding adjacent to the energized bushing.

If the Overall power factor is high, then the Cross-Checks will help determine if the condition is general or if the high losses are confined to one area (e.g., one of the bushings may be contributing high losses). The sum of the current and watts for Tests 2, 3, and 4 should approximate the Overall (Test 1) values. If there is a large discrepancy between the Overall and the Cross-Check watts, this may indicate a discontinuity in the circuit of the primary winding.

Tests 5 and 6 are excitation-current measurements which detect internal winding and core problems. Refer to ”Transformer Excitation-Current Tests” on page 5-44. Only the current value is recorded for Tests 5 and 6 (which are both performed at the same test potential), and they should equal each other. The excitation currents should compare with previous results (if any), and with results obtained for other similar units.

Investigation of abnormal results on MOs may include separate power-factor and other screen tests on a representative sample of the insulating oil. Drawing of liquid samples may not be feasible and must take into account the total liquid volume of the unit, which may be small.

Voltage Regulators

Introduction

Voltage regulators are either of the step-voltage or induction type. Regulators may be single-phase or three-phase, and may be applied line-to-neutral or line-to-line. The overwhelming majority of units are liquid filled, although at least one is known to be a dry type. The bushings are usually designated as: S (Source); L (Load); and SL (Neutral or Line), as shown in Figure 5.15.

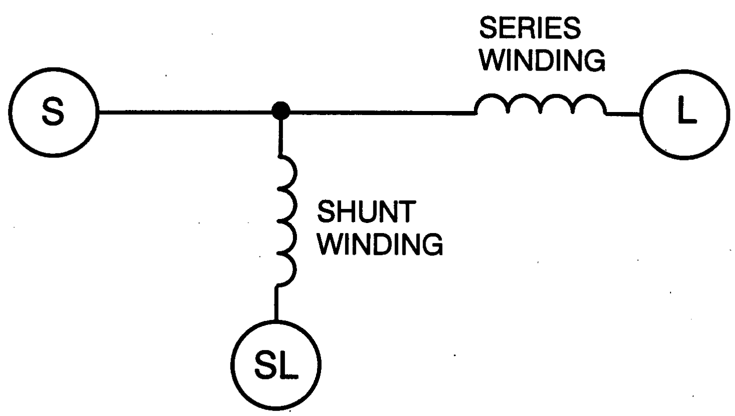


Figure 5.15 Single-Phase Voltage Regulator

Test Voltages

The following test voltages are recommended for all liquid-filled voltage regulator; that is, units designed for line-to-line application as well as those designed for line-to-neutral application:

Table 5.16 Doble Recommended Test Voltages for Liquid-Filled Voltage Regulators

Regulator Voltage Rating (kV)	Test Voltages (kV)
12 and above	10
5 to 8.66	5
Below 5	2

For dry-type voltage regulators refer to the discussion in this section under ”Power and Distribution Transformers” – ”Dry-Type Power and Distribution Transformers” on page 5-6.

Test Procedure

Usually the series and shunt windings cannot be effectively isolated from each other, and therefore, the voltage regulator test consists of one measurement to ground, with the S. L, and SL terminals connected together. The jumpered bushings are energized, and no Low Voltage Lead is necessary, as the return current is measured using the test ground lead. If a three-phase regulator has only one SL terminal, then again only one power-factor test is performed, with all line terminals and the neutral connected together. If a three-phase regulator has three SL terminals, then test it like a three-phase shunt reactor (Figure 5.7).

NOTE ☝ **All Power-Factor tests should be performed with the tap changer on an off-neutral position to effectively short-circuit any arrester valve elements connected between the tapped and excited windings.**

The measured power factors obtained for oil-filled regulators should be corrected for temperature, using the curve labeled *Oil and Oil-Filled Power Transformers (Free Breathing and Older Conservator Types).*

When units are not equipped with liquid temperature gauges, the top oil temperature must be approximated. A unit which has been out of service for an appreciable time may be close to the ambient temperature. For a unit just removed from service, the top oil temperature may be approximated as described under “General” – ”Variation Of Power Factor with Temperature” on page 1-14.

Separate tests should be performed on the bushings. As in the case of power transformers, all windings should be short-circuited for the bushing tests. Hot-Collar tests should be performed on the bushings if they are not equipped with taps.

Excitation-Current tests should also be performed with Terminal L energized and Terminal SL connected to UST (Terminal S is left floating). Excitation tests should be performed on various load tap-changer positions as described under ”Transformer Excitation-Current Tests” below.

An oil sample should be drawn and tested for power factor.

Analysis Of Results

The winding insulation power factors should be compared with previous test results (if any), with similar results recorded for units on the system, and with the data tabulated in the Regulator section of the *Test-Data Reference Book.*

If a high power factor is obtained, make certain that the LTC was in an off neutral position during the test. Otherwise, an abnormally high power factor could occur as a result of internal arrester elements which are not effectively short circuited with the LTC in the neutral position.

Sometimes it is useful to investigate abnormal results by making a series of tests at several voltages, to determine if the condition causing the abnormal result is nonlinear or voltage sensitive within the range of Doble test voltages. This might include increasing the test voltage to 12 kV in the case of regulators normally tested at 10 kV.

Transformer Excitation-Current Tests

Introduction

The use of Doble test equipment in the measurement of transformer excitation currents (I_e) during routine field-acceptance and Preventive-Maintenance tests has been recommended since 1967. This test has been effective in detecting and confirming winding and core faults, even though, in some instances, normal turn-ratio and Winding-Resistance test results had been obtained.

Test Considerations

The following comments summarize the technique and should be useful guides in conducting tests of this type:

1. All loads should be disconnected and the transformer de-energized.
2. Tests usually can be confined to the high-voltage windings. Defects in the low-voltage windings will still be detected, and the charging current required will be reduced. In the case of suspected problems or defects in transformers, consideration may be given to attempting excitation-current measurement in low-voltage winding(s).

3. If the neutral bushing is not accessible, alternate methods of testing are presented.
4. Winding terminals normally grounded in service should be grounded during routine tests, except for the particular winding energized for test. For example, with a Wye/Wye transformer, the neutral of the winding energized for test would be connected to the UST (Ungrounded Specimen Test) circuit, while the neutral of the second winding would be connected to ground.
5. Caution should be exercised in the vicinity of all transformer terminals, because voltage will be induced in all windings during a test.
6. The following series of excitation-current measurements should be performed in initial tests on all transformers, and when investigating questionable units:
   - Test on each position of the load tap changer (LTC), either Raise or Lower. If the transformer is also equipped with a de-energized tap changer, or DETC (sometimes referred to as a no-load tap changer, or NLTC), then it should be set to the nominal voltage position or the normally used position for these tests.
   - One tap position in the direction opposite to that selected above; that is, one tap position off Neutral, either Lower or Raise.
   - The Neutral position.
   - All other positions of the DETC with the LTC on Neutral.
7. On a routine basis, excitation-current measurements should be made on the following LTC positions with the DETC (if any) on the normally used position:
   - LTC on full Raise or full Lower.
   - LTC one position off Neutral in the Raise direction, and one position off Neutral in the Lower direction. Both these tests include the preventative autotransformer of the LTC, and in addition, check the proper operation of the LTC reversing switch.
   - LTC on Neutral.
8. All Doble excitation-current tests are performed in the UST mode, using **Line Sync Reversal** (not the usual Line Frequency Modulation). If using the Clipboard, select Line Sync Reversal under the LC column. DTA automatically selects this mode for you.
9. Test voltages should not exceed the rated line-to-line voltage for Delta-connected windings, rated line-to-neutral voltage for Wye-connected windings, or rated winding voltage for single-phase transformers.

10. Test voltages should be the same for each phase, and because of the nonlinear behavior of exciting current at low test voltages, should be set accurately if results are to be compared. Abnormal Excitation-Current results should be investigated by performing tests at several voltages. For three-phase transformers, it is of interest to note if, and how much, the normal pattern is affected at different test potentials. Begin the investigation with a test at a voltage which is relatively low compared with the normal test voltage; then, take successive measurements as the voltage is raised, in 1 or 2 kV steps, up to the maximum test voltage allowed, perhaps even to 12 kV.

NOTE ☟

Excitation-current measurements should be performed at the highest test voltage possible within the range of the set, but should never exceed the voltage rating of the winding across which the test voltage is applied. While it is generally desirable to make all excitation-currrent tests on a given transformer at the same potential, there may be certain exceptions in the case of units with LTC. Sometimes it is possible to excite each winding at 10 kV when the preventative autotransformers associated with each phase of the LTC are effectively bypassed.

It may not be possible to excite the winding above some relatively low voltage (say, for example, 2 kV) when the LTC position is such that the preventative autotransformer is included in the winding circuit. This is one occasion when it is desirable to make the Excitation-Current tests at some relatively high voltage (e.g., 10 kV) on those taps which do not include the preventative autotransformer, and at some lower test voltage when the preventative autotransformer is included in the winding circuit.

If the test voltage can be raised to some moderate level (e.g., 6 kV) with the preventative autotransformer in the circuit, then make all tests on all positions of the LTC at a convenient voltage such as 5 kV.

11. Record exciting currents with the windings energized alternately from opposite ends of single-phase transformers. This should be done on the individual phases of three-phase transformers, if the unit is suspect or if the initial exciting-current measurements are questionable.

12. The probability of residual magnetism of sufficient magnitude to affect routine tests is small.

13. The probability should be considered if abnormal (high) currents are measured in a given transformer. Methods for neutralizing the residual have been outlined at Doble Client Conferences (refer to the 1976 *Doble Client Conference Minutes, Sec. 6-1101*, paper titled “Transformer Exciting Current Measured with Doble Equipment (A Progress Report”).

The following sections summarize test connections recommended for use in routine and investigatory tests, and discuss patterns of test results recorded. A more complete discussion of test result patterns may be found in the 1992 *Doble Client Conference Minutes, Sec. 6-6.1*, in the paper titled “The Influence of Transformer Load Tap Changers on Single-Phase Exciting-Current Test Results” by M. O. Lachman.

Test Procedures

Multiple Tests

DTA can perform multiple tests to save time. These multiple tests are applicable only to cases where multiple taps of on-load tap changers are being tested. The multiple tests are made on one phase at a time, starting on the current line and moving down the page. Between tests, a message is displayed advising the tester to change the tap, and to continue the test when ready. Test voltage is maintained on the tap changer during a multiple test. Upon finishing testing all desired taps on the first phase, the tester must move the cursor in DTA to the beginning of the next multiple test on the next phase, and begin the next multiple test. Using the multiple test feature would require three multiple tests, one per phase. If you make the fist series of tests from 16R to 16L, you can make the second series of tests from 16L to 16R, and so forth.

NOTE

When performing multiple exciting current tests, do no operate the tap changer manually (i.e. by hand cranking the mechanism); instead, operate it electrically.

Figure 5.16 through Figure 5.23 illustrate test procedures for routine measurement of exciting currents (I_e) in transformer windings.

Single Phase Transformer

Test No.	Test Mode	Energize	UST	Float*	I_e
1	UST	H_1	H_2**	X_1X_2	H_1–H_2*
2	UST	H_2*	H_1	X_1X_2	H_2*–H_1

* Some transformers have windings which are rated for low-voltage operation; for example, potential transformers with 120 volt secondary windings. Excessive voltage could be impressed on these low-voltage windings due to electrostatic coupling from the energized winding. For transformers with low voltage rated secondary or tertiary windings, ground one leg of each low-voltage winding for the excitation-current tests.

** H_2 may be designated as H_0.
Normally grounded terminals of X and Y must be grounded.

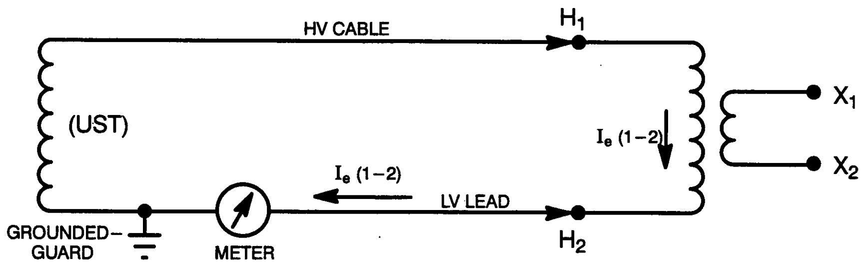


Figure 5.16 Measurement of I_e in a Single-Phase Transformer

Place the high voltage cable on the bushing in the **Energize** column, and place a low voltage lead on the bushing in the **UST** column.

Single Phase Autotransformer

Test No.	Test Mode	Energize	UST	Float*	I_e
1	UST	H_1	H_0X_0	Y_1Y_2	H_1–H_0X_0
2	UST	H_0X_0	H_1	Y_1Y_2	H_0X_0–H_1

* If present.

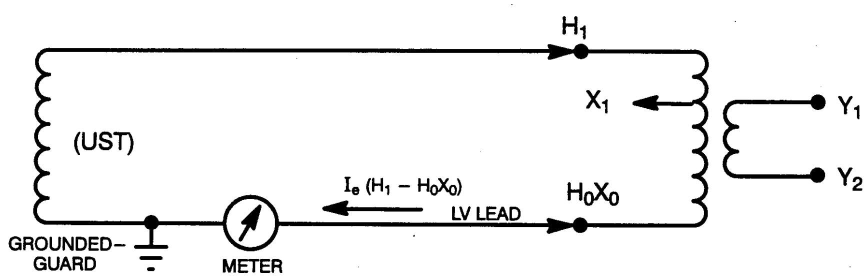


Figure 5.17 Measurement of I_e in a Single-Phase Autotransformer

Place the high voltage cable on the bushing in the **Energize** column, and place a low voltage lead on the bushing in the **UST** column.

Three Phase Wye Connected Winding

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_1	H_0	*	H_2H_3, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	$H_1–H_0$
2	UST	H_2	H_0	*	H_1H_3, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	$H_2–H_0$
3	UST	H_3	H_0	*	H_1H_2, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	$H_3–H_0$

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

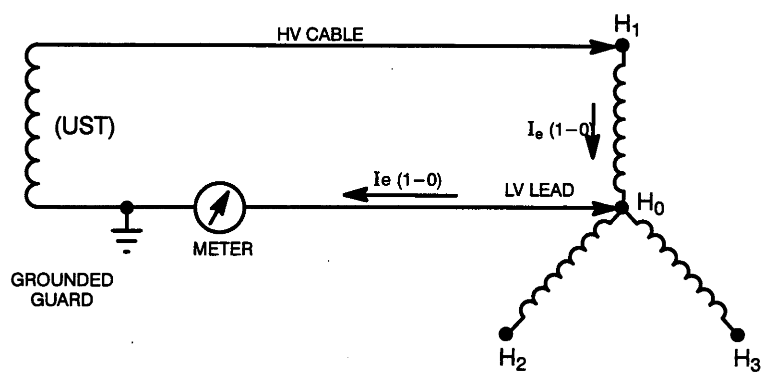


Figure 5.18 Measurement of I_e in a Wye-Connected Transformer Winding (Routine Method)

Place the high voltage cable on the bushing in the **Energize** column, and place a low voltage lead on the bushing in the **UST** column. Float the other two bushings.

Three Phase Wye Connected Winding, No Accessible Neutral

Table 5.17 No Acessible Neutral Bushing, Standard Method

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_1	H_2	*	H_3, $X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_1–H_0 + H_0-H_2
2	UST	H_2	H_3	*	H_1, $X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_2–H_0 +H_0-H_3
3	UST	H_3	H_1	*	H_2, $X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_3–H_0 + H_0-H_1

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

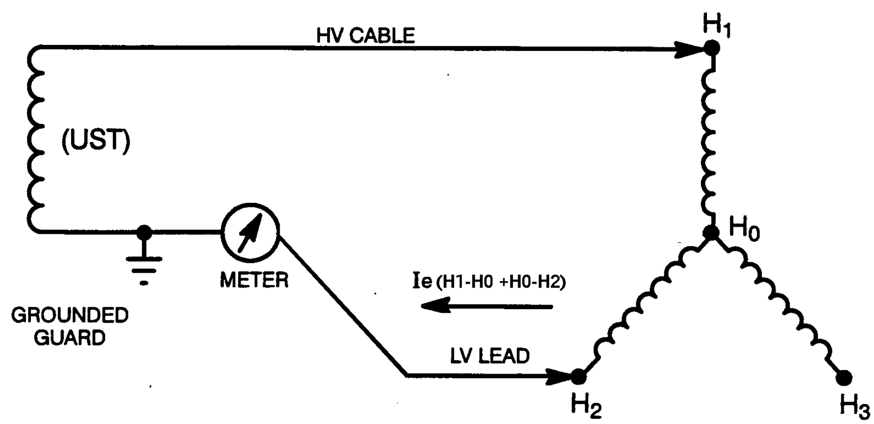


Figure 5.19 No Accessible Neutral Bushing, Standard Method

Place the high voltage cable on the bushing in the **Energize** column, and place a low voltage lead on the bushing in the **UST** column. Float the other two bushings.

Although the method shown above is the preferred one when encountering a wye connected winding with no accessible neutral bushing, it may be that the previous test was made using an alternate method. The alternate method differs from the above method in that two bushings are shorted together for each test, and the measurement is made between the two shorted bushing and the third, floating one. The test procedure would be as follows:

Table 5.18 No Accessible Neutral Bushing, Alternate Method

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	$H_1 + H_2$	H_3	*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_1H_2 - H_3
2	UST	$H_2 + H_3$	H_1	*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_2H_3 - H_1
3	UST	$H_3 + H_1$	H_2	*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_3H_1 - H_2

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

The standard method would yield two similar and one high current reading, whereas the alternate method would yield two similar and one low reading. Yet a second alternative exists, similar to the preferred method described above in Table 5.17, but with the third bushing grounded instead of floating.

Delta Connected Winding

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_1	H_2	H_3*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_1–H_2
2	UST	H_2	H_3	H_1*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_2–H_3
3	UST	H_3	H_1	H_2*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_3–H_1

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

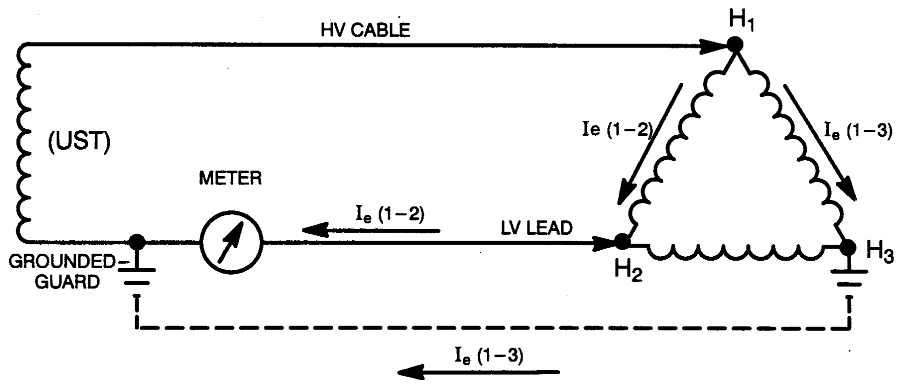


Figure 5.20 Measurement of I_e in a Delta-Connected Transformer Winding (Routine Method)

Place the high voltage cable on the bushing in the **Energize** column, and place a low voltage lead on each of the other two bushings. One will be measured, one grounded. If using DTA, follow the prompts. For example, if you are testing the B phase (generally denoted as H1-H2) with the high voltage cable on H1 and the red lead on H2, blue on H3, you want to measure red, ground blue. You therefore choose the UST-R circuit from the choice list. In DTA, the three phases (H1-H2, H2-H3, H3-H1) are tested in the same row, across the screen. The order of the connections labels dictates the order in which the tests will be found in the three mA columns.

Figure 5.21, Figure 5.22 and Figure 5.23 represent methods used to verify or investigate questionable results. The procedures are relatively straightforward and require little explanation.

Wye Connected Winding, Reverse Method

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_0	H_1	*	H_2H_3, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	H_0–H_1
2	UST	H_0	H_2	*	H_1H_3, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	H_0–H_2
3	UST	H_0	H_3	*	H_1H_2, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	H_0–H_3

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

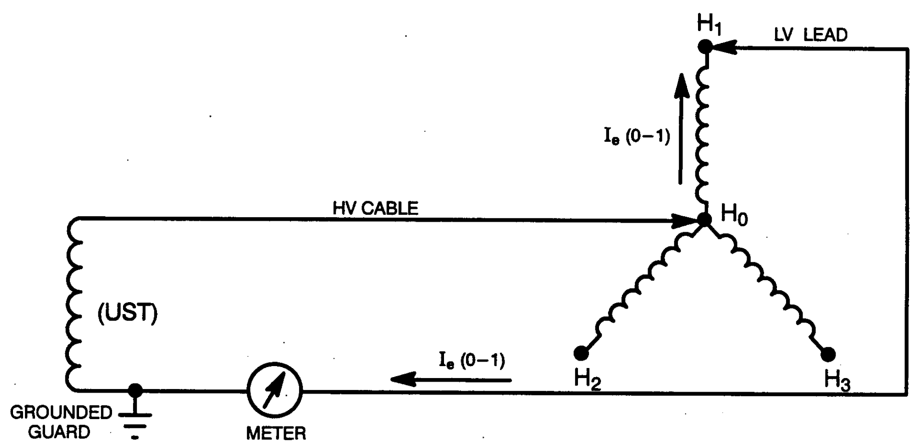


Figure 5.21 Measurement of I_e in a Wye-Connected Transformer Winding (Reverse Method)

Delta Connected Winding, Reverse Method

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_1	H_3	H_2*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_1–H_3
2	UST	H_3	H_2	H_1*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_3–H_2
3	UST	H_2	H_1	H_3*	$X_1X_2X_3$ ($Y_1Y_2Y_3$)	H_2–H_1

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

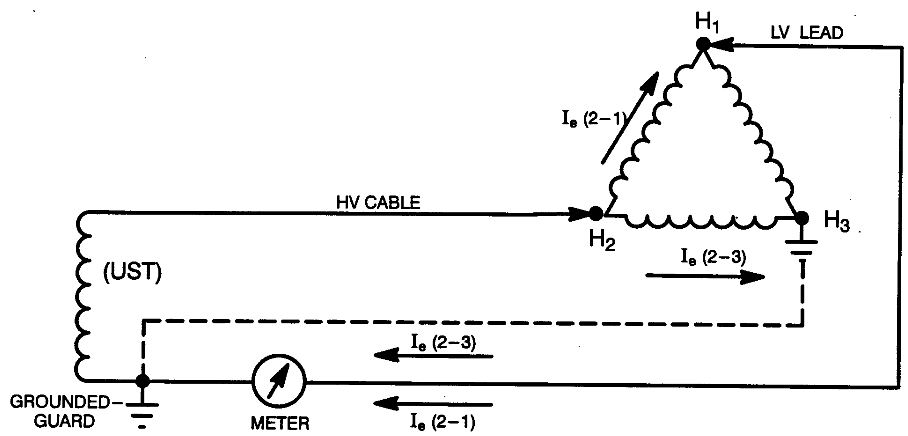


Figure 5.22 Measurement of I_e in a Delta-Connected Transformer Winding (Reverse Method)

Delta Winding, Alternate Method

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_1	H_2,H_3	*	$X_1X_2X_3$ (Y1Y2Y3)	$(H_1–H_2)$+ $(H_1–H_3)$
2	UST	H_2	H_1,H_3	*	$X_1X_2X_3$ (Y1Y2Y3)	$(H_2–H_1)_+$ $(H_2–H_3)$
3	UST	H_3	H_1,H_2	*	$X_1X_2X_3$ (Y1Y2Y3)	$(H_3–H_1)_+$ $(H_3–H_2)$

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

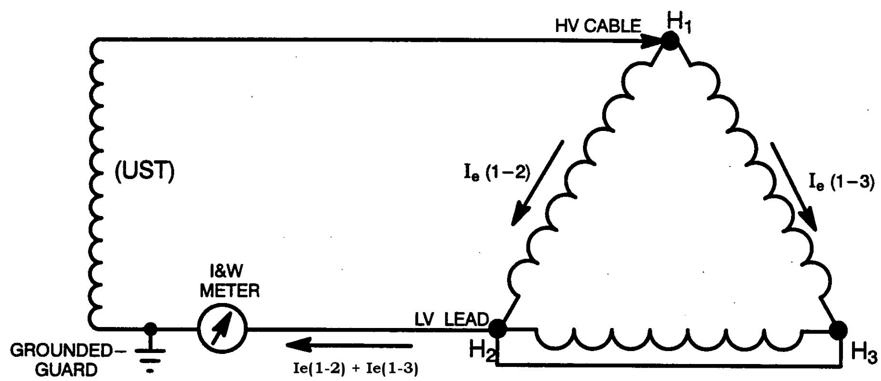


Figure 5.23 Measurement of I_e in a Delta-Connected Transformer Winding (Alternative Method)

Analysis Of Results

The analysis depends on the presence of an LTC and on whether the test is an initial or a subsequent one. When an LTC is present, both the LTC pattern and the absolute value of the reading are evaluated. When an LTC is not present, only the absolute value of the reading is evaluated.

In modern transformers (predominantly in EHV single-phase units), the combination of high core steel quality (which requires less inductive energy) and high turn-to-turn capacitance (to control the impulse voltage distribution) results in the energy stored in the turn-to-turn and other insulation components being comparable with the energy stored in the core. In such transformers, $\mathbf{I_L}$ can be comparable with $\mathbf{I_C}$ and, in some units, can even be lower, resulting in a capacitive measured current. The consequences may be an unexpected current pattern, as described below.

Initial Test with the LTC Present

The following steps are suggested for the initial test:

1. To establish a reliable benchmark, the unit should be demagnetized before the initial test is performed.

2. The LTC pattern should be identified by comparing data behavior with one of the typical patterns (see the article “The Influence of Transformer Load Tap Changers On Single-Phase Exciting-Current Test Results”, by Mark F. Lachman, in Doble’s white “General Reference Book”). It should be the same on all three phases for both the exciting current and loss.

3. To evaluate the absolute value, the data from different phases should be compared for each LTC position with DETC in the normally used position as well as for the remaining DETC positions with the LTC in neutral. This comparison is referred to as the identification of the *phase pattern*. For units where all three phases represent an inductive specimen, the following has been observed:

a) The two high similar readings and one lower reading are obtained on any three-legged core-type unit and five-legged shell-type unit. (On these shell-type units, the middle phase is typically reversed). The lower reading is obtained on a phase located on the middle leg of the core. If the measurement is performed by testing two phases of the wye-connected winding in series (used when the neutral point is not accessible) or by testing two phases of the delta-connected winding in parallel (by short-circuiting the third phase), the resulting phase pattern is two lower similar readings and one high reading.

b) Three similar readings are obtained on any five-legged core-type unit and on three single-phase units.

c) The same phase pattern is obtained for both the exciting current and the loss readings.

For units where at least one phase represents a capacitive specimen (typically, all three phase are capacitive), the following has been observed:

a) The exciting current reading depends on the relative values of the inductive and capacitive components and, as such, can result in any phase pattern. Therefore, the obtained phase pattern is accepted as the initial benchmark; however, some practical considerations can be applied. For example, if a reading on one of the phases is twice (or only a small fraction of) the readings on the other two phases, this most likely represents an abnormal condition.

b) A phase pattern obtained for the exciting current may differ from one obtained for the loss. The loss reading is always dominated by the core loss, and, as such, will normally have the phase pattern as defined above for inductive specimens. The last observation becomes very useful in interpreting the current readings. For example, when current shows three dissimilar readings and the loss exhibits a familiar two high similar and one lower readings, then it is most likely that the current pattern is influenced by the insulation capacitance, and it should be accepted as a benchmark reading.

Some units are inductive in the bridging positions and capacitive in the non-bridging positions; other units are inductive for a range of sequential tap positions and then become capacitive for the remaining positions. In these cases (quite rare), the inductive and capacitive positions should be analyzed differently. Although the identification of the phase pattern requires familiarity with the above information, it stops being essential when a reliable benchmark is obtained and a subsequent test is performed.

Subsequent Test with the LTC Present

The following steps are suggested for the subsequent test:

1. The LTC pattern is compared with initial LTC pattern. Both should be obtained on the same DETC position.

2. For each LTC position, the absolute value is compared with the initial measurement. In some cases, the presence of residual magnetism changed the subsequent reading by as much as 30-50%.

Initial Test when the LTC is Not Present

The following steps are suggested for the initial test:

1. To establish a reliable benchmark, the unit should be demagnetized before the initial test is performed.

2. To evaluate the absolute value, the data from different phases should be compared for each DETC position. Analysis is the same as described under item 3 in section *Initial test with the LTC present*. Some units are inductive for a range of sequential DETC tap positions and then become capacitive for the remaining positions. In these cases (quite rare), the inductive and capacitive positions should be analyzed differently.

Subsequent Test when the LTC is Not Present

The following is suggested for the subsequent test:

1. For a normally used DETC position, the absolute value is compared with the initial measurement. In some cases, the presence of residual magnetism changed the reading by as much as 30-50%.

Figure 5.20 illustrates a routine test connection on a three-phase Delta-connected unit. As noted, the unenergized or static winding (H_2–H_3) for the connection shown is shunting the meter during the test. In most instances, this shunting has had little, if any, effect on the measurements. The pattern of currents recorded for the three phases would be the typical two high, similar currents, and one lower current. Data has been received on Delta windings which did not follow this pattern, but rather included the one lower current with two higher but dissimilar currents. This latter pattern was attributed to residual magnetism or the shunting effect of the unenergized or static winding. To eliminate the question of the shunting effect of the static winding, the procedure outlined in Figure 5.23 can be used. A normal pattern of currents for this parallel measurement of two phases of a Delta-connected winding would be two similar currents, with the third current being higher rather than lower as nominally observed on the individual phases.

If it is assumed that the currents recorded for an individual phase are the same when measured from alternate ends, that is H_1 to H_2, or H_2 to H_1, then the currents for the individual phases can be calculated by adding the currents recorded for any two measurements in Figure 5.23, subtracting the third, and dividing by two. For example, to determine a value of H_1–H_2:

$$\text{Add:}\quad \begin{array}{l} (H_1-H_2)+(H_1-H_3) \\ (H_2-H_1)+(H_2-H_3) \\ \hline 2(H_1-H_2)+(H_2-H_3)+(H_1-H_3) \end{array}$$

$$\text{Subtract:}\quad \begin{array}{l} (H_3-H_2)+(H_3-H_1) \\ \hline 2(H_1-H_2) \end{array}$$

Dividing by 2 will result in the current for the H_1–H_2 winding.

Wye Connected Winding, No Acessible Neutral Bushing

If the standard method is used, the results will be two similar and one high current. This unusual combination is due to the fact that we are measuring two phase currents together each time. If we consider that the two outside phases (H1-H0 and H3-H0) have a “high” current, and the middle phase (H2-H0) has a “low” current, then the resulting measurements are as follows: H1-H2 is a “high” (H1-H0) plus a “low” (H2-H0); H2-H3 is a “low” (H2-H0) plus a “high” (H3-H0); and H3-H1 is a “high” (H3-H0) plus a “high” (H1-H0). So there are two “low” plus “high” measurements and one “high” plus “high” measurement, resulting in two similar and one high reading. If the alternate method is used, you are short-circuiting two of the three phases, so that essentially you are back to measuring the current through one phase at a time again, the phase that is not short-circuited. The standard two similar and one low current pattern is obtained.

Turns Ratio Tests With The Doble Capacitor

Introduction

Turns ratio tests are traditionally made at a very low voltage (perhaps 100 volts), which will confirm the status of the winding in all but a few cases. An example of such a case would be a spot on a turn where the insulation has been almost entirely lost due to some kind of unwanted activity, but where there is still enough to withstand the low voltage applied by the typical TTR test set. Take that same spot and energize it at 10 kV, and the little remaining insulation would break down and show the shorted turn. It is an extra tool that is especially useful on a suspect transformer where other tests may not yield useful information. In addition, by having test results entered automatically into electronic forms if using the M4000 with the DTA program, expected ratios and permissible limits for each test are automatically calculated for the user, saving time and helping prevent human error.

Transformer turns ratio tests at 10 kV may be performed with the M4000, providing the optional Doble Turns Ratio Capacitor is available. The capacitance of the turns ratio capacitor is measured, and is used as the “true” capacitance value. The capacitor is then measured again by energizing the high voltage winding of the transformer with the capacitor connected to the corresponding winding of the low voltage or opposite winding. This is referred to as the “apparent” capacitance. The turns ratio is then calculated by using the ratio of the “true” to the “apparent” capacitance.

Since this is a single phase test, a separate test is made for each phase. In the case of a three winding transformer, three sets of ratio tests are made: High to Low, High to Tertiary, and Low to Tertiary.

NOTE **The determination of the phases on opposite windings that correspond to each other is made using the nameplate vector diagram.**

How To Make The Right Connections

In order for the Turns Ratio test to yield positive results, the connections must be made to corresponding phases and in the right polarity. This information is contained in the vector diagram located on the transformer nameplate. *Corresponding Phases* means the HV and the LV windings must be represented by parallel lines on the vector diagram. The *Right Polarity* means that the same end of each of these parallel lines must be grounded for the test. For example, using Figure 5.24 on page 5-61, the line H1-H2 is parallel to the line X0-X2, so we know they both correspond to the same phase. To get the polarity right, H2 is at the same end of the H1-H2 line as X2 is on the X0-X2 line, so H2 corresponds to X2 in polarity, as does H1 to X0. So if we decide to energize the H2 end of the H1-H2 winding, and ground the H1 end, then we must place the Doble Capacitor on the corresponding end of the corresponding phase of the X winding; that is, the Doble Capacitor goes on the X2 end of the X2-X0 winding, and the X0 end is grounded.

NOTE ☝ **The connections shown in the following examples correspond to their associated vector diagrams. Use them as a guide to determine the correct connections to other vector diagrams that you might encounter.**

DTA Connections Fields

If using DTA, there are fields in which to record the connections made for each of up to three tests (phases) per winding pair. For each phase tested, there are four fields: winding terminal energized and winding terminal grounded, high voltage; and, winding terminal UST'ed through the Doble Capacitor and winding terminal grounded, low voltage. "UST'ing a winding terminal through the Doble Capacitor" means connecting its hook to that winding terminal and connecting a Low Voltage Lead to the other end of the Doble Capacitor. Below is a typical Connections field filled out for a three phase Delta-Wye transformer whose nameplate vector diagram is shown as well:

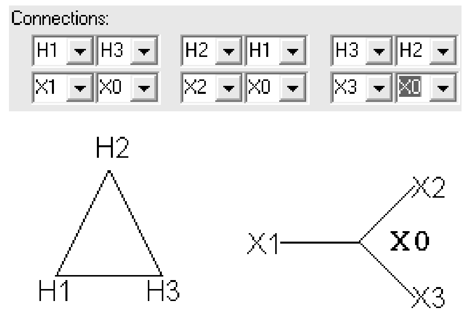


Figure 5.24 Typical Connections For Turns Ratio Test

In this example, the first test would be run by energizing H1, grounding H3, UST'ing X1 through the capacitor, and grounding X0. The H winding connections have been selected so that the X winding neutral (X0) connection can remain the same throughout the three tests. For each of the three sets of four fields described above, there is a column in which to enter the resulting test data, representing a single phase test on a winding pair. The three columns are labeled *Ratio*:

Ratio	Ratio	Ratio

Figure 5.25 DTA Turns Ratio Data Entry Columns, Corresponding To "Connections" Label

Test Voltages

The Doble Capacitor may be energized at up to 10 kV. Follow the directions for energizing transformers found under "Test Voltages" on page 5-2.

Measuring The Doble Capacitor

1. If using DTA, use the **Doble Ratio Tests** screen and place the cursor in the **True Capacitance** field for the following 3 steps.
2. Measure the static Doble capacitor by placing the High Voltage cable on the hook end of the capacitor.
3. Attach the low voltage lead to the opposite end of the capacitor. The capacitance is measured by energizing the capacitor at 10 kV using a UST circuit.

4. Record the results (picofarads). If using DTA, the results are automatically entered in the **True Capacitance** field.

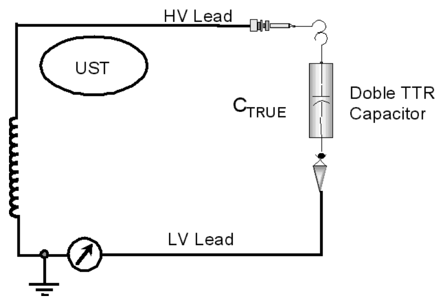
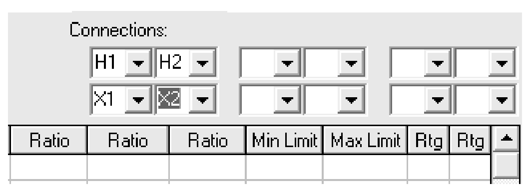


Figure 5.26 Turns Ratio "True" Capacitance Measurement

Turns Ratio Test, Single Phase Transformers

Two Windings

1. Record the high and low voltage winding voltages for the tap positions you intend to ratio from the transformer nameplate, as well as the tap positions themselves.
2. Record the "True" capacitance of the Doble capacitor as described above.
3. If using DTA, use the two winding transformer form with **Configuration** set to 1-Phase, and **# Phases** set to 1. Enter into the "Connections" fields the H, X, or Y terminals corresponding to each column of test data in the *Ratio* columns. For example, if you plan your first test to be, Energize H1, ground H2, and UST X1, ground X2, make entries as follows:



4. Since there will be only one test run in this case, the rest of the "Connections" fields will be left blank.
5. Place the High Voltage hook on one end of the high voltage winding (H1), and ground the other (H2).
6. Place the Doble capacitor hook on one end of the low voltage winding (X1), ground the other (X2), and attach the Low Voltage lead to the other end of the capacitor.

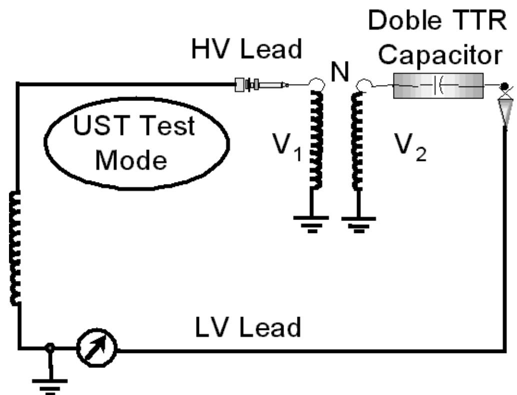


Figure 5.27 Turns Ratio "Apparent" Capacitance Measurement, Single Phase Two Winding Transformer

7. If using DTA, Tab the cursor over to the first of the three *Ratio* columns.

8. Test voltage is determined by the rating of the transformer and bushing insulation ratings (see "Test Voltages" on page 1-11).

9. Run the test using the UST Test Mode and record the results. If using DTA, DTA will compare the results with the value in the "Cal Ratio" column. They will be rated "G" if the measured value is within 0.5% of the calculated ratio.

Three Windings

Follow the procedure described for a single phase, two winding transformer, above, except that, if using DTA, the three winding transformer form is used, and three tests must be run instead of one, one for each pair of windings. Use the connections shown below:

Table 5.19 Test Procedure, Single Phase Three Winding Transformer

Test	Measured Ratio*	Energize	UST Through Capacitor	Ground
1	H1-H2/X1-X2	H1	X1	H2, X2
2	H1-H2/Y1-Y2	H1	Y1	H2, Y2
3	X1-X2/Y1-Y2	X1	Y1	X2, Y2

* These ratios are determined using the transformer nameplate drawing by the process described under"How To Make The Right Connections" on page 5-60.

If using DTA, each of the winding pairs has a form (H-X, H-Y, X-Y), so each test will be made in the first of the *Ratio* columns on its corresponding page. In the **Connections** fields on each page, type into the H, X, and Y fields the contents of the “Energize” (into the first field) and “Ground” (into the second field) columns in the table above for each respective winding.

Single Phase Auto With Tertiary

Follow the procedure described for a single phase, two winding transformer, above, except that, if using DTA, the three winding transformer form is used, and three tests must be run instead of one, one for each pair of windings. Use the connections shown below:

Table 5.20 Test Procedure, Single Phase Auto With Delta Tertiary

Test	Measured Ratio*	Energize	UST Through Capacitor	Ground
1	H1-H0X0/X1-H0X0	H1	X1	H0X0
2	H1-H0X0/Y1-Y2	H1	Y1	H0X0, Y2
3	X1-H0X0/Y1-Y2	X1	Y1	X0H0, Y2

* These ratios are determined using the transformer nameplate drawing by the process described under”How To Make The Right Connections” on page 5-60.

If using DTA, each of the winding pairs has a form (H-X, H-Y, X-Y), so each test will be made in the first of the “MEASURED RATIO True/Apparent columns on its corresponding page. In the **Connections** fields on each page, type into the H, X, and Y fields the contents of the “Energize” (into the first field) and “Ground” (into the second field) columns in the table above for each respective winding.

Single Phase Auto Without Tertiary

Follow the procedure used for a single phase, two winding transformer.

Table 5.21 Test Procedure, Single Phase Auto Without Tertiary

Test	Measured Ratio	Energize	UST Through Capacitor	Ground
1	H1-H0X0/X1-H0X0	H1	X1	H0X0

Turns Ratio Test, Three Phase Transformers

Two Windings

1. Record the high and low voltage winding voltages for the tap positions you intend to ratio from the transformer nameplate, as well as the tap positions themselves.

2. Fill in the Connections fields on the Doble ratio test screen.

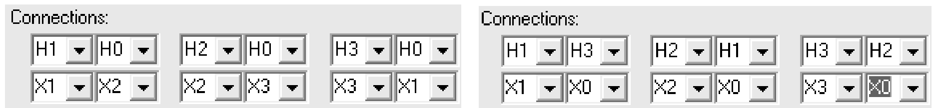


Figure 5.28 Connections for Wye-Delta (Left) and Delta-Wye Configurations of Figure 5.29 and Figure 5.30.

3. Record the “True” capacitance of the Doble capacitor as described in ”Measuring The Doble Capacitor” on page 5-61.
4. Place the High Voltage hook on one end of the winding terminal (the *Energize* column in the examples below), and ground the other end of the winding.
5. Place the Doble capacitor hook on one low voltage winding terminal (the *UST Through Capacitor* column in the example below), and attach the Low Voltage lead to the other end of the Doble capacitor.
6. To determine the corresponding winding terminals to use, always observe the nameplate vector diagram. See the examples in Figure 5.29 and Figure 5.30.
7. Ground the other end of the low voltage winding.
8. All other bushings remain floating.

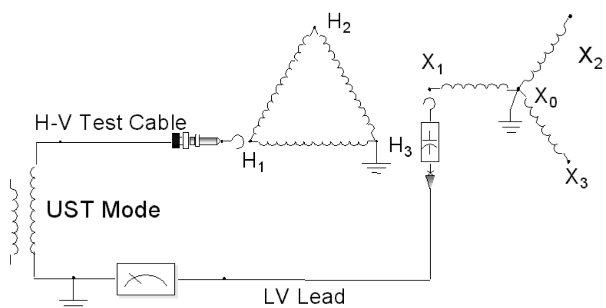


Figure 5.29 Test Setup For One Phase Of A Delta-Wye Transformer

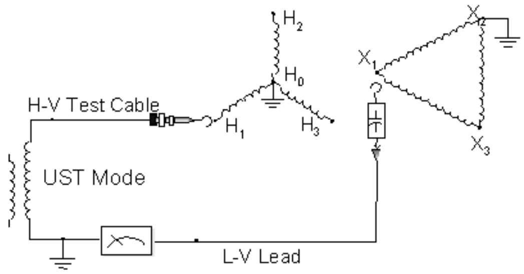


Figure 5.30 Test Setup For One Phase Of A Wye-Delta Transformer

9. If using DTA, Tab the cursor over to the first of the three *Ratio* columns.

10. Test voltage is determined by the rating of the transformer and bushing insulation ratings (see ”Test Voltages” on page 5-2).

11. Run the test and record the results. If using DTA, DTA will compare the results with the value in the “Cal Ratio” column. They will be rated “G” if the measured value is within 0.5% of the calculated ratio.

12. Repeat the test for each phase, using the nameplate vector diagram as a guide for making the connections. Observe winding polarity. If using DTA, move to the second *Ratio* column for the second phase, and to the third column for the third phase.

Table 5.22 Test Procedure for Figure 5.29 above.

Test	Measured Ratio	Energize	UST Through Capacitor	Ground
1	H1-H3/X1-X0	H1	X1	H3, X0
2	H2-H1/X2-X0	H2	X2	H1, X0
3	H3-H2/X3-X0	H3	X3	H2, X0

Table 5.23 Test Procedure for Figure 5.30 above.

Test	Measured Ratio	Energize	UST Through Capacitor	Ground
1	H1-H0/X1-X2	H1	X1	H0, X2
2	H2-H0/X2-X3	H2	X2	H0, X3
3	H3-H0/X3-X1	H3	X3	H0, X1

Zig-Zag Windings

Connect to the terminals of a zig-zag winding as if it were a delta winding.

Table 5.24 Test Procedure For Delta-Zigzag

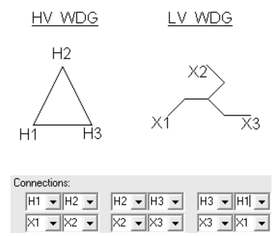
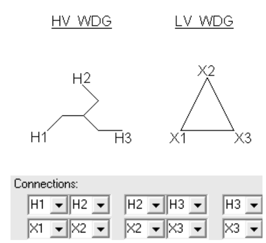
Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H2/X1 -X2	H1	X1	H2, X2	
2	H2-H3/X2 -X3	H2	X2	H3, X3	
3	H3-H1/X3 -X1	H3	X3	H1, X1	

Table 5.25 Test Procedure For Zigzag-Delta

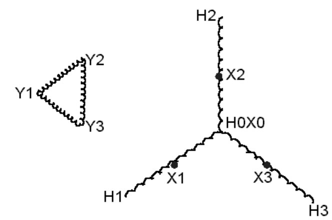
Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H2/X1-X2	H1	X1	H2, X2	
2	H2-H3/X2-X3	H2	X2	H3, X3	
3	H3-H1/X3-X1	H3	X3	H1, X1	

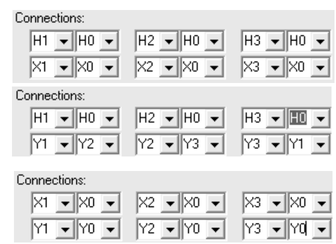
Auto With Tertiary

An auto with a tertiary tests like a three winding transformer, in that there are nine tests. Tests between each pair of windings are on their own pages. Test all three phases of each pair of windings before moving on to the next pair. All winding terminals not being tested float. Follow the same procedure as for the three phase two winding configuration described above, using the test procedure table below.

Table 5.26 Test Procedure For Autotransformer With Delta Tertiary

Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H0X0/X1-H0X0	H1	X1	HOXO	
2	H2-H0X0/X2-H0X0	H2	X2	H0X0	
3	H3-H0X0/X3-H0X0	H3	X3	H0X0	
4	H1-H0X0/Y1-Y2	H1	Y1	HOXO,Y2	
5	H2-H0X0/Y2-Y3	H2	Y2	H0X0, Y3	
6	H3-H0X0/Y3-Y1	H3	Y3	H0X0, Y1	
7	X1-H0X0/Y1-Y2	X1	Y1	H0X0, Y2	
8	X2-H0X0/Y2-Y3	X2	Y2	H0X0, Y3	
9	X3-H0X0/Y3-Y1	X3	Y3	H0X0, Y1	



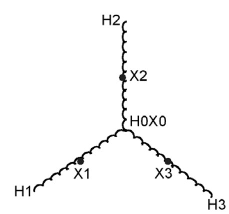


Auto Without Tertiary

There is one pair of windings, and the tests are all placed on one page, if using DTA.

Table 5.27 Test Procedure For Autotransformer Without Tertiary

Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H0X0/X1-H0X0	H1	X1	H0X0	
2	H2-H0X0/X2-H0X0	H2	X2	H0X0	
3	H3-H0X0/X3-H0X0	H3	X3	H0X0	



Three Windings

There are nine tests. In DTA, the three tests between each pair of windings are on their own pages. Test all three phases of each pair of windings before moving on to the next pair. All winding terminals not being tested float. Follow the same procedure as for the three phase two winding configuration described above, using the test procedure table below.

Table 5.28 Test Procedure For Wye-Wye-Delta Configuration

Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H0/X1-X0	H1	X1	H0, X0	
2	H2-H0/X2-X0	H2	X2	H0, X0	
3	H3-H0/X3-X0	H3	X3	H0, X0	
4	H1-H0/Y1-Y2	H1	Y1	H0, Y2	
5	H2-H0/Y2-Y3	H2	Y2	H0, Y3	
6	H3-H0/Y3-Y1	H3	Y3	H0, Y1	
7	X1-X0/Y1-Y2	X1	Y1	X0, Y2	
8	X2-X0/Y2-Y3	X2	Y2	X0, Y3	
9	X3-X0/Y3-Y1	X3	Y3	X0, Y1	

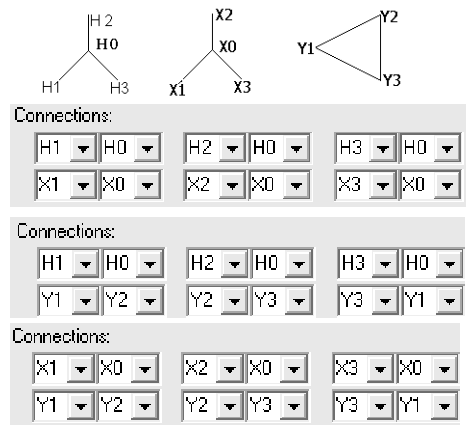


Table 5.29 Test Procedure For Wye-Delta-Delta Configuration

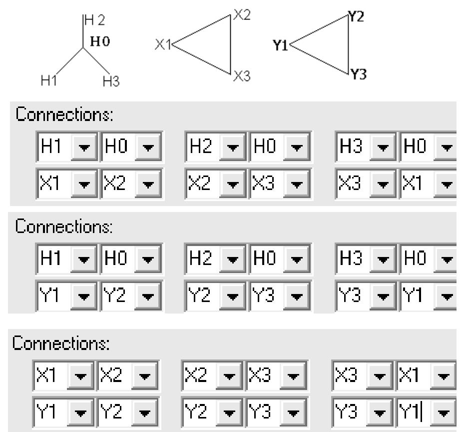
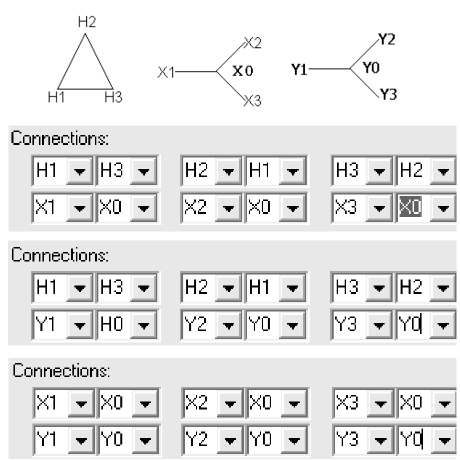
Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H0/X1-X2	H1	X1	H0, X2	
2	H2-H0/X2-X3	H2	X2	H0, X3	
3	H3-H0/X3-X1	H3	X3	H0, X1	
4	H1-H0/Y1-Y2	H1	Y1	H0, Y2	
5	H2-H0/Y2-Y3	H2	Y2	H0, Y3	
6	H3-H0/Y3-Y1	H3	Y3	H0, Y1	
7	X1-X2/Y1-Y2	X1	Y1	X2, Y2	
8	X2-X3/Y2-Y3	X2	Y2	X3, Y3	
9	X3-X1/Y3-Y1	X3	Y3	X1, Y1	

Table 5.30 Test Procedure For Delta-Wye-Wye Configuration

Test	Measured Ratio	Energize	UST Through Capacitor	Ground	Vector Diagram, Connections
1	H1-H3/X1-X0	H1	X1	H3, X0	
2	H2-H1/X2-X0	H2	X2	H1, X0	
3	H3-H2/X3-X0	H3	X3	H2, X0	
4	H1-H3/Y1-Y0	H1	Y1	H3, Y0	
5	H2-H1/Y2-Y0	H2	Y2	H1, Y0	
6	H3-H2/Y3-Y0	H3	Y3	H2, Y0	
7	X1-X0/Y1-Y0	X1	Y1	X0, Y0	
8	X2-X0/Y2-Y0	X2	Y2	X0, Y0	
9	X3-X0/Y3-Y0	X3	Y3	X0, Y0	

Analysis Of Results

The measured Turns Ratio must be within 0.5% of the calculated ratio. If using DTA, the calculated ratio is automatically displayed once the voltages of the two windings being measured are recorded in the Doble Turns Ratio form, and upper and lower limits are also displayed based on the 0.5% rule.

Leakage Reactance Testing

Introduction

Winding deformation which leads to an immediate transformer failure may be the result of several overcurrent events. The probability of overcurrent conditions is not very high and, as a result, a transformer can remain in service with partially deformed windings, although the reliability of such a transformer is reduced. Many transformer failures begin with mechanical deformation but eventually occur for electrical reasons. Consequently, determining mechanical deformation should be given very serious consideration. Even small changes in measured parameters should be treated with the utmost respect.

Several methods have been used to detect winding deformation. They are:

- frequency response analysis
- low-voltage impulse test
- capacitance measurement
- leakage reactance measurement

Methods one and two have inherently very promising searching capabilities. The relative sophistication of the instruments and the expertise required for these measurements has yet to allow them to become “household tools” at many utilities.

Capacitance measurements are performed as a part of the routine AC-insulation tests and normally include all three phases. Capacitance between the windings, and between each winding and the core/tank, is a function of their geometric relationships, as well as the dielectric constants of the intervening insulation. It is known that capacitance may exhibit minor variations due to temperature changes or serious contamination.

Leakage reactance measurements are performed by short-circuiting the low voltage winding (for details, see ”Test Setup Using the M4110 or the M4130” on page 5-82.

Test Considerations

There are two options being offered for measuring leakage reactance using the M4000. The M4130 Leakage Reactance Module requires the use of an external user-supplied variac and user-supplied current cables. The M4110 Leakage Reactance Interface includes all controls, cables, and safety interlocks, and the Leakage Reactance Module in a single package. Following are instructions for use of the M4110.

In addition to the M4000, it is necessary to have the following equipment for Leakage Reactance Testing:

- Doble Leakage Reactance Interface, including
- Set of M4110 Voltage Source Cables
- Set of M4110 Voltage Sense Cables
- M4110 Ground Cable
- The M4110 leakage reactance software module for the M4000

If using the M4130 Leakage Reactance Module, a variac and three cables are required to connect the variac autotransformer to the transformer bushings and the Leakage Reactance Module. The size of the cable must be in accordance with the variac rating. Note that the M4130 Leakage Reactance Module is rated 400 volts, 50 amperes. The M4130 is supplied with voltage sense cables and a DC power supply cable.

Information Needed Before Running a Test

Although it is possible to run a test without any transformer nameplate information or benchmark data, % Reactance and % Impedance cannot then be calculated. Transformer nameplates include the following information which should be entered into the M4000 program prior to running a test:

- Percent Impedance
- Base VoltAmperes (in MVA) for this impedance
- Base Line-to-Line voltage (in kV) for this impedance
- Tap positions for which the nameplate values were obtained

NOTE

For Single Phase transformers only, the Base Voltage in kV should be the Line-to-Ground, and not the Line-to-Line, kV.

If available from previous testing the following additional benchmark information should be entered:

- Benchmark percent impedance
- Benchmark percent reactance

If not, use the nameplate impedance in these fields.

Test Voltages

The objective is to select a voltage sufficient to allow an accurate measurement of the leakage reactance. The source can be a 120 or 240 volts outlet. The M4000 Leakage Reactance Interface can deliver a maximum test current of 25 amperes for 3-5 minutes before tripping the output circuit breaker. Its maximum continuous output current rating is 9.5 amperes. It is equipped with a thermal shutdown circuit that prevents the output from being energized in the event the variac autotransformer temperature has exceeded the safe operating limit. The red overload light indicates overload.

If using the M4130 Leakage Reactance Module, choose a variac with the ratings of the M4130 in mind (50 A, 400V).

Once you enter the transformer nameplate information (Percent Impedance, and kV, MVA, and tap positions on which this number is based) and the benchmark information, the M4000 calculates and suggests a test current. You can then adjust the variac to the recommended test current.

If transformer nameplate information reference information is not available, a test may still be run. However, if using the M4110, you must adjust the variac so as to achieve at least 15 volts on the winding.

CAUTION

Take care to assure all connecting cables are rated for the expected test current. Since one of the windings will be short-circuited for this test, the jumper cables must be rated for the expected current in the short-circuited winding. Although the current cables used to energize a winding will need to carry 25 amperes or less, the jumpers used to short-circuit the opposite winding may be required to carry many times this current.

Selective Test Method

The following approach to selecting the test type is recommended.

On a new or rebuilt three-phase transformer or during the initial test on a used transformer, a three-phase equivalent test and per-phase tests should be performed. This allows the comparison with the nameplate value (the three phase equivalent test), between the phases (per-phase tests) and provides a benchmark for future tests (per-phase tests). On a single-phase unit, only one test can be performed (Figure 5.33 M4110 Setup (a)). For comparison, tests should be performed on the same LTC positions as the nameplate values.

Once the comparison with the nameplate is verified, follow-up tests can include per-phase tests only. Besides being a more searching test, it allows the comparison not only with the previous test results but between the phases as well.

The initial tests should be performed on all the de-energized tap changer positions. It is conceivable that throughout its service life a transformer may be energized in several DETC positions. When units trip off-line, the service personnel may be reluctant to change the DETC positions solely to perform a test in positions in which the initial leakage reactance measurement was performed

Special Considerations

The test performed from the high-voltage winding at a given voltage requires a lower current from the source than the test performed at the same voltage from the low-voltage winding.

It is recommended to perform the test at the highest possible voltage to minimize the effects of the magnetizing reactance. For further information, see Proceedings of the *Sixty Second Annual International Conference of Doble Clients,* 1995, sec. 8-12.1. When nameplate data is available and input to the M4000 software, these test settings are selected for you.

For certain winding configurations, the results of the per-phase will not compare with the nameplate value or results of the three-phase equivalent test. For further information see Proceedings of the *Sixty-Second Annual International Conference of Doble Clients, 1995,* sec. 8-13.1.

Test Connections

Test connections for use with the M4110 are shown in Figure 5.33 M4110 Setup (a) and Figure 5.34 M4110 Setup (b). Test connections for use with the M4130 are shown in Figure 5.35 M4130 Setup (a) and Figure 5.36 M4130 Setup (b).

NOTE

These test connections represent common transformer winding vector relationships. Always check your transformer nameplate drawing to be sure the phase short-circuited corresponds to the phase energized! The consequence of short-circuiting the wrong winding will be that the tester will not be able to obtain the recommended current to run the test. For example, for a Per-Phase Wye test, a transformer with the following vector representation of its winding relationship would require the different connections shown:

Table 5.31 Example of Modified Connections for Leakage Reactance Per-Phase Wye Test

Connections Shown In Manual For Per-Phase Wye Test		**Connections Required by Per-Phase Wye Test For Wye-Delta Vector Diagram Shown Below**	
Energize	Short	Energize	Short
H1-H0	X1-X3	H1-H0	X2-X1
H2-H0	X2-X1	H2-H0	X3-X2
H3-H0	X3-X2	H3-H0	X1-X3

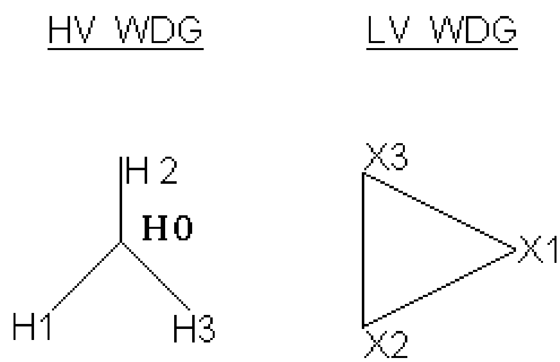


Figure 5.31 Example of Transformer Winding Vector Diagram Requiring Modified Leakage Reactance Test Connections

Test Procedures for a Two-Winding Three-Phase Unit

With the M4000 insulation analyzer, which uses single-phase excitation, the leakage reactance of a three-phase unit can be measured using two methods: the three-phase-equivalent test and the per-phase test.

Three-phase equivalent test

One test is performed on each phase, by connecting the voltage source and sense leads from the Leakage Reactance Interface to each pair of line terminals. All three line terminals on the opposite winding are connected together with jumpers, as shown on Figure 5.34 M4110 Setup (b) (if using the M4110), and Figure 5.36 M4130 Setup (b) (if using the M4130).

Per-phase test

One test is performed on each phase, by connecting the voltage (source and sense) leads from the Leakage Reactance Interface to a line and the neutral terminals on wye and zig/zag windings or to a pair of line terminals on a delta winding. The terminals on the opposite winding should be short-circuited, as shown in Figure 5.33 M4110 Setup (a) (if using the M4110), and Figure 5.35 M4130 Setup (a) (if using the M4130).

NOTE

Use the vector diagram on the transformer nameplate to assure that the phase being short-circuited corresponds to the phase being energized. The examples in the above-mentioned figures may not always correspond to the vector diagrams representing your transformer.

Test procedures for a two-winding single-phase unit

The test connections for a single-phase unit are shown in Figure 5.33 M4110 Setup (a) or Figure 5.34 M4110 Setup (b) (if using the M4110), and Figure 5.35 M4130 Setup (a) or Figure 5.36 M4130 Setup (b) (if using the M4130).

CAUTION

Be aware of the transformer turns ratio, and the high currents that may result on the short-circuited winding. Be sure the jumper cables are rated for that current!

Test procedures for a multi-winding unit

In a multi-winding (more than two windings) unit, the leakage reactance associated with each pair of windings should be tested. Pick two windings between which you wish to measure the Leakage Reactance, and (after entering the nameplate data corresponding to that winding pair) energize the higher-voltage one while shorting the lower-voltage one in accordance with the connection instructions. The line terminals of the other windings should be left floating. In a three-winding unit, the test procedures described above are applied to three pairs of windings. In a four-winding unit, they are applied to six pairs of windings. The figure below shows the Per-Phase leakage reactance test on one phase between the H and X windings of a three-winding transformer. Tests would then be made between H and Y windings (X floating), and between X and Y (H floating).

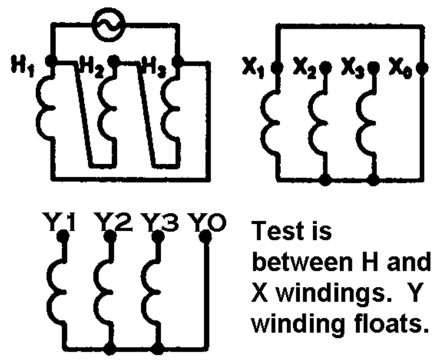


Figure 5.32 Leakage Reactance Test on a Three-Winding Transformer

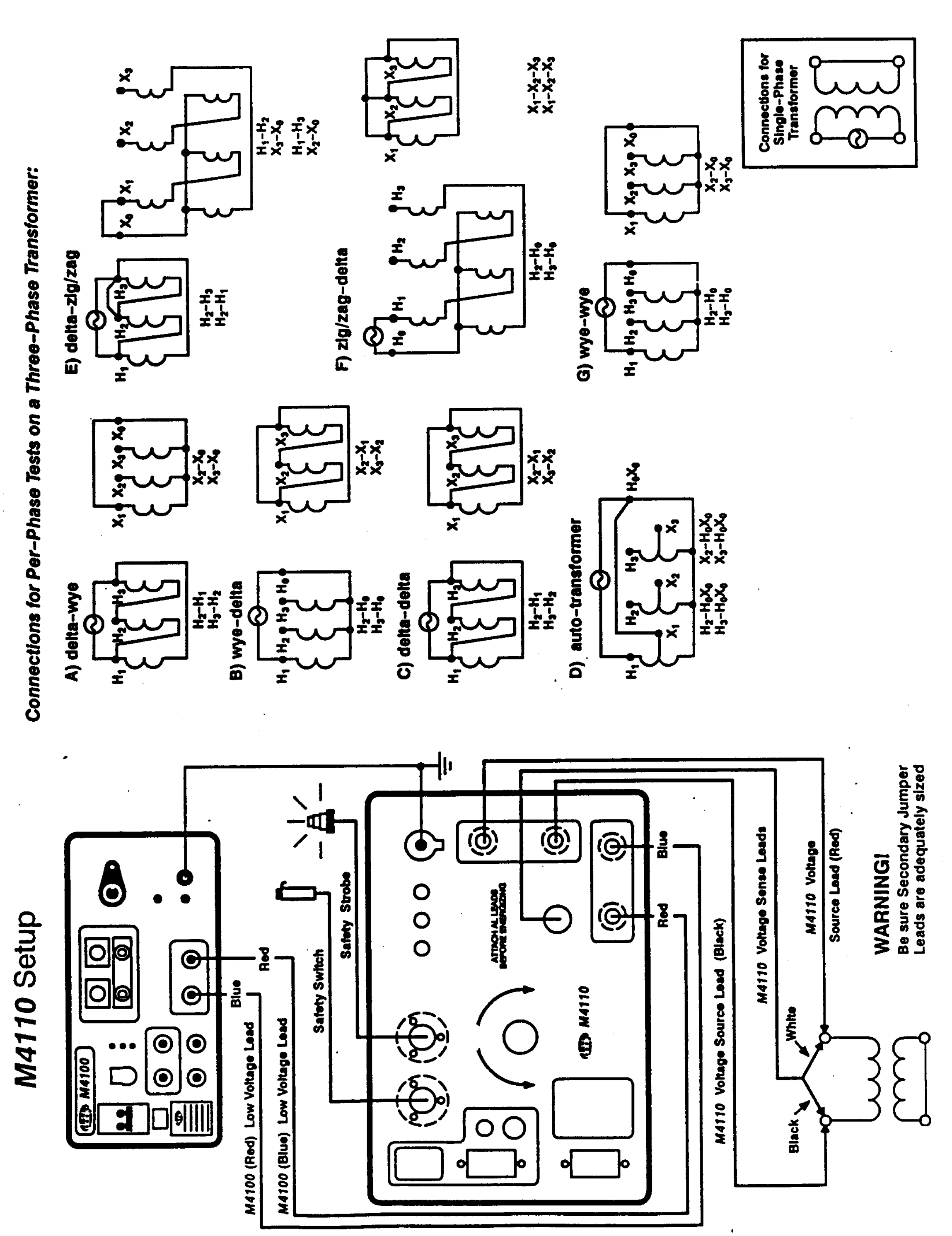


Figure 5.33 M4110 Setup (a)

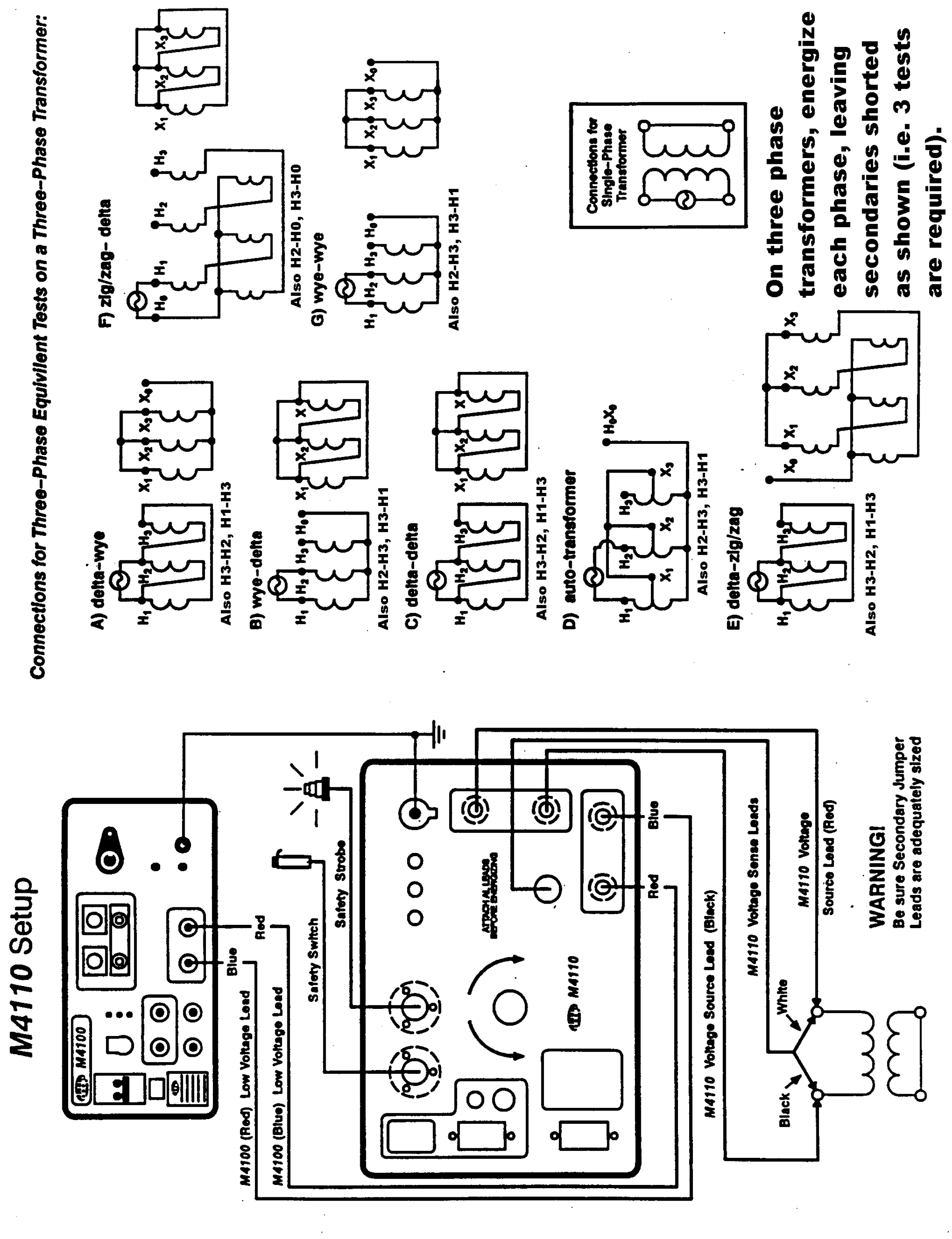


Figure 5.34 M4110 Setup (b)

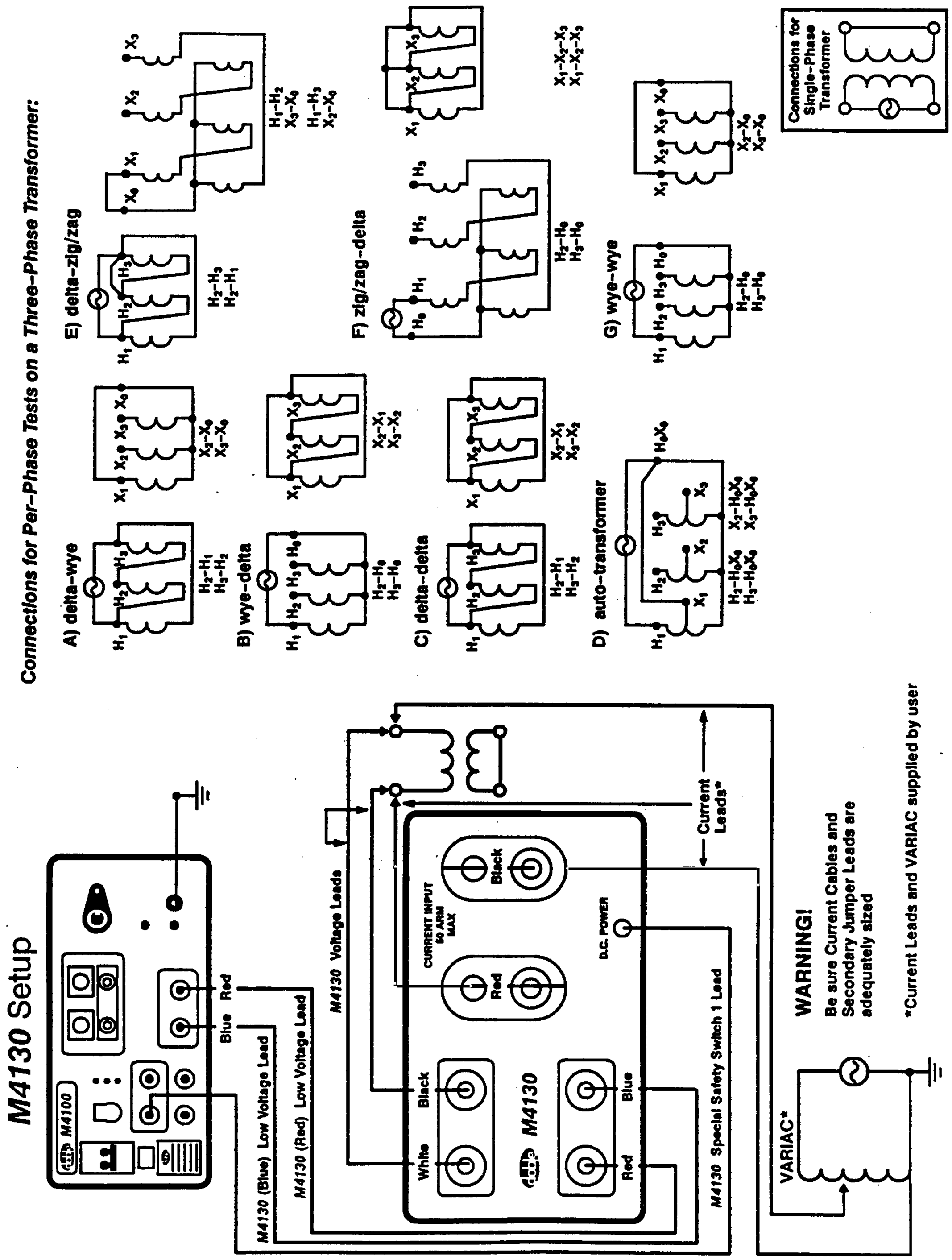


Figure 5.35 M4130 Setup (a)

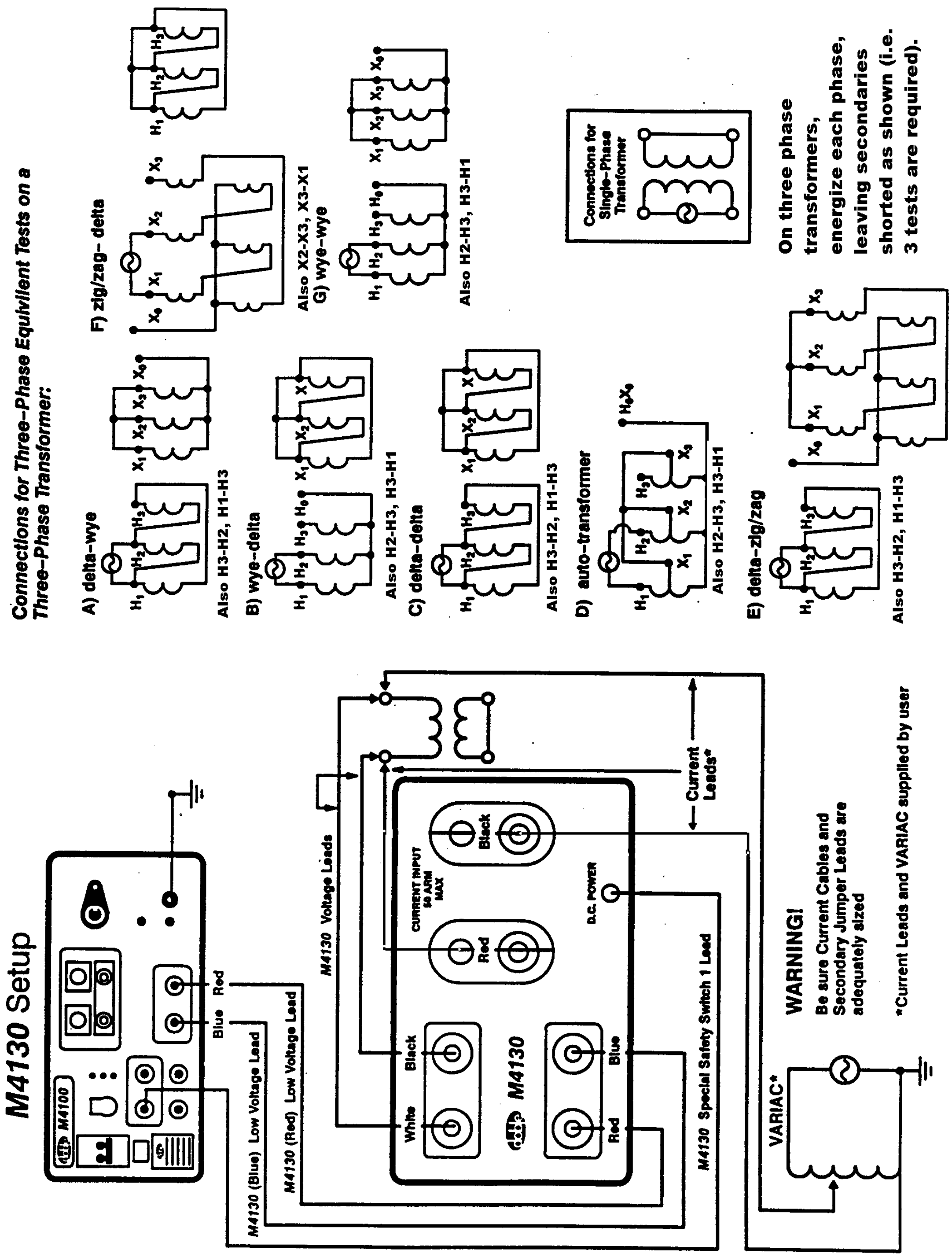


Figure 5.36 M4130 Setup (b)

Test Setup Using the M4110 or the M4130

Use Figure 5.33 M4110 Setup (a), Figure 5.34 M4110 Setup (b), Figure 5.35 M4130 Setup (a), and Figure 5.36 M4130 Setup (b) to select the connection that applies to your transformer winding configuration.

Setup for a Single-Phase Transformer Test, M4110

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4110 Leakage Reactance Interface ground cable to ground. Make sure the M4100 and M4110 test ground leads are connected to a common ground point.
3. Connect one end of each of the two voltage source leads across the winding to be energized, and the other end of each to the M4110 Leakage Reactance Interface Voltage Source Terminals.
4. Connect the black and white clips on one end of the voltage sense cable across the same winding as the voltage source leads, connect the connector on the other end to the Leakage Reactance Interface Voltage Sense Terminals, observing the color coding of the leads. THE VOLTAGE SOURCE AND VOLTAGE SENSE LEADS MUST BE CONNECTED IN SUCH A WAY THAT THE BLACK TERMINALS OF EACH ARE CONNECTED TO THE SAME BUSHING; AND THE RED SOURCE AND WHITE SENSE TERMINALS ARE CONNECTED TO THE OTHER BUSHING.
5. Jumper together the two terminals of the opposite winding (see Figure 5.33 M4110 Setup (a) or Figure 5.34 M4110 Setup (b)).
6. Connect the M4100 safety switch to the M4110 Leakage Reactance Interface.
7. Connect the M4100 safety strobe to the M4110 Leakage Reactance Interface.
8. Connect the Red and Blue leads between the M4100 and the M4110 Leakage Reactance Interface, observing the color coding.
9. Connect the M4200c, the M4100, and the M4110 to your AC power source.

Setup for a Single-Phase Transformer Test Using the M4130

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4130 DC power supply cable between the M4130 Leakage Reactance Module and the M4100 Safety Switch #1 connector.
3. Connect the three sections of user-supplied current leads so as to complete a circuit from the user-supplied variac, across the winding to be energized, through the M4130 Leakage Reactance Module, and back to the variac (see Figure 5.35 M4130 Setup (a)).

4. Connect the black and white leads from one end of the voltage cable across the same winding as the current leads, and the leads from the other end to the M4130 Leakage Reactance Module Voltage Input Terminals, observing the color coding of the leads. THE CURRRENT AND VOLTAGE CABLES CONNECTED TO THE BLACK TERMINALS ON THE M4130 MUST BE CONNECTED TO THE SAME TRANSFORMER BUSHING, AND THE CURRENT CABLE CONNECTED TO THE RED M4130 TERMINAL MUST BE CONNECTED TO THE SAME BUSHING AS THE VOLTAGE CABLE CONNECTED TO THE WHITE M4130 TERMINAL (See Figure 5.35 M4130 Setup (a) or Figure 5.36 M4130 Setup (b)).
5. Jumper together the two terminals of the opposite winding (see Figure 5.35 M4130 Setup (a) or Figure 5.36 M4130 Setup (b)).
6. Connect the Red and Blue leads between the M4100 and the M4130 Leakage Reactance Module, observing the color coding.
7. Connect the M4200c and the M4100 to your AC power source.

Setup for a Three-Phase Transformer Test Using the M4110

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4110 Leakage Reactance Interface ground cable to ground. Make sure the M4100 and M4110 test ground leads are connected to a common ground point.
3. If performing a Per-Phase test, connect one end of the voltage source leads across a phase of a winding (such as H_3–H_1 or H_3-H_0), and the other end to the M4110 Leakage Reactance Interface Output Terminals, matching the terminal colors to those of the lead connectors. If performing a Three Phase Equivalent test, connect one end of the voltage source leads across two phase terminals (the neutral bushing is not used), and the other end to the M4110 Leakage Reactance Interface Output Terminals, matching the terminal colors to those of the lead connectors
4. Connect one end of the voltage sense leads across the same terminals as the voltage source leads. Connect the other end to the M4110 Leakage Reactance Interface Voltage Input Terminals, observing the color coding of the leads. THE SOURCE AND SENSE LEADS MUST BE CONNECTED IN SUCH A WAY THAT THE BLACK CONNECTORS ON THE SOURCE AND SENSE LEADS SHOULD BOTH BE CONNECTED TO THE SAME BUSHING ON THE TRANSFORMER UNDER TEST. ALSO, THE RED SOURCE LEAD AND THE WHITE SENSE LEAD SHOULD BOTH BE CONNECTED TO THE BUSHING ON THE OTHER END OF THE TRANSFORMER WINDING UNDER TEST.

5. **<u>If performing a Per-Phase test</u>**, jumper only the phase of the opposite winding corresponding to the phase under test, as determined by the winding vector diagram on the transformer nameplate, except in the case of a zig-zag winding (see Figure 5.33 M4110 Setup (a)). **<u>If performing a Three-Phase Equivalent Test</u>**, jumper all three line terminals of the opposite winding.
6. Connect the M4100 safety switch to the M4110 Leakage Reactance Interface.
7. Connect the M4100 safety strobe to the M4110 Leakage Reactance Interface.
8. Connect the Red and Blue leads between the M4100 and the Leakage Reactance Interface, observing the color coding.
9. Connect the M4200c, the M4100, and the M4110 to your AC power source.

Setup for a Three-Phase Transformer Test Using the M4130

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4130 DC power supply cable between the M4130 Leakage Reactance Module and the M4100 Safety Switch #1 connector.
3. <u>If performing a Per-Phase test</u>, connect one end of the voltage source leads across a phase of a winding (such as H_3–H_1 or H_3-H_0), and the other end to the M4130 Leakage Reactance Module Output Terminals, matching the terminal colors to those of the lead connectors. <u>If performing a Three Phase Equivalent test,</u> connect one end of the voltage source leads across two phase terminals (the neutral bushing is not used), and the other end to the M4130 Leakage Reactance Module Output Terminals, matching the terminal colors to those of the lead connectors
4. Connect one end of the current leads across a phase of a winding (such as H_3–H_1), and the other end to the M4130 Leakage Reactance Module Input Terminals.
5. Connect one end of the voltage leads across the same phase as the current leads. Connect the other end to the M4130 Leakage Reactance Module Voltage Input Terminals, observing the color coding of the leads. THE CURRENT AND VOLTAGE LEADS MUST BE CONNECTED IN SUCH A WAY THAT THE CURRENT LEAD AND THE VOLTAGE LEAD CONNECTED TO THEIR RESPECTIVE BLACK COLORED TERMINALS ON THE M4130 LEAKAGE REACTANCE MODULE SHOULD BOTH BE CONNECTED TO THE SAME BUSHING ON

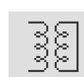
THE TRANSFORMER UNDER TEST. ALSO, THE CURRENT LEAD CONNECTED TO THE RED TERMINAL AND THE VOLTAGE LEAD CONNECTED TO THE WHITE TERMINAL ON THE M4130 LEAKAGE REACTANCE MODULE SHOULD BOTH BE CONNECTED TO THE BUSHING ON THE OTHER END OF THE TRANSFORMER WINDING UNDER TEST.

6. **<u>If performing a Per-Phase test</u>**, jumper only the phase of the opposite winding corresponding to the phase under test, as determined by the winding vector diagram on the transformer nameplate, except in the case of a zig-zag winding (see Figure 5.35 M4130 Setup (a)). **<u>If performing a Three-Phase Equivalent test</u>**, jumper all three line terminals of the opposite winding.
7. Connect the Red and Blue leads between the M4100 and the M4130 Leakage Reactance Module, observing the color coding.
8. Connect the M4200c and the M4100 to your AC power source.

Setup For a Transformer With Three Or More Windings

1. Follow the instructions for a two winding transformer
2. Leakage Reactance should be measured between all pairs of windings (H-X, H-Y, X-Y, etc)
3. The windings not under test must be left floating

Running A Test

1. Once the connections are made, turn on the test set.
2. Select Mode/Leakage Reactance from the Main Menu bar, or click the Leakage Reactance Icon. 
3. Select the winding configuration. This must be done first, since doing so automatically sets the available test configuration and resulting nameplate data and benchmark data entry fields. If using DTA, this will be automatically filled in on the Leakage Reactance nameplate screen when you enter transformer configuration on the main nameplate screen.

4. Some of the Test Configurations are available for selection only with certain winding configurations.

   Select a Test Configuration:

Winding Configuration	**Test Configurations Available**
Single-Phase	Single-Phase
Delta-Wye	Three-Phase Equivalent, Per-Phase Delta, Per-Phase Wye
Delta-Delta	Three-Phase Equivalent, Per-Phase Delta
Wye-Delta	Three-Phase Equivalent, Per-Phase Wye
Wye-Wye	Three-Phase Equivalent, Per-Phase Wye
Delta-Zigzag	Three-Phase Equivalent, Per-Phase Delta, Per-Phase Zigzag
Wye-Zigzag	Three-Phase Equivalent, Per-Phase Wye, Per-Phase Zigzag
Other	Three-Phase Equivalent, Per-Phase, Other

5. Enter transformer identification in the Nameplate Information fields.

To enter this nameplate and benchmark information:

- On the Leakage Reactance form, click the *Benchmark* tab.
- Enter the tap positions (ignore a field if there is no on-load tap changer) on the first available row.
- In the *Phase* column, identify the phase.
- In the *Base Voltamperes (MVA)* and *Base Volts (kV)*, enter the values given on the nameplate.
- In the *Nameplate % Impedance*, enter the nameplate impedance.

- Unless this is the first test, enter the values obtained for the % impedance and % reactance for each phase of the first (benchmark) per-phase tests. If this is the first test, and you have no benchmark data, enter the transformer nameplate impedance in both of these fields, and the results from this first per-phase test will be entered as the benchmark values for all future tests.
- If using DTA, the benchmark data is entered on the Leakage Reactance test screen, with values for % Impedance and % Reactance entered on the screen corresponding to the tab selected below.

6. There will be one nameplate value and one benchmark value per single-phase transformer. The M4000 allows three single-phase tests to be made on a single screen, in the event the user is testing a bank of three single-phase transformers. When *Winding Configuration* is selected as *Single*, the letter next to the *Serial Number* field indicates which single phase transformer is being identified. Click the button to advance the display to the next serial number.

7. The three-phase equivalent test will have one nameplate value and one benchmark value.

8. The per-phase-delta (or wye) will both have one nameplate value and three benchmark values, one per phase.

NOTE ☝ **For all but the single phase transformers, base voltage must be line-to-line; for single phase transformers, it must be line-to-ground.**

9. Enter information in the Administration and Test Conditions buttons as needed.

10. Depending on the selected Test Configuration, there may be up to three rows (phases) where test data will be entered. Make sure the desired row in the Phase column is filled in before testing, in order to identify the terminals energized and the terminals shorted for the record. When starting a test, you will be asked which row (phase) you are testing.

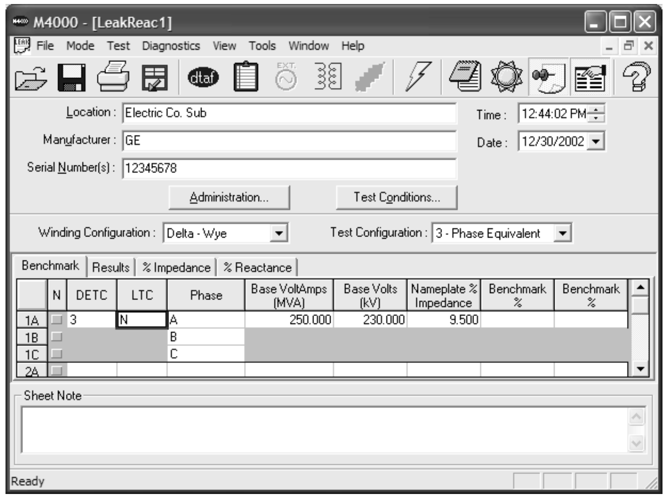


Figure 5.37 Leakage Reactance Test Nameplate Data

11. To begin the test, press F2 or click the lightning bolt icon. If the Nameplate data has not been entered, you will be presented with a final warning screen before you start the test.

WARNING

If using the M4130 Leakage Reactance Module, the safety switches and safety strobe are not used! Observe necessary safety precautions!

12. Adjust the variac until the value of current opposite the analog current bar on the screen falls in or as near as possible to the recommended test current range. The test voltage should exceed at least 15 volts.

13. Press the F3 key to measure. The message, “Do not change voltage; collecting data” will be displayed.

14. When the M4000 has made the necessary measurements, the message, “Test Done” will be displayed.

15. Press F5 to accept the results, or any of the other keys whose functions are described at the bottom of the screen:

F1	Screen Help
F2	Restart Test
F5	Accept Results
F6	Discard Results
F7	Print Results
F8	Save Results

16. Repeat the test for each phase of the winding, making sure the correct column is highlighted before starting.
17. Start a new Leakage Reactance form for each pair of windings being tested. You will need three forms for a three-winding transformer, and six for a four winding transformer.

Interpretation of Test Results

There are three tabs which show test results: the *Results* tab shows many of the measured variables. The main analysis is done with the data in the *% Impedance* and *% Reactance* tabs. Besides the measured and benchmark values, they contain the Delta Benchmark and Delta Average values. The analysis depends on whether the test is an initial or a subsequent one. During the initial test, both the three-phase equivalent and the per-phase measurements are performed. The subsequent test (with some exceptions, discussed below) requires only the per-phase measurements.

The factory data are usually expressed in terms of the average short-circuit impedance. Therefore, they should be compared with the impedance value measured in the field using the three-phase equivalent measurement. The comparison between the initial and subsequent tests should be performed on the basis of the per-phase leakage reactance test results. For transformers whose nameplate impedance is less than 5% and whose power rating is less than or equal to 500 KVA, the tester should perform only the per phase test and its results analysis, and not the three phase equivalent.

Initial Test

The objective of the initial test is twofold: to compare results with factory data and to establish a benchmark for subsequent tests. The purpose of the three-phase equivalent test is to produce results for comparison with the factory data (*Delta Benchmark*, if the factory nameplate impedance was used as a benchmark value). When results are not within 3% of the nameplate values, the explanation may lie in different instrumentation and test setups (a different de-energized tap was used), difference in flux distribution under the three- and single-phase excitation, and/or the presence of the winding distortion. The latter can be confirmed through the per-phase test, where the comparison between phases (*phase pattern*) may help to explain the difference between factory and field results. The average value of the three per-phase impedances is calculated, and the percentage difference between each per-phase value and this average is show in the *Delta Average* column. If each of the three phases is within 3% of their average value, the winding distortion most likely is not an issue. For the single-phase units (for obvious reasons), all the analyses are based on the per-phase measurements only.

Typically, the results of the per-phase measurements are used as a benchmark for subsequent measurements. On some units, however, the per-phase results are influenced by the reluctance of the leakage flux path outside the leakage channel (due to the peculiarities of the single-phase excitation), thus masking the changes in the leakage channel. Under these conditions, all three per-phase values may exceed the factory data by as much as 10-30%, while the three-phase equivalent test may be comparable with the factory data. Therefore, in these cases the results of the three-phase equivalent measurement may be used as a benchmark for subsequent tests.

In a three-winding unit, the sign of a change in leakage reactance associated with three pairs of windings can be used to identify the distorted winding. These limits simply state whether the distortion is present. The real challenge is in defining the limits that, if not exceeded, will allow the unit to remain in service even with distorted windings. At the same time, the same percent change in the measured leakage reactance can be caused by different levels of distortion in different transformers. Therefore, these limits may be different for different transformer designs. In the meantime, experience suggests that a winding distortion could be suspected if both the three-phase equivalent results deviate from the factory data, and the per-phase results deviate from each other by more than 3% of the measured value.

In conclusion, the *Delta Benchmark* is generally used for the initial test data analysis, using the three phase equivalent test, and for subsequent tests, using the per-phase tests. The *Delta Average* is used mainly for the initial per-phase test, before a real benchmark for these values has been established.

Subsequent Test

During the subsequent test, results of the per-phase test or (if applicable) the three-phase equivalent test are compared with results of initial (benchmark) measurements. We recommend treating changes exceeding 2% of the leakage reactance measured during the initial tests as an indication of winding distortion.

6. Surge Arresters

Introduction

The surge arrester is one of the most important protective devices in use on electric systems, ensuring continuity of operation despite repeated surges resulting from lightning and switching. Its function must be that of a circuit breaker, normally open, but closing to discharge transient currents accompanying a disturbance. After discharging transient currents, it must reopen to prevent the flow of system power which would be destructive to itself and result in system disturbances. It must be an insulator under normal conditions, but at the instant of a disturbance, it must become a conductor of low-enough resistance to prevent a development of dangerous voltages which would destroy the apparatus it protects. With the passing of the disturbance, it must revert to its role of an insulator.

With the exception of extremely old units and some modern EHV units, most station- and intermediate-class arresters currently installed on systems are of the “unit design”, where gap and valve elements are enclosed in a single porcelain housing, resulting in each unit being an independent arrester. These employ a series gap element with shunting resistors to shield the gaps and to provide uniform voltage distribution across the individual gaps and units. In addition, the shunt resistors provide sufficient heat to maintain an internal temperature slightly above ambient, and therefore, help to protect the gaps against moisture. The valve elements all utilize materials displaying nonlinear volt-ampere characteristics, resulting from the ability of the materials to reduce their electrical resistances when the voltage across their terminals is increased.

The shunted gap elements and valve elements in an arrester unit make up a series circuit which is shunted by the porcelain housing. The arrester thus has electrical characteristics, such as AC grading current and dielectric loss, which are measurable. The resistors shunting the gap elements are generally selected for uniformity so that their contributions to these characteristics are quite consistent among similar units. The valve blocks, being of relatively high resistance, do not have any appreciable effect on the test characteristics of an arrester in good condition.

Modern arresters of the oxide-film type are currently available from most major arrester manufacturers; some manufacturers employ gaps in their design, while some do not.

Failures of modern-day arresters, in most cases, can be attributed to one of five causes. These are:

1. Damaged, defective, or contaminated units.
2. Direct, or nearly direct, lightning strokes.
3. Long-duration surges resulting from switching, etc.
4. Misapplication.
5. Prolonged dynamic overvoltages.

Of these, the last four are matters of design and application. Experience has shown that the measurement of dielectric loss is effective in detecting defective, contaminated, and deteriorated arresters. While the dielectric-loss test may not relate directly to the protective characteristics of an arrester, it is a test of its mechanical condition and insulating qualities, and it will be recalled that for most of its life an arrester relies on its ability as an insulator. Those conditions, which alter the mechanical and insulating qualities of an arrester, also may affect its ability to function as a protective device.

Test Voltages

Surge arresters have nonlinear volt-ampere characteristics (i.e., the resistance/impedance varies with applied voltage). It is important that Doble AC dielectric-loss tests on arresters be performed at prescribed test voltages, in order to permit meaningful comparisons to be made between units. The following voltages should be applied for Doble tests on arresters:

Arrester Type	MCOV kV	Arrester Unit Rating (kV)	Doble Test Voltage (kV)
Silicon Carbide		3.0	2.5
		4.5	4.0
		6.0	5.0
		7.5	7.0
		9.0/10.0	7.5
		12.0 and above	10.0
Metal Oxide	2.2 to 2.55	2.7 to 3.0	2.0
	3.7 to 10.6	4.5 to 12.0	2.5
	12.7 and higher	15.0 and higher	10.0

In some cases the tabulated watts-loss data obtained using Doble 10 kV sets is limited for given makes and types of arresters. Although, for some of these units there may be data recorded in terms of milliwatts obtained using Doble 2.5 kV sets. In these instances, supplementary tests should be performed at 2.5 kV using the M4000 set, and the Equivalent 10 kV watts-loss values obtained converted to Equivalent 2.5 kV milliwatts using the following formula:

- Equivalent 2.5 kV milliwatts = 62.5 x Equivalent 10 kV watts*

  *As measured with the M4000 set at a test voltage of 2.5 kV.

The calculated Equivalent 2.5 kV milliwatts are then compared directly with tabulations of milliwatts obtained using Doble 2.5 kV sets.

Test Procedures

Multiple Tests

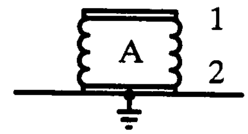
DTA can perform multiple tests to save time. In the procedures described below, any two arrester units which can be tested without changing the test leads can be tested with a multiple test. The user must only specify the low voltage lead used and the test circuit to be used for each test. For example:

1. In the two unit arrester stack test procedure described below, tests 1A and 2A can be made with a multiple test. If you have connected the red LV lead to (1), the two test circuits you will have to select when prompted by DTA are: test 1A) UST measure Red, ground Blue to measure unit A; and test 2A) GST-Guard Red to measure unit B.

2. In the five unit arrester stack test procedures described below, tests 2 and 3 can be made with one multiple test, and tests 4 and 5 with another. For tests 2 and 3, the circuit selections to be made if connecting the Blue lead to 2 and the Red to 4 would be: test 2) GST-Guard Red ground Blue to measure unit B; and test 3) UST Red and Ground Blue to measure unit C. For tests 4 and 5, with Red connected to 4, the circuit selections would be: test 4) UST Red ground Blue; and test 5) GST-Guard Red ground Blue (ignore Blue in this test, since it isn't being used).

Arrester assemblies consisting of single units per phase are generally tested by the grounded-specimen test method (GST) as shown in Table 6.1. The line connected to the arrester is first de-energized and grounded, then disconnected from the arresters.

Table 6.1 Test Procedure for Single-Unit Arrester Stack

Test No.	Test Mode	Test kV	Energize	Ground	Measure	Bus Disconnected
1	GST	*	1	2	A	

* Refer to discussion under TEST VOLTAGES

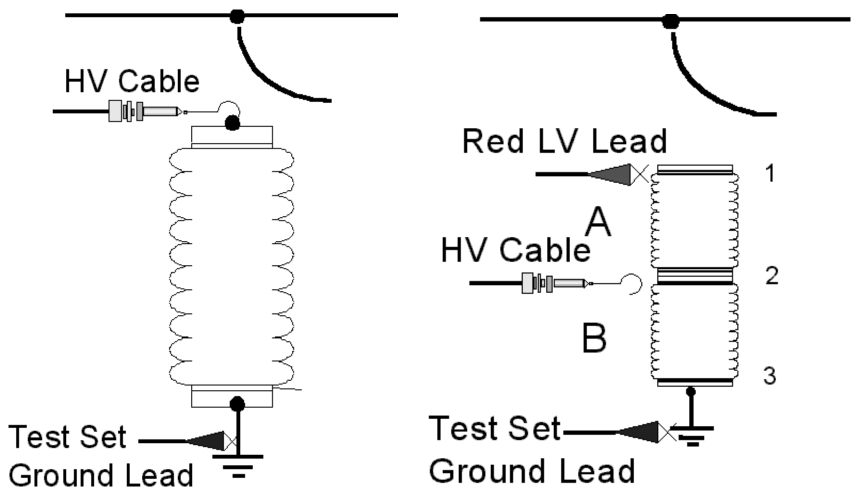
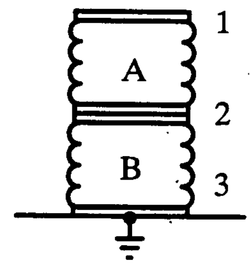


Figure 6.1 Surge Arresters, 1 and 2 Unit Stacks, Test Connections

Care should be taken in the case of arrester units which are grounded through leakage-current detectors or discharge counters. For test purposes, the detector or counter should be short-circuited by applying a ground directly to the base of the arrester. The short-circuit must be removed before the arrester is returned to service.

Assemblies consisting of two units per phase are tested in the manner outlined in Table 6.2. Again, the line is de-energized and grounded then disconnected from the arrester stack.

Table 6.2 Test Technique on Double-Unit Arrester Stack

Test No.	Test Mode	Test kV	Energize	Ground	Guard	UST	Measure	Bus Disconnected
1	GST	*	1	2	—	—	A	
2	GST	*	2	3	—	—	B	
				or				
1A**	UST	*	2	3	—	1	A	
2A**	GST	*	2	3	1	—	B	

* Refer to discussion under TEST VOLTAGES

** SeeFigure 6.1 above.

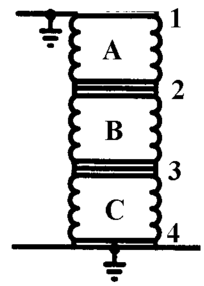
Two separate methods are outlined in Table 6.2, one involving direct measurements by GST (Tests 1 and 2), and an alternative method with measurements by both the UST and GST methods (Tests 1A and 2A). It should be noted that, in the method involving the UST measurement, dielectric losses measured for the A and B units should be practically identical if they are the same type and kV rating. The charging current of the UST measurement (Test 1A) may be appreciably lower than the current measured in the GST measurement (Test 2A), since stray currents to ground which are included in the GST measurement are not included in the UST reading. Figure 6.1 above illustrates the test connections for tests 1A and 2A.

In the case of assemblies of three arresters or more per-phase, it is only necessary to de-energize the line and to ground the top of the arrester stack. The bus need not be disconnected from the arrester stack. The individual units in the stack may be tested by using several variations of the GST and UST methods. One variation is shown in Table 6.4.

Table 6.3 Test Technique 3 Unit Stack

Test No.	Test Mode	Test kV	Energize	Ground	Guard	UST	Measure	Bus Disconnected
1	GST	*	2	1, 4	3	—	A	
2	UST	*	3	1, 4		2	B	
3	GST	*	3	1, 4	2	—	C	

* Refer to discussion under TEST VOLTAGES



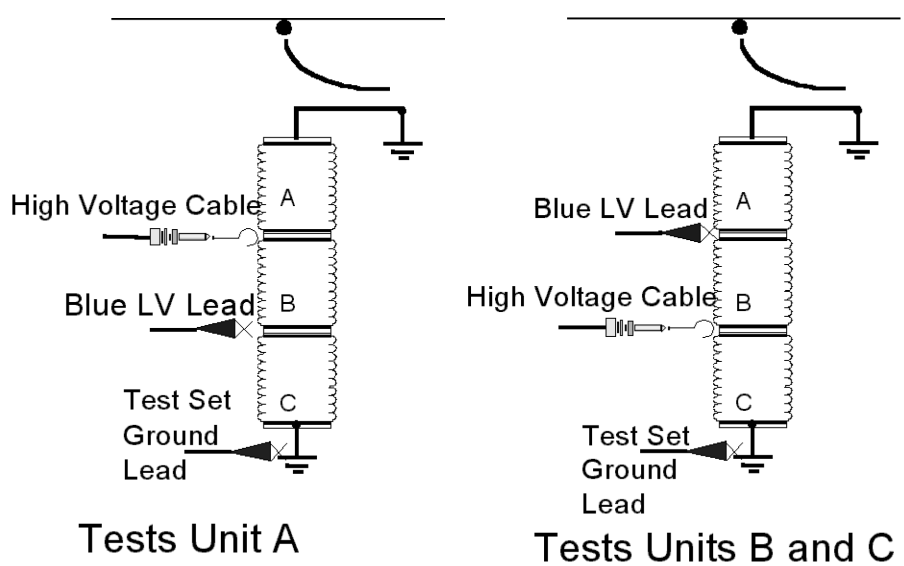


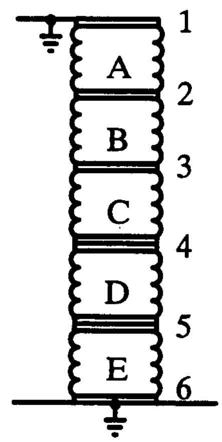
Figure 6.2 Surge Arrester, 3 Unit Stack Test Connections

Table 6.4 Test Procedure for Multi-Unit (5) Arrester Stack

Test No.	Test Mode	Test kV	Energize	Ground	Guard	UST	Measure
1	GST	*	2	1,6	3	—	A
2	GST	*	3	1,2,6	4	—	B
3	UST	*	3	1,2,6	—	4	C
4	UST	*	5	1,6	—	4	D
5	GST	*	5	1,6	4	—	E

* Refer to discussion under TEST VOLTAGES

Bus Disconnected



All arresters should be tested individually and not in parallel. Note that, in the UST measurements of Table 6.4 (Tests 3 and 4), arrester currents measured may be lower than those recorded for similar units in GST measurements because of elimination of stray currents to ground in the UST determination: although the watts-losses should be similar.

Analysis of Results

To assist in the analysis of the test results, tabulations are published on the various makes and types of station- and intermediate-class arresters. This data appears in the *Doble Arrester Field-Test Guide* and in the Arrester section of the *Test-Data Reference Book.*

In cases where data for a specific type may be lacking, the test engineer should make the analysis by comparing losses obtained for similar units tested at the same time and test voltage, and under the same conditions. This is usually possible, since similar arresters are normally installed at the same location. Once a range of losses has been established, any deviation, either higher or lower, should be investigated. Because of the basic characteristics of arresters, the tests are rated on the losses obtained. The power factor need not be calculated. Temperature correction factors are unnecessary throughout the normal range of temperatures encountered.

Since the results of tests on arresters are affected to varying degrees by surface leakage, analysis of test results should take this into account. Surface losses can usually be minimized by wiping the porcelain with a plain, dry cloth, but it may be necessary to resort to use of cleaning agents and waxes, application of heat to the porcelain surface, or utilization of guard collars.

Where the effects of surface leakage can be discounted, abnormal losses usually can be attributed to one or more of the following:

Higher-Than- Normal Losses

1. Contamination by moisture and/or dirt or dust deposits on the inside surfaces of the porcelain housing, or on the outside surfaces of sealed-gap housings.
2. Corroded gaps.
3. Deposits of aluminum salts apparently caused by the interaction between moisture and products resulting from corona.
4. Cracked porcelain.

Lower-Than- Normal Losses

1. Broken shunting resistors.
2. Broken pre-ionizing elements.
3. Mistake in assembly.
4. Poor contact and open circuits between elements.

NOTE

SAFETY IN HANDLING SUSPECT ARRESTERS Certain precautions should be taken when handling arresters thought to be defective. For example, with reference to “suspect” arresters equipped with relief diaphragms, gas pressures may exist below the rupturing pressure of the diaphragm. These units must be handled with appropriate care. If a decision is made to disassemble a suspect unit, it must be vented in accordance with company safety practices before the disassembly process begins. For additional comments, refer to the *Doble Arrester Field Test Guide.*

7. Capacitors

Coupling Capacitors

Introduction

Doble tests are ideally suited to the oil-paper or newer paper/film/synthetic fluid coupling capacitor. They check not only the insulating qualities of a unit but also its functional characteristics. Capacitors are designed for a low insulation power factor, which, along with their designed capacitance, must remain stable. Abnormal changes in either value may affect not only the performance of a capacitor installation, but also may indicate the development of a failure hazard.

A typical coupling capacitor is constructed of a series-parallel arrangement of oil- or synthetic fluid-impregnated paper-foil or paper-polypropylene film-foil capacitor units. It is evident therefore that, as the ratings of the coupling capacitors increase, the number of units is also increased and the effect of a single unit on the overall test results is decreased. Measurements and interpretation must be made with care if small, but significant, changes are to be detected.

The first, or lowermost, porcelain in the stack contains two capacitors (C2 and C1-1) connected together inside the porcelain at the potential (POT) terminal. Modern coupling capacitors do not allow direct access to the POT terminal for testing. Instead, the terminal is grounded through the potential grounding switch, and each of the two capacitors are tested by energizing their opposite ends, and performing a GST test to ground through this grounding switch. The C2 capacitor’s percent power factor and capacitance is usually available on the nameplate, but the C1-1 may not be. Instead, the values for a combination of C2 and C1-1 may be given. Thus, the user may have to use the alternate method (testing C2 and C1-1 in series) or make some field calculations to obtain a value for C1-1 to compare to nameplate. If there is no potential grounding switch, then this alternate test may be the only test available.

The acceptable power factor limit for oil/paper construction is 0.5%. The acceptable power factor limit for synthetic fluid/paper/film construction is 0.2%.

Test Voltages

All tests are performed at 10 kV except where the potential (POT) or carrier (CAR) terminals are energized. The POT terminal is usually rated 5 kV; if in doubt, consult the manufacturer's instruction book. The CAR terminal must not be energized at over 2 kV, unless otherwise specified by the manufacturer.

Test Procedures

Figure 7.1 through Figure 7.3 show typical coupling-capacitor installations. Note that an installation generally consists of the porcelain-clad capacitor unit(s) mounted above a base housing which contains carrier-current and/or potential-device networks. It is obvious that, if field test results are to be compared with nameplate or earlier field data, test procedures must be consistent. Also, knowledge of the carrier and potential-device networks is necessary in order that they be properly grounded or disconnected to eliminate any effect they might have on the measurement.

The test procedures outlined below are designed to produce the data required for individual capacitors with a minimum of disconnection, while enhancing safety. Basically, the procedure can be summarized as follows:

1. De-energize the capacitor.

2. Ground the capacitor line terminal using a safety ground. On units with an accessible POT terminal, the ground normally remains connected during the routine tests outlined. If the POT terminal is not accessible, and the stack has two or less units of porcelain, the ground must be removed for testing.

3. Unless otherwise indicated, close both of the grounding switches on the device housing, to ground the bottom terminal of the capacitor and the POT terminal.

NOTE

On multi-unit installations, the individual units should be discharged separately before test connections are made.

4. Remove connections to the terminals of the capacitor as necessary.

5. Proceed with test connections and measurements as outlined below.

6. Units with accessible POT terminals are generally characterized by an air-filled basebox. Those with inaccessible POT terminals generally have inaccessible oil-filled baseboxes.

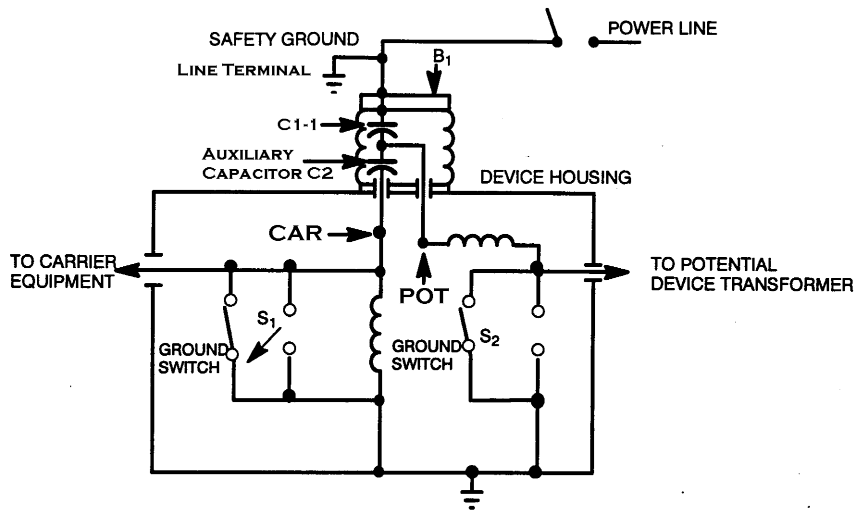


Figure 7.1 Single Porcelain Coupling Capacitor With Accessible POT Terminal

Test Procedure, Single Porcelain Unit and Accessible POT Terminal

1. De-energize capacitor by disconnecting from the power line.
2. Without disconnecting line terminal, ground B_1 (Top) using safety ground.
3. Close Ground Switches S_1 and S_2 on the side of the device housing.
4. Disconnect the POTand CAR terminals inside the device housing. POT and CAR may be found connected together, or POT may be floating if the capacitor is used only with carrier equipment. CAR will be found grounded if the capacitor is used only with a potential device.
5. If using DTA, this is Capacitor Arrangement #7. Test as follows:

NOTE

All tests are performed at 10 kV except where noted otherwise with an asterisk.

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	UST	POT*	B1(TOP)	—	CAR	C_2
2	GST	POT*	B_1(TOP)	CAR	—	C_{1-1}
3**	GST	CAR*	B_1(TOP)	—	—	C_2, C_{1-1} in series

In some instances it may be more convenient to disconnect the line terminal (after grounding) on a single-unit installation. In those instances, tests may be made as follows:

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1A	UST	POT*	—	—	CAR	C_2
2A	UST	B_1	—	—	POT	C_{1-1}
3A**	UST	B_1	—	—	CAR	C_{1-1}, C_2 in series

* Test voltages not to exceed rating of terminals of the Auxiliary Capacitor. Do not exceed 2 kV for CAR, unless higher rating known. The POT terminal is usually rated 5 kV or above. However, if in doubt, consult the manufacturer's instruction book covering the specific type of device.

** Tests 3 and 3A are an “alternate” test which are necessary only if it is desired to obtain the capacitance of this series combination to compare to a nameplate value.

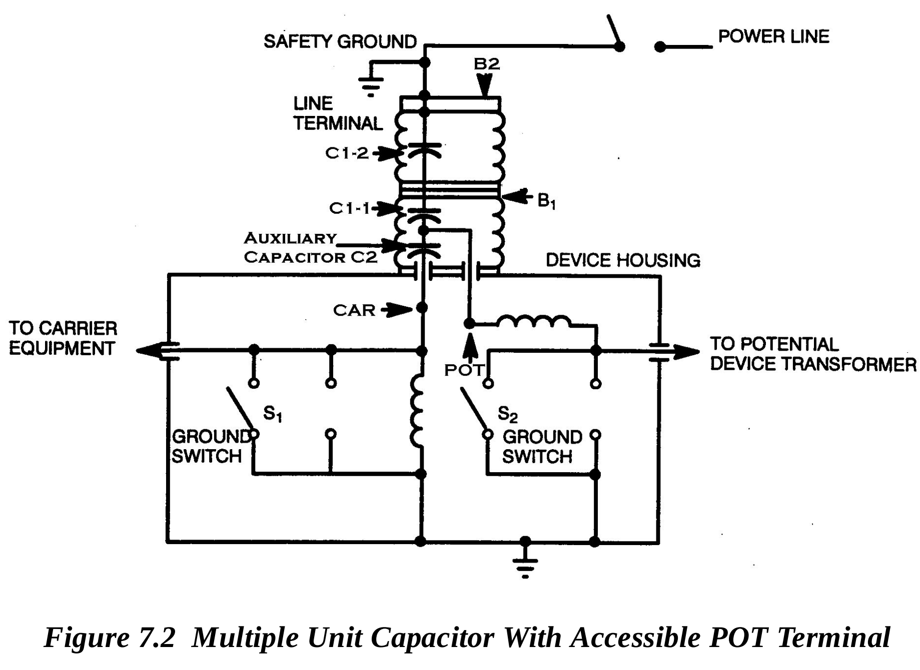


Figure 7.2 Multiple Unit Capacitor With Accessible POT Terminal

Test Procedure, Two Porcelain Units and Accessible POT Terminal

1. De-energize capacitor by disconnecting from power line.
2. Without disconnecting line terminal, ground B2 (Top) using safety ground.
3. Close Ground Switches S_1 and S_2 on the side of the device housing.

NOTE ☝ **On multi-unit installations, the individual units should be discharged separately before test connections are made.**

4. Disconnect POT and CAR inside the device housing. POT and CAR may be found connected together, or POT may be floating if the capacitor is used only with carrier equipment. CAR will be found grounded if the capacitor is used only with a potential device.
5. If using DTA, this is Capacitor Arrangement #8. Test as follows:

NOTE ☝ **All tests are performed at 10 kV except where noted otherwise with an asterisk.**

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	UST	POT*	B_2(TOP)	—	CAR	C_2
2	UST	B_1	B_2(TOP)	—	POT	C_{1-1}
3	GST	B_1	B_2(TOP)	—	—	C_{1-2}
4**	UST	B1	B_2(TOP)	—	CAR	$C_{1\text{-}1,}$ C_2 in series

* Test voltage not to exceed the voltage rating of POT Terminal of the Auxiliary Capacitor. POT Terminal is usually rated 5 kV or above. However, if in doubt, consult the manufacturer’s instruction book covering the specific type of device.

** Test 4 is an “alternate” test which is necessary only if it is desired to obtain the capacitance of this series combination to compare to a nameplate value.

Test Procedure, Three Porcelain Units and Accessible POT Terminal

1. Follow steps 1-5 above. If using DTA, this is Capacitor Arrangement #9. Test as follows:

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	UST	POT*	B_3(TOP)	—	CAR	C_2
2	UST	B_1	B_3(TOP)	—	POT	$C_{1–1}$
3	UST	B_1	B_3(TOP)	—	B_2	$C_{1\text{-}2}$
4	GST	B_2	B_3(TOP)	—	—	$C_{1–3}$
5**	UST	B_1	B_3(TOP)	—	CAR	$C_{1\text{-}1,}$ C_2 in series

* Test voltage not to exceed the voltage rating of POT Terminal of the Auxiliary Capacitor. POT Terminal is usually rated 5 kV or above. However, if in doubt, consult the manufacturer’s instruction book covering the specific type of device.

** Test 5 is an “alternate” test which is necessary only if it is desired to obtain the capacitance of this series combination to compare to a nameplate value.

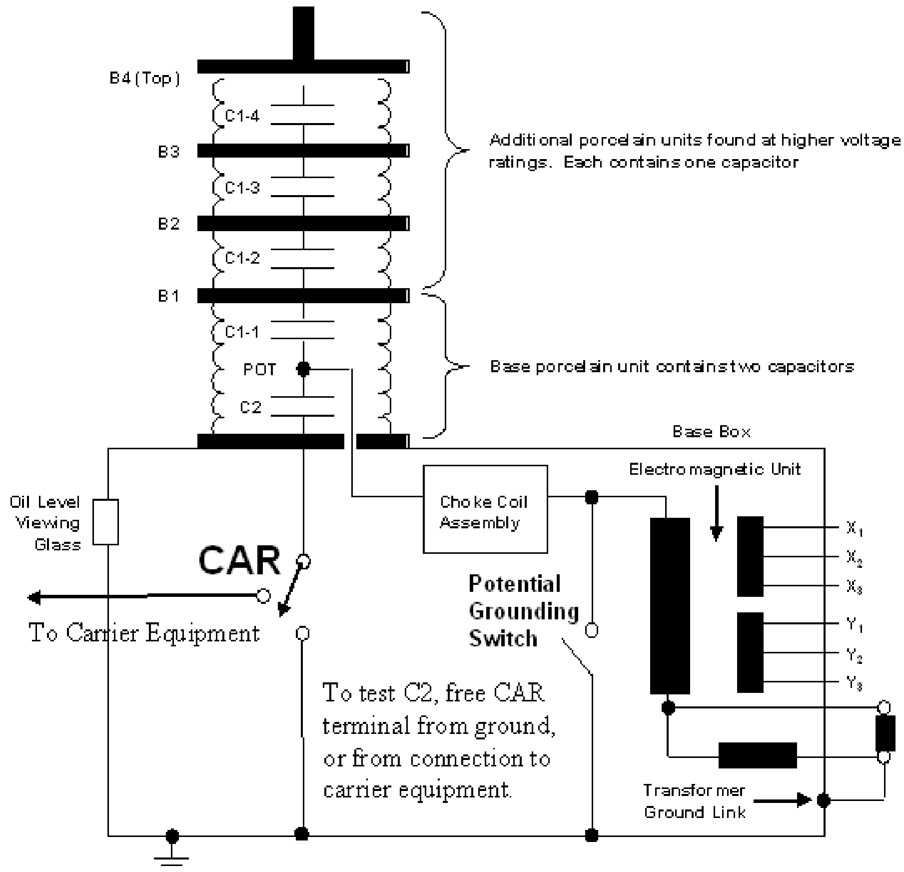


Figure 7.3 Multiple Unit Capacitor With No Accessible POT Terminal

Test Procedure, One Porcelain Unit and No Accessible POT Terminal

1. De-energize capacitor by disconnecting from the power line.
2. Ground top using safety ground. On multi-porcelain units, the individual units should be discharged separately before test connections are made. The device housing (base box) must be connected to ground.
3. For one and two porcelain units, disconnect the line terminal, removing both the line and ground connections. For units with three or more porcelain sections, leave the line terminal connected and ground it.
4. Close Potential Ground Switch S_2 on the side of the device housing. If there is no such switch, then only the Alternate test may be performed (see ”Alternate Test, C2 and C1-1 Series Measurement, No Accessible POT Terminal” on page 7-9).

5. Disconnect the CAR terminal inside the device housing for test 1 only. Make sure the Carrier lead is kept away from P_1 and P_2 terminals, due to the high voltage that will be found there. CAR will be found grounded if the capacitor is used only with a potential device.

WARNING

The Carrier lead must be reconnected prior to returning the coupling capacitor to service.

6. If using DTA, this is Capacitor Arrangement #1. Test as follows:

NOTE

All tests are performed at 10 kV except where noted otherwise with an asterisk.

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	GST	CAR*	POT	—	—	C_2
2	GST	TOP	POT, CAR	—	—	C_{1-1}

* Energize the carrier terminal at **<u>no more than</u>** 2 kV.

Test Procedure, Two Porcelain Units and No Accessible POT Terminal

1. Follow steps 1-5 as shown in the test procedure for one porcelain unit and no accessible POT terminal, above.

2. If using DTA, this is Capacitor Arrangement #2. Test as follows:

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	GST	CAR*	POT	—	—	C_2
2	GST	B_1	POT, CAR	TOP	—	C_{1-1}
3	UST	B_1	POT, CAR	—	TOP	C_{1-2}

Energize the carrier terminal at **<u>no more than</u>** 2 kV.

Test Procedure, Three Porcelain Units and No Accessible POT Terminal

1. De-energize the power line.

2. Ground top using safety ground. On multi-porcelain units, the individual units should be discharged separately before test connections are made. The device housing (base box) must be connected to ground.

3. The line terminal may be left connected, but the top must be grounded.

4. Close the Potential Grounding Switch (S_2).

5. The carrier lead is disconnected for test 1 only. Make sure the carrier lead is kept away from the P_1 and P_2 terminals because of the high voltage which will appear there.

WARNING

The Carrier lead must be reconnected prior to returning the coupling capacitor to service.

6. If using DTA, this is Capacitor Arrangement #3. Test as follows:

NOTE

All tests are performed at 10 kV except where noted otherwise with an asterisk.

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	GST	CAR*	B_3(TOP), POT	—	—	C_2
2	GST	B_1	B_3, POT, CAR	B_2	—	C_{1-1}
3	UST	B_2	B_3, POT, CAR	—	B_1	C_{1-2}
4	GST	B_2	B_3, POT, CAR	B_1	—	C_{1-3}

*Energize the carrier terminal at **no more than** 2 kV.

Alternate Test, C2 and C1-1 Series Measurement, No Accessible POT Terminal

In some cases, there is no nameplate value for the C_{1-1} capacitance, but the combined value of C_2 and C_{1-1} in series is given instead. The procedures above for coupling capacitors with accessible POT terminals include a provision for this alternate test. The alternate test procedure for coupling capacitors with no accessible POT terminal is shown below. In the following procedure, keep in mind that this alternate test for units with oil-filled bases and no accessible POT terminal is good for measuring the capacitance of C2 and C1-1 in series, but not for measuring power factor! This test procedure must also be followed for Coupling Capacitors without a Potential Grounding Switch. The user can follow this procedure:

1. Follow steps 1-5 above applicable to the number of porcelain units but **do not** close the Potential Grounding Switch. This switch must be left open for this alternate test.

2. Remove the transformer ground link(s), allowing the terminal to float. Otherwise, your test will measure an alternate path to ground through the transformer, and the measured capacitance may not match the nameplate value (see Figure 7.3). Trench and Ritz call this terminal P_2.

WARNING **The Transformer ground link and the Carrier lead must be reconnected prior to returning the coupling capacitor to service.**

3. Connect the low voltage lead to the CAR terminal.

NOTE **Since the potential grounding switch is open and the transformer ground link is removed, be aware that there will be a high voltage at this link point for this test.**

4. Test as follows:

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	UST	B_1	*	—	CAR	C_2, C_{1-1} in series

* This alternate test procedure is an extension of the procedures for coupling capacitors with no accessible POT terminal listed above. Accordingly, the top is grounded only if 3 or more porcelain units exist in the capacitor stack.

Analysis of Results

The insulation power factor and capacitance of a new unit should be comparable to the nameplate values, when these are given, or to values for other units of the same manufacturer, type, and rating. Units with power factors and/or capacitances that are either higher than normal or have increased significantly since the previous test should be removed from service either on a routine or immediate basis, depending upon the values obtained.

Percent power factor limits depend on the materials used in construction of the capacitors. Older paper/oil type coupling capacitors have power factors of the order of 0.25% when new. Units with power factor above 0.5% should be removed from service (an exception being some older General Electric Company 46 kV Type C_2 and C_3 capacitors which may have “normal” insulation power factors in the range of 2% to 3.5%). Newer paper/foil/synthetic fluid types have power factors of the order of 0.1% when new. Units of this new construction with power factors above 0.2% warrant a call to Doble for discussion. An increase in capacitance of the order of several percent is an indication of short-circuited layers of insulation, requiring that the unit be removed from service.

Note that the Auxiliary Test for units with no accessible POT terminal (DTA Capacitor arrangements 1-6) includes the influence of the electromagnetic circuit, which cannot be disconnected for the test. Because of its influence, this Auxiliary test for these layouts can be used to confirm nameplate capacitance but not nameplate power factor.

Experience to date indicates little, if any, temperature correction is necessary throughout the normal range of temperature in which coupling capacitors probably would be tested. In addition, a number of units are tested at the same time and may be compared at the same test temperature, thereby reducing the need for a temperature correction for analysis of test results.

Supplementary Tests

The routine test procedures outlined above are designed to check the main condenser elements of each capacitor, which are of paramount importance. For older-type base capacitors (units mounted on the device housing) with accessible POT terminals and air-filled housings, it is possible to measure separately the porcelain insulators associated with Terminals POT and CAR. In some capacitor designs this also includes an insulated cover end-plate which seals the bottom end of the capacitor around Terminals POT and CAR.

It is recommended that, where practical, the following supplementary tests be performed. This is particularly important when investigating abnormal Doble results on the main capacitor elements and when investigating suspect devices (e.g., units whose potential device output is low or erratic).

Table 7.1 The Capacitor Stack Must be Disconnected from the Power Line and All Terminals Must be Isolated. Procedure is for units with Auxiliary Capacitor in Porcelain Housing. If in Base, Energize POT and Guard B_1. (Test 1 not possible).

Supplementary Test No.	Test Mode	Energize	Guard	Measure
1	GST	CAR*	POT	CAR Bushing Terminal
2	GST	POT*	B1 & CAR	POT Bushing Terminal

* Tests are performed at reduced voltages; see test procedures above.

In the foregoing tests the charging current and dielectric-losses are expected to be very small, and the porcelains associated with POT and CAR should be thoroughly clean and dry. It is possible that cracks in the porcelain bushings of POT and CAR (perhaps masked during the standard tests) may be revealed by these supplementary measurements. This may be manifested by fluctuating watts meter readings.

Power-Factor Correction Capacitors

Power-factor correction capacitors have very high capacitances. They are used to improve the power factor or phase angle of a load current when it is lagging or highly inductive. Power-factor correction capacitors are either of the double- or single-bushing design. Because of the relatively high capacitance of the main insulation (C_1) of these capacitors, they are generally beyond the range of the set, although tests are possible on the ground insulation (C_2) of two-bushing correction capacitors.

Before any test connections are made to the capacitor, the housing and both bushings should be grounded so that the unit is completely discharged. This applies to units that have not been energized, as well as those that have just been removed from service. The ground insulation ($C_2 = C_2' + C_2''$) of a two-bushing capacitor can be tested in the GST mode as shown in Figure 7.4. The test voltage should not exceed the line-to-ground rating. While this method does not measure the main insulation (C_1), it is effective in detecting problems associated with the bushings and internal ground-wall insulation.

The power factor of the ground insulation is expected to be on the order of 0.5% or less, and should be compared among similar units tested under the same conditions.

NOTE ☛ **The main C_1 insulation of these capacitors has a much lower power factor inherently.**

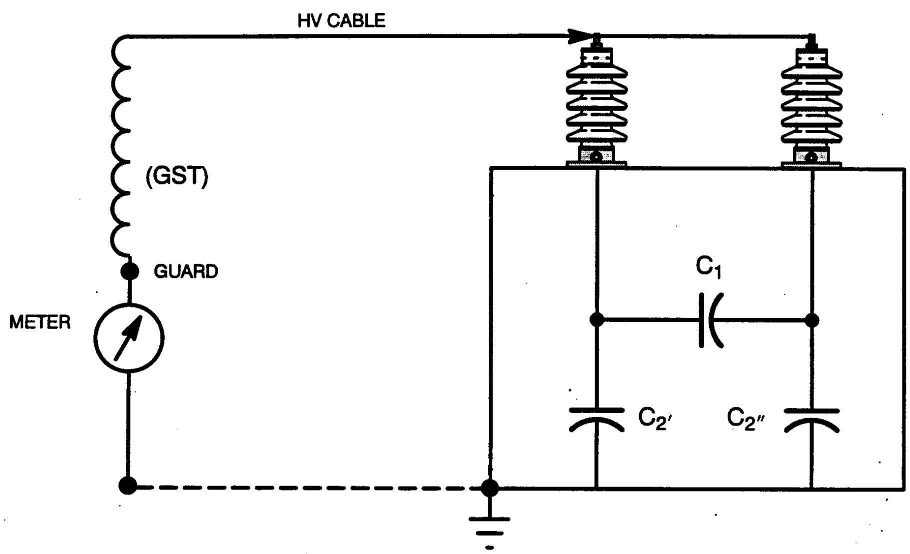


Figure 7.4 Test by GST Method on the Ground Insulation of a Two-Bushing Capacitor

Surge Capacitors

Surge capacitors are used in conjunction with surge arresters to protect rotating machinery insulation by sloping the wave front of voltage surges, thus reducing the turn-to-turn voltage stress.

Capacitance of surge capacitors are usually within the range of the M4000 set, although it may be necessary to test these at a reduced voltage below the operating line-to-ground rating.

NOTE

0.25 microfarads is a typical nominal capacitance for a surge capacitor. This represents about a 1000 milliampere specimen.

When the Doble Type C Resonating Inductor is used with the M4000 set, it then may be possible to test these capacitors up to their operating line-to-ground voltage rating (e.g., 8 kV for a surge capacitor applied to a 13.8 kV generator).

Since surge capacitors are applied line-to-ground, they generally consist of one bushing in a grounded metal housing (or “can”). To test, the capacitor is first completely isolated; the can must be properly grounded. Energize the line terminal with the test set circuit description set to GND-RB. The results are graded on the basis of power factor and capacitance. The capacitance should compare with the nameplate value and with test values obtained for similar units. Measured power factors are generally less than 0.50% and also should be compared to similar units. Power factors for surge capacitors are not corrected for temperature.

8. Rotating Machinery

Generators, Motors, and Synchronous Condensers

General

Doble dielectric-loss and power-factor tests on the stator-winding insulation of generators, motors, and synchronous condensers are useful in determining the presence of moisture, other contaminants, and corona. Power-factor tests made on a new winding before it is put in service will show whether it has absorbed excessive moisture during transportation and installation. An initial test is also valuable in providing benchmark data to which subsequent maintenance-test results can be compared. For additional comments, refer to the Rotating Machinery section of the Doble *Test-Data Reference Book* and to the *Rotating Machinery Insulation-Test Guide*. If running these tests using Clipboard, you must select the **Line Sync Reversal** Mode, found under the LC column. If using DTA, DTA will choose this circuit for you.

Test Voltages

Doble tests on phase-to-ground insulation of stator windings are performed at several voltages, beginning at a voltage below any partial discharge activity, typically 2 kV, and continuing, in steps, up to the rated operating line-to-ground voltage. Sometimes the operating line-to-ground voltage cannot be reached, either because the voltage rating of the machine (i.e., the operating line-to-ground rating of the machine) is greater than 12 kV (which is the maximum output voltage of the M4000) or the machine insulation capacitance is so great that the M4000 cannot supply the charging current requirements. If the former is the case, then make the upper-voltage test at some convenient voltage near the maximum possible. Otherwise, the Type C Resonator may be used in conjunction with the M4000, which will permit an increase in the charging current capabilities, thus enabling achievement of the proper test voltage. See Chapter 2. ”Using A Resonator”.

Whenever possible, it is desirable that the stator insulation be tested further at 10% to 25% above the operating line-to-ground voltage. This could accentuate a corona condition beyond that which was observed at operating line-to-ground voltage. Please refer to Table 8.1 on page 8-2.

Table 8.1 Recommended Test Voltages

Machine Voltage Rating (kV)	Test Voltage (kV)
2.4	1.4
4.16	0.5, 2.4
7.2	1, 4
12.47	2, 4, 6, 7.2
13.8	2, 4, 6, 8
14.4	2, 4, 6, 8, 8.3
18	2, 4, 6, 8, 10.4
20	2, 4, 6, 8, 10, 11.5

Test Procedure

Three Phase, Single Winding

Before testing the stator-winding insulation of a rotating machine, it is necessary to disconnect the machine from the station bus, and open the neutral so that each phase is completely isolated. The disconnections should be made at the terminals to avoid inclusion of cable and bus insulation in the test circuit. It is necessary to separate the phases so that each phase can be tested by itself, and tests can be made on the interphase insulation. The line and neutral end of the energized phase is short circuited. The following auxiliary apparatus is also grounded to the machine frame: stator resistance temperature detectors (RTD) and thermocouples (TC), auxiliary stator windings and any other devices associated with the stator winding, current transformer secondary windings, rotor winding terminals and shaft. The tests are performed as outlined in Table 8.2.

If using DTA, select this type of layout in the *Config* choice list.

Table 8.2 Test Procedure For Units Without Water Cooling

Test No.	Test Mode	Phase Energized	Phase Grounded	Phase UST	Insulation Measure
1	GST	A	B,C	—	A+(A–B & A–C)
2	UST	A	C	B**	A–B(Interphase)***
3	GST	B	C,A	—	B+(B–C & B–A)
4	UST	B	A	C**	B–C(Interphase)***
5	GST	C	A,B	—	C+(C–A & C–B)
6	UST	C	B	A**	C–A (Interphase)***

* The line and neutral terminals of the energized phase are always short-circuited.

** If this phase is grounded through the LV Lead during the preceding test, the connections for this phase-to-phase measurement remain the same. The Circuit Description is simply changed from GROUND to UST.

*** Make special note of the polarity of the watts-loss readings.

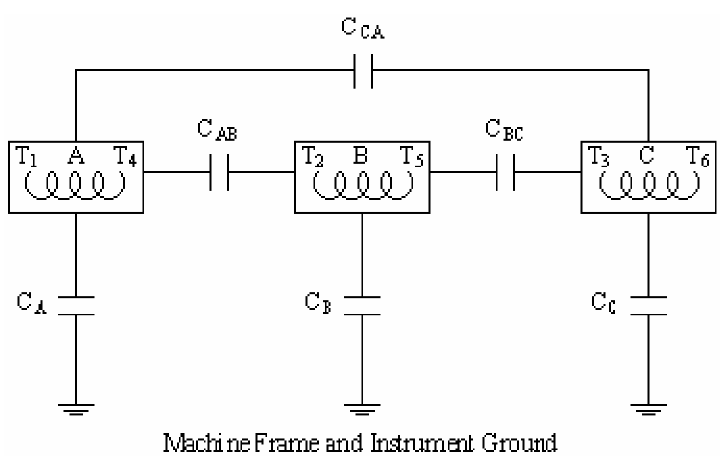


Figure 8.1 Test Procedure for Rotating Machinery Stator Insulation

The charging current and watts-loss are recorded for the six measurements and the power factors calculated. It has been observed that rotating machinery Stator insulation exhibits very little variation with temperature over the range of temperatures normally encountered during tests. The power factors are not corrected for temperature.

For the interphase tests, particular attention should be paid to the polarity of the watts-loss readings. Sometimes the polarity of the watts-loss value (and, subsequently, the calculated power factor) is negative.

Three Phase, Water-Cooled Unit

Water-cooled units have added losses due to the columns and insulated hoses associated with the water cooling system. The proper test procedure requires that these losses be determined and removed from the power factor measurements of the winding to ground measurements. The corrected measurement approximates the watt loss and power factor of the winding insulation.

The procedure requires that the deionized water be circulating in the winding during testing. The water conductivity should not be greater than 0.25 microsiemens per centimeter (micromho per centimeter). The losses due to the cooling water system are measured by performing a dc insulation resistance test on each phase-winding. The result is then normalized to the ac test voltage. The capacitance and power factor of each phase-winding should be measured at several voltages, refer to Figure 8.1 above for the proper connection and test procedures. The additional tests associated with a water-cooled unit are outlined in Table 8.3.

If using DTA, select this type of layout in the *Config* choice list.

Table 8.3 DC Insulation Resistance Test (Measured With A Third-party Instrument)

Test No.	Phase Energized	Phase Grounded	Insulation Measured
1	A	B, C	R_A
2	B	C, A	R_B
3	C	A, B	R_C

The three phase-windings are separated and the cooling water is circulating at rated flow. The dc insulation resistance of each phase-winding is commonly measured at 2.5, 5.0, or 10.0 kV dc.

For each phase-winding calculate the dc power losses (P_{Ldc}), normalized to the ac test voltage (V_{ac}), by using the measured dc insulation resistance (R_{dc}) and the ac test voltage*.

$$**P_{Ldc} = \frac{V_{ac^2}}{R_{dc}} = \frac{V^2}{\text{Megohms}}$$

* The ac test voltage is always 10 since the test voltage is referenced to 10 kV.

** The voltage is in kV, the resistance is in megohms and the power will be in watts.

***The correction is performed on the stator winding ground insulation only.

Subtract the dc power losses (P_{Ldc}) from the ac power losses (P_{Lac}) measured at each ac test voltage to obtain the corrected power loss, P_{corr}.

$$P_{Lac} - P_{Ldc} = P_{corr}$$

Calculate the corrected power factor using the corrected loss (P_{corr}) at each test voltage using the following equation:

$$\frac{P_{corr} \times 10}{mA} = \% \text{ PF}$$

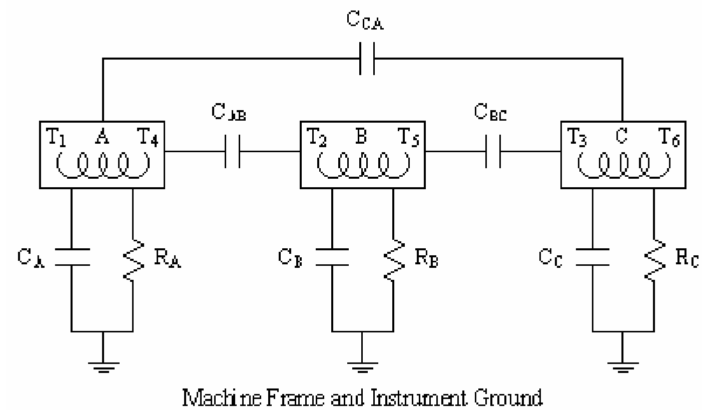


Figure 8.2 Additional Tests For Water-Cooled Unit

Three-Phase, Double-Winding, Twelve-Terminal Machine

A two-winding motor or generator requires additional testing to properly evaluate the insulation condition of both windings. The phase to ground insulation of both windings are measured by energizing each phase and grounding the remaining phases. The phase to phase insulation is measured by energizing each phase and measuring to the adjacent phase of the same winding and measuring to each phase of the second winding.

If using DTA, select this type of layout in the *Config* choice list.

Test No.	Phase Energized	Phase Grounded	Phase UST	Measure
1	A	B,C,A’,B’,C’	-	$C_A+C_{AB}+C_{AC}+C_{AA'}+C_{AB'}+C_{AC'}$
2	A	C,A’,B’,C’	B	C_{AB}
3	A	B,C,B’,C’	A’	$C_{AA'}$
4	A	B,C,C’,A’	B’	$C_{AB'}$
5	A	B,C,A’,B’	C’	$C_{AC'}$
6	B	C,A,A’,B’,C’	-	$C_B+C_{BC}+C_{BA}+C_{BA'}+C_{BB'}+C_{BC'}$
7	B	A,A’,B’,C’	C	C_{BC}

Test No.	Phase Energized	Phase Grounded	Phase UST	Measure
8	B	C,A,C’,A’	B’	$C_{BB'}$
9	B	C,A,A’,B’	C’	$C_{BC'}$
10	B	C,A,B’C’	A’	$C_{BA'}$
11	C	A,B,A’,B’,C’	-	$C_C+C_{CA}+C_{CB}+C_{CA'}+C_{CB'}+C_{CC'}$
12	C	B,A’,B’,C’	C	C_{CA}
13	C	A,B,A’,C’	B’	$C_{CC'}$
14	C	A,B,B’,C’	C’	$C_{CA'}$
15	C	A,B,C’,A’	A’	$C_{CB'}$
16	A’	A,B,C,B’,C’	-	$C_A+C_{A'A}+C_{A'B}+C_{A'C}+C_{A'B'}+C_{A'C'}$
17	A’	A,B,C,C’	B’	$C_{A'B'}$
18	B’	A,B,C,C’,A’	-	$C_{B'}+C_{B'A}+C_{B'B}+C_{B'C}+C_{B'C'}+C_{B'A'}$
19	B’	A,B,C,A’	C’	$C_{B'C'}$
20	C’	A,B,C,A’,B’	-	$C_{C'}+C_{C'A}+C_{C'B}+C_{C'C}+C_{C'A'}+C_{C'B'}$
21	C’	A,B,C,B’	A’	$C_{C'A'}$

Hydrogen-Cooled Generators

A hydrogen-cooled unit may be tested in air with the hydrogen removed or with the hydrogen present at the normal operating pressure. Hydrogen at pressures lower than 15 psig has a lower breakdown voltage than air at atmospheric pressure. At high Hydrogen pressures, corona activity is suppressed.

Miscellaneous

If the winding of a motor or generator is such that the neutral point cannot be separated, the proper test procedure is to perform an overall test to ground. This is accomplished by tying the line leads together, placing the ground lead on the machine ground and selecting the GST-ground mode.

Analysis of Results

Power factor, power-factor tip-up, capacitance, and when performed, radio-influence voltage (RIV) should be compared between phases, with previous test results (if any), with data recorded for similar units on the system, against factory data (if any), and with the data tabulated for similar units in the Rotating Machinery section of the Doble *Test-Data Reference Book.* The results should compare closely between phases.

An indication of the inherent power factor of stator insulating material and its condition with respect to general deterioration, moisture, and/or dirt are what should be expected of a power-factor test at test potentials below corona-starting voltage. To confirm the presence or absence of atmospheric contamination, the routine test procedure includes ungrounded specimen tests between phases. Because of the effect of the stator iron in shielding the slot sections of the phases from one another, the interphase test becomes essentially a test of the exposed end-turn insulation which is affected most by atmospheric contamination. Interphase power factors are generally higher than those recorded for phase-to-ground insulation, being affected not only by contamination but by the type of corona control in the end turns.

Attention should also be given to the phase-to-ground capacitance (charging current) of the stator winding, particularly for the first several tests on a new winding. A drastic reduction in the capacitance of a new winding after an initial period of operation may be indicative of incomplete curing of the winding and may be a precursor of loss of compactness and corona in the slot sections. This topic is discussed further in the Conference paper entitled “Doble Tests on Generator Insulation (A Status Report)” Sec. 7-401,*1964 Doble Conference Minutes*, and in more recent Conference presentations.

The increase in power factor with voltage is referred to as the power factor tip-up and gives an indication of the void content in the insulation. (The increase in power factor between the lowest test voltage (usually 2 kV) and operating line-to-ground voltage is taken as the fundamental tip-up. This is the value which is tabulated in the Rotating Machinery section of the *Test-Data Reference Book*.) Power-factor tip-up also serves as a measure of the power available to attack the binding material of the stator coils.

Occasionally the interphase watts-loss and power factor is negative in polarity. This may be due to the effects of the semiconducting paint which is used to grade the voltage stress in the area where the coils leave the slots. In general, negative watts-loss and power factors are not in themselves cause for concern unless there is a drastic discrepancy between phases or with previous results. For additional comments on negative power factor, refer to the 1960 Doble Client Conference paper, “Application and Significance of Ungrounded-Specimen Tests” (Sec. 3-201, 27AC60), which may be found in the General section of the *Test-Data Reference Book* (Sec. 1-2.1, TDRB).

Radio-influence voltages (RIV) measured for stator insulation provide a quantitative indication of corona resulting from the overstressing and ionization of voids in the insulation. High RIV may also be the result of coil looseness in the slots. Under normal conditions, there should be good agreement in the radio-influence voltages recorded for individual phases of a particular stator. Experience shows that agreement should also be expected between results recorded for periodic tests on the same winding.

Temperature in the range encountered appears to have little effect on the results of RIV measurements, although moisture and surface contamination have very definite effects. These factors should be considered in comparing the results of tests on individual phases of a machine or results of a series of tests on the same machine. In some instances it is necessary to clean terminal-bushing surfaces carefully before acceptable readings could be obtained.

It does not appear possible, at present, to compare RIVs recorded for different types and sizes of machines. This is due to differences in materials and designs, and the attenuating or shunting effects of specimen capacitance.

Testing Individual Stator Coils

One of the most important applications of power-factor tip-up is in the testing of individual stator coils to determine whether they conform to a purchase specification or are within a range deemed to be acceptable. (The Institute of Electrical and Electronics Engineers has published Standard No. 286-1975, “IEEE Recommended Practice for Measurement of Power-Factor Tip-Up of Rotating Machinery stator Insulation.”) The tip-up technique is also useful in determining the condition of individual coils for possible reuse in the rewinding of a machine.

For additional comments relating to power-factor tip-up testing of individual coils, refer to the Doble *Rotating Machinery Insulation-Test Guide.*

9. Cables and Terminations ("Potheads")

Introduction

Testing of cables generally requires additional precautions on the part of the test engineer, since the entire specimen subject to test voltage is not visible. Both ends of the cable under test should be clearly identified and isolated.

Effective power-factor tests can be performed on relatively short lengths of cable (especially on shielded cables and unshielded cables enclosed in a metallic sheath). Tests on cables should be performed from both ends.

The measured power factor may be considered as the average of the power factor of each elementary length of insulation. Thus, the ability to detect a localized fault diminishes as the length of the cable under test increases. Power-factor tests have proven useful in indicating general deterioration and/or contamination. An increase in power factor with test voltage (i.e., power factor tip-up) may be an indication of a serious general condition of corona in the insulation.

Hot-Collar methods provide a most effective test for terminations associated with cable, regardless of cable length. In addition, high-voltage terminations may be equipped with power-factor test taps to facilitate testing installed terminations.

Test Voltages

Cables rated up to 15 kV insulation class should be tested at several voltages up to the operating line-to-ground voltage. For example, 15 kV insulation class cable on 13.8 kV systems normally operate 8 kV to ground and should be tested at several voltages up to 8 kV. Additional tests, performed at 10% to 25% above the operating line-to-ground voltage, are desirable in that they may accentuate corona and other high-loss conditions.

Doble tests on 25 kV class cables should be made at least two voltages, starting with 2 kV, then continuing up to the highest test voltage possible or permitted.

Cables rated above 25 kV insulation class should be tested at 10 kV or at the highest test voltage possible or permitted.

Cable Testing

Single-Conductor Shielded or Sheathed Cable

The cable should be removed from service and all associated electrical equipment disconnected. The test procedure consists of applying the test voltage to the cable conductor with the cable shield or sheath effectively grounded. The test is made in the GST mode with the circuit description set to GND-RB.

Single-Conductor Unshielded and Unsheathed Cables

A test procedure similar to that outlined for single-conductor shielded cables is used. When tests are made on single-conductor unshielded cables, the measurement may not be confined to the cable insulation alone, but may include the material which surrounds the cable (e.g., fiber ducts), or any material that forms the ground return path of the leakage current. That is, losses in the extraneous material (which may not be an essential part of the cable insulation) are included in the measurement, resulting in unpredictably high power factors.

Multiconductor - Individually Shielded Cables

A similar procedure to that outlined for single-conductor shielded cables should be utilized. Cable conductors not under test should be grounded.

Multiconductor - Unshielded or Unsheathed Cables

The same condition exists in the case of multiconductor unshielded cable as in single-conductor unshielded cable. In this case it is possible, by UST, to perform power-factor measurements between two conductors which are practically confined to the insulation between the two conductors. Any other conductors not included in the test are grounded. The procedure is repeated to include all conductors individually in at least one measurement.

Multiconductor - Unshielded Cables Enclosed in a Common Metallic Sheath

In testing multiconductor cables, each conductor is tested individually with the other conductors and sheath grounded. The Overall test is made with all conductors connected together and energized with the sheath grounded. When a significant difference in power factor exists among the conductors, supplementary tests should be made to determine the condition of the insulation between two conductors by the Ungrounded-Specimen Test (UST) method.

Partly Shielded Cables

Asbestos braid over unshielded cable becomes semiconducting under conditions of moderate or high humidity, and acts as a poor shield. A braid cover which is impregnated with graphite makes a more effective shield, but it does have appreciable resistivity which is often non-uniform. In any shield which is not a good conductor, losses are produced in the shield by the charging current of the cable. The magnitude of loss depends on the shield resistivity and the distance between ground points on the shield. The losses cause an apparent increase in the power factor of the cable insulation which are difficult to account for when test results are analyzed. Fortunately, from the test standpoint, unshielded and partially-shielded cable is used for the most part on low-voltage, less critical circuits.

Termination (Pothead) Tests

Hot-Collar tests are extremely effective in detecting contamination and voids in terminations associated with cables. They are performed in accordance with instructions under ”Test Technique - Bushings in Apparatus” – ”Hot-Collar Tests” on page 3-5.

On high-voltage pipe-type cable systems, the terminations may be equipped with test-tap electrodes to facilitate testing by the UST method. Tests can be performed by energizing the cable and connecting the test-tap electrode to the UST circuit. Often, the high capacitance of the cable insulation precludes building up an appreciable test voltage on the cable; in this case the terminations are tested by the Inverted UST method (see ”Test Technique - Bushings in Apparatus” – ”Inverted UST (Tap to Center Conductor, C1)” on page 3-12. The test-tap electrode is energized at rated tap voltage with the cable conductor connected to the UST circuit.

Analysis of Cable and Pothead Results

Correction for the effects of temperature on cable power factors is normally not made, since it requires a fairly close approximation of cable temperature, a knowledge of the type of insulation and the date of its manufacture, temperature characteristics which are not normally available, etc.

Evaluation of cable tests should be based on one or more of the following:

1. Comparison of power factors obtained for similar insulated cables obtained at time of test and under the same conditions.
2. Comparison with previous test results.
3. Comparison of results obtained from both ends.

4. Comparison with the tabulated power factor data for similar cables in the Cables and Accessories section of the *Test-Data Reference Book.*

5. Comparison with available manufacturer data.

The results of Hot-Collar tests are analyzed in accordance with instructions under ”Single Hot-Collar Test” . Abnormally high values of current and watts indicate the presence of moisture in the vicinity of the applied collar; abnormally low values of current indicate voids or the absence of filling compound or oil.

Evaluation of termination test results obtained by UST methods utilizing test taps should be based on comparisons of measured power factors and capacitances with nameplate data, the results of prior tests, and the results of tests on similar apparatus tested at the same time. Power factors of modern high-voltage terminations can be expected to be 0.5% or less.

For additional information on cables and terminations, refer to the Doble *Reference Book on Cables and Accessories.*

10. Liquid Insulation

Introduction

In order that samples of liquid insulation may be tested with the Doble test sets, a special Oil Test Cell has been constructed, which is essentially a capacitor utilizing the insulating liquid as the dielectric. Provided with the cell is a plastic container in which the cell may be housed and carried when not in use, or to insulate the cell from ground during the test. Figure 10.1 shows the cell and the plastic container. Obviously, the cell should be cleaned each time a different sample is tested. Generally, so long as the same type of liquid is to be tested, the cell can be cleaned adequately by washing it out with either a new oil sample, or with a portion of the sample to be tested. If the cell is dirty or will be used to test a different type of liquid, it should be flushed with a suitable solvent and the contents disposed of properly. Following this, the cell should be dried. It is best not to wipe out the container with rags, since cotton fibers, etc., may be left in the cell and affect the test results of the sample.

When drawing a sample of liquid insulation from either a transformer or circuit breaker, care should be taken to obtain a representative sample. Let sufficient liquid drain through the pipe and sampling valve so that any dirt or water lodged in the pipe will be drained before filling the cell.

The Test Cell holds approximately one quart, and should be filled until there is about three-quarters of an inch of liquid above the top of the cylinder inside the cell. When the cover is replaced, the cylinder or bell of the cover should be covered with liquid. If there is an insufficient amount of liquid in the cell, sparking may take place above the liquid level.

The Test Cell should be set either in the bottom of the plastic container (shown in Figure 10.1), or on some insulating material on a level base so that the surface of the liquid will be approximately level. The cover should be properly seated. Air bubbles, water, and other foreign material are the usual cause of breakdown in the cell. If the sample is allowed to stand in the cell for a short time before the test is made, the entrapped air will have a chance to work out and any foreign particles to settle to the bottom. Also, any entrapped air bubbles in the liquid can be released through holes in the inner cylinder or bell of the cover by slowly rotating the cover while it is seated.

Figure 10.1 Doble Liquid-Insulation Power-Factor Test Cell and Carrying Case

Test Procedure

The test connections are made as shown in Figure 10.2. The high-voltage terminal or hook of the High-Voltage Cable should be connected to the handle on the cell cover with a short clip lead to reduce stray currents. The Guard Ring on the cable outboard pothead should be connected to the Guard Ring on the cell cover, using another suitable clip lead. The outer cylinder should be insulated from ground and connected to the UST circuit. A clearance of several inches should be maintained between the cable hook and the Cell Guard Ring, so that flashover will not occur between these parts.

The test voltage should be raised gradually to 10 kV. As the spacing between the plates of the Cell is about 3/16 of an inch, the sample should not break down at this voltage unless it is in very poor condition (should the M4000 trip before 10 kV is reached, then attempt a measurement at some lower voltage such as 2 kV). Current and watts meter readings should be taken, and the power factor calculated in the normal manner.

Immediately after the sample has been tested, its temperature should be taken while still in the Cell. The power factor then should be corrected to 20°C, using instructions and table of multipliers listed under "Variation Of Power Factor with Temperature" on page 1-14.

When transporting the cell, it should be packed carefully to prevent damage. The plastic carrying case in which the cell is shipped should be utilized for this purpose.

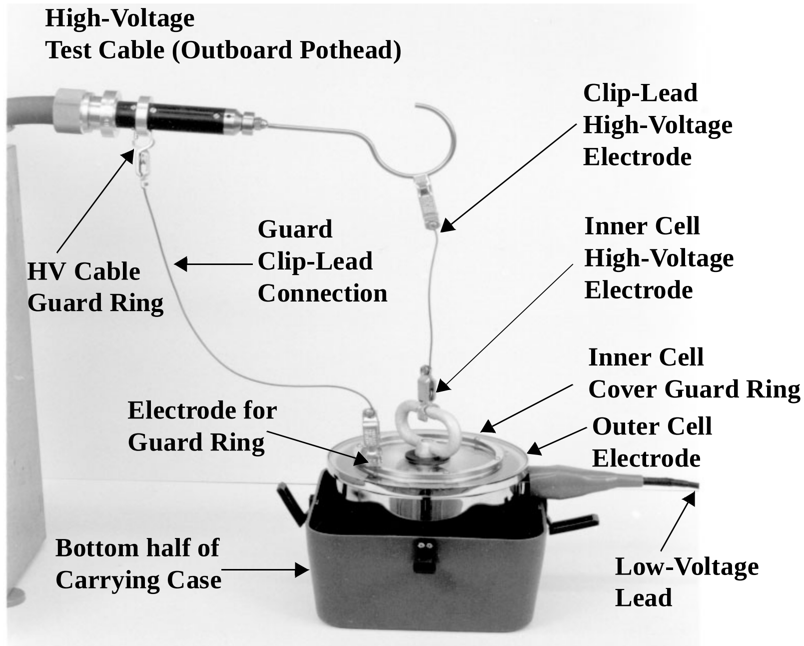


Figure 10.2 Liquid Insulation Cell (Connected for Testing)

Analysis of Results – Oil

Good new oil has a power factor of 0.05% or less at 20°C. Higher power factors indicate deterioration and/or contamination with moisture, carbon or other conducting matter, or with varnish, Glyptal, sodium soaps, asphalt compounds, or deterioration products. Carbon or asphalt in oil can cause discoloration. Carbon in oil will not necessarily increase the power factor of the oil unless moisture is also present. It is suggested that the following guides serve for grading oil by power-factor tests:

- Used oil having a power factor of less than 0.3% at 20°C is usually considered satisfactory for continued service.
- Oil having a power factor greater than 0.5% at 20°C should be considered in doubtful condition, and at least some type of investigation (dielectric breakdown tests) should be made.
- Oil having a power factor greater than 1.0% at 20°C should be investigated, and either reconditioned or replaced.

These guides may be elaborated on by saying that good, new oil has a power factor of approximately 0.05% or less at 20°C, and that the power factor gradually can increase in service to a value as high as 0.5% at 20°C without, in most cases, indicating sufficient deterioration to warrant investigation. When the power factor exceeds 0.5%, an investigation is indicated. The question of what decision to make regarding disposition of the oil depends upon what is causing the high power factor. Dielectric-breakdown or water content tests should be made to determine the presence of moisture. The necessity for further tests will depend to a large extent upon the magnitude of the power factor, the importance of the apparatus in which the oil was used, its rating, and the quantity of oil involved.

Analysis of Results – Askarel

Askarel has a power factor of 0.05% or less at 20°C. Higher power factors indicate contamination with moisture, carbon or other conducting matter, or with asphalt compounds, varnish, Glyptal, gasket materials, and/or other foreign matter or deterioration products. It is suggested that the following guides serve for grading askarel by power-factor tests:

- Askarel having a power factor of less than 0.5% at 20°C is usually considered satisfactory for service.
- Askarel having a power factor greater than 0.5% at 20°C should be considered in doubtful condition, and at least some investigation (dielectric-breakdown tests) should be made.
- Askarel having a power factor greater than 2.0% at 20°C should be investigated to determine the cause of the high power factor. If the high power factor is caused by water or other conducting matter, free chlorides or a high neutralization number, the askarel is probably an operating hazard. If the high power factor is not due to these causes, it is probably not an operating hazard, except that when the power factor is quite high it may result in excessive heating of the device in which it is used. Care should also be taken that the high power factor is not due to dissolved materials from gaskets or insulation necessary for safe operation of the askarel-filled device. High power factor due to askarel contamination may mask other defects in askarel-filled devices.

NOTE

Askarel is considered to be hazardous to the environment, and must be disposed of in accordance with government regulations.

Other Insulating Liquids

The foregoing test procedure and comments, particularly those for oil, can be applied to other silicone and hydrocarbon fluids being used in electrical equipment, and which have power factors comparable to or lower than oil when new.

For additional information, refer to the Doble *Reference Book on Insulating Liquids and Gases.*

11. Insulators

Suspension Insulators

Porcelain suspension insulators forming part of a string can be tested by the dielectric-loss method. The section of line connected to the insulators must be removed from service and grounded.

The procedure consists of grounding the hardware above one insulator and below another with test potential of 10 kV applied to the hardware between them, thus testing two insulators in paralell.

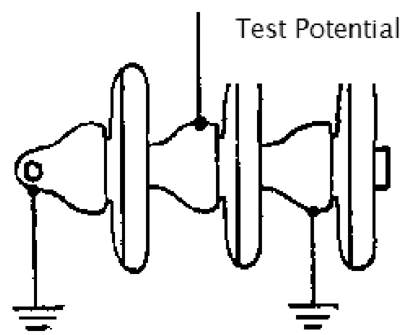


Figure 11.1 Testing A Suspension Insulator

After a number of similar units have been tested under the same conditions, normal average values of current and watts-loss can be determined. Insulators having currents and losses appreciably above the average should be removed from service.

Experience has shown that a pair of typical, good insulators, tested as shown above, will have a current and loss of 250 to 300 microamperes and 0.05 to 0.10 watts respectively at 10 kV.

Bus Insulators

One-piece porcelain insulators (Figure 11.2) forming part of a bus structure can be tested individually by the dielectric-loss method.

The procedure consists of grounding the bus and insulator base, and applying 10 kV test potential to the center of the porcelain. This test measures the losses in the top and lower halves of the porcelain in parallel to ground. Contact to the porcelain should be made by a snug-fitting Hot Collar.

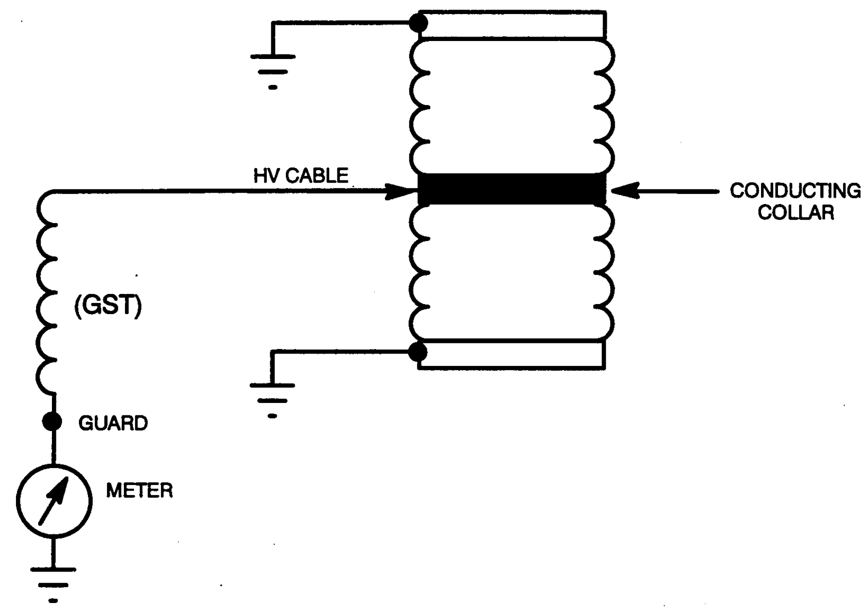


Figure 11.2 Test Procedure on Single-Piece Post-Type Bus Insulator

After a number of similar insulators have been tested under the same conditions, average values for current and watts can be obtained. Insulators having losses that are appreciably above the average should be removed from the bus structure for further tests, and examined for cracks and the possibility of internal contamination.

12. Buswork

Test Procedures

Isolated-Phase Bus

Test No.	Energize	LV Lead	LV Switch	Ground	Measure
1	A	—	Ground	—	C_A
2	B	—	Ground	—	C_B
3	C	—	Ground	—	C_C

Non-Segregated and Switchgear Bus

Test No.	Energize	LV Lead	LV Switch	Ground	Measure
1	A	B	Ground	C	$C_A+C_{AB}+C_{AC}$
2	A	B	UST	C	C_{AB}
3	B	C	Ground	A	$C_B+C_{BA}+C_{BC}$
4	B	C	UST	A	C_{BC}
5	C	A	Ground	B	$C_C+C_{CA}+C_{CB}$
6	C	A	UST	B	C_{CA}

NOTE

1. The test set test ground lead should be connected to the ground terminal of the bus enclosure

2. If permitted by the bus voltage rating, the Grounded Tests should be performed at 2 kV and phase-to-ground voltage (i.e., 2 and 8 kV for 13.8 kV bus) to determine if the test results are voltage sensitive (power-factor tip-up). The Ungrounded-Specimen Test (UST) are normally performed at phase-to-ground voltage.

3. Porcelain insulated bus typically has power factors of 0.5% or less. Bus insulated with other materials may have power factors ranging up to 4%. Short lengths of bus should be evaluated by the measured current and losses. A section with questionable losses should be compared with a section known to be in good condition.

4. High power factors measured for porcelain insulated bus may be investigated by performing a Hot-Collar tests on each insulator and by the procedure shown in Figure 11.2 on page 11-2.

13. Wood and Other Insulating Members

General

The insulating qualities of wood or other insulating members may be judged by the dielectric loss (or AC resistance) measured between conducting bands placed some distance apart along the member. Any of the assortment of conducting collars furnished with Doble test sets can be used in this application. If none are the appropriate size for a particular insulating member, or in the case of rectangular-shaped members, bands of metal foil can be used. If foil is used, it may be necessary to lash the bands to the specimen, using one or two turns of fine wire, to ensure intimate contact between the foil and surface contour of the insulating member.

Test Procedures

Normally, two three-inch sections of the insulating material are tested at the same time, by wrapping the member with three conducting bands approximately three inches apart. See Figure 13.1. These bands should be approximately one-inch wide. The two outside bands are connected to UST and the middle band is energized at 10 kV. If a high loss is obtained for the two sections in parallel, either section can be tested separately by connecting the outer band of the other section to the grounded-guard circuit. The section of the member between the energized electrode and the grounded-guard electrode is then not in the measuring circuit, and the losses in that section are not measured.

Alternative test methods using the GST circuit are also possible.

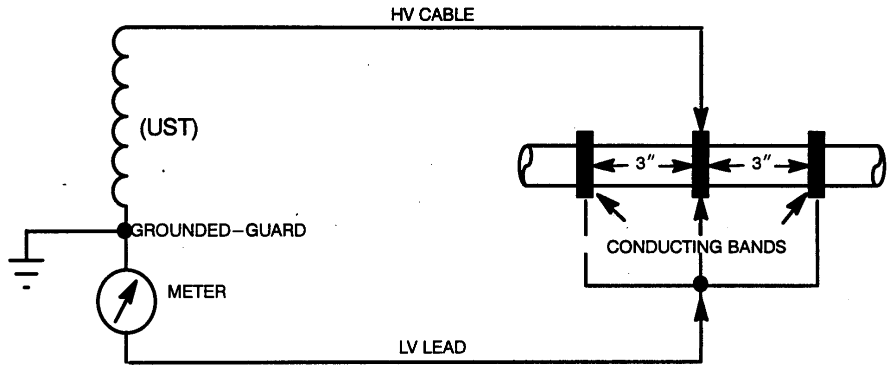


Figure 13.1 Three-Electrode Test Technique

The Three-Electrode method described permits tests on a relatively short section of an insulating member. Depending upon the length of the member, tests at several locations may be desirable. An electrode system which reduces the time necessary for tests on switch sticks and hot-line tools, and permits tests along their entire length, is described in the 1947 *Doble Client Conference Minutes, Sec. 3-201*, as well as in other more recent papers.

Analysis Of Results

Breaker lift-rods and guide members are considered suitable for service when the loss for a three-inch section is less than 0.20 watts at 10 kV. Plastic-coated members are considered suitable for service when the loss for a three-inch section is less than 0.15 watt at 10 kV. The loss for a three-inch section of either material in excellent condition is usually less than 0.02 watt at 10 kV.

In order to make the test results independent of test voltage, AC resistance instead of dielectric-loss can be used as a criterion. The formula for AC resistance is:

$$R = \frac{E^2}{W}$$

where E is the test voltage in volts, and W the measured is watts-loss. To calculate the AC resistance in megohms, using 10 kV or Equivalent 10 kV watts-loss recorded with the Type M2H set, the formula is:

$$R\ (megohms) = \frac{100}{Watts}$$

14. Resistive-Coupled Potential Device

General

Some coupling potential devices utilize a resistive element instead of a capacitor to couple to a high-voltage line. The high-voltage resistor of one such device is immersed in insulating oil and sealed in an outdoor porcelain housing. The values of the resistors of the various units are such as to provide the same nominal current at the rated voltage of each unit.

Because the units are resistive, their power factors approach 100%. Therefore, their condition is based on a comparison of the currents and losses rather than power factor. If desired, the resistance of the unit can be calculated and compared with either the nameplate value or information supplied by the manufacturer. The calculation of AC resistance is discussed under ”Wood and Other Insulating Members” on page 13-1.

Test Procedures

The procedure for testing the resistive element of a resistance-type potential device is shown in Figure 14.1.

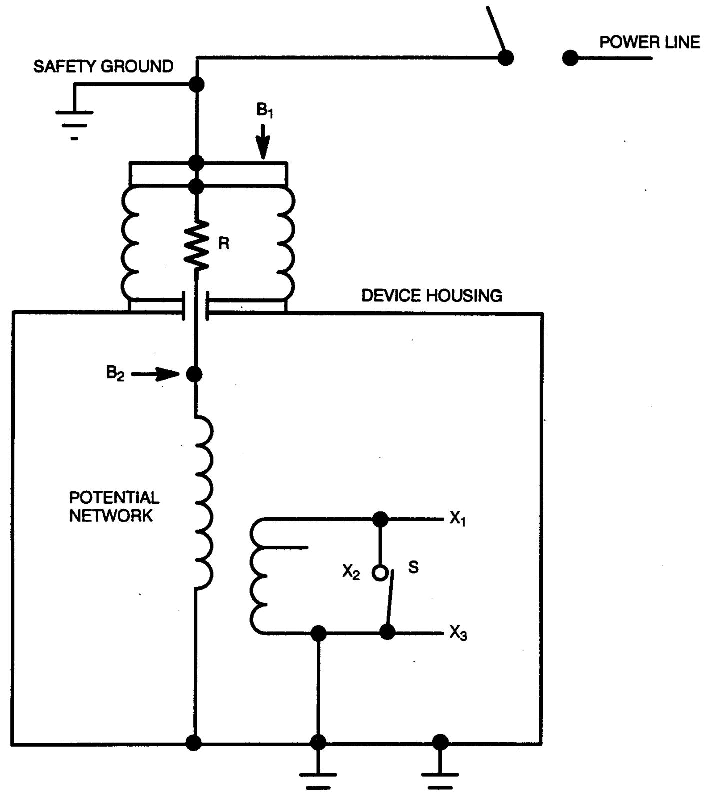


Figure 14.1 Test Procedures for Resistance-Type Potential Device

1. De-energize power line.
2. Without disconnecting power line, ground B_1.
3. Close Ground Switch S on the side of the device housing.
4. Disconnect B_2 inside the device housing.
5. Test as follows:

Test kV	Test Mode	Energize	Guard	Measure
2.5	GST	B_2	B_1	R

In some instances it may be more convenient to disconnect the line terminal (after grounding). In those instances a test may be made as follows:

Test kV	Test Mode	Energize	Guard	Measure
10	GST	B_1	B_2	R

15. Bucket Trucks

The insulating boom of bucket trucks may be tested by fabricating electrodes as described in the discussion under ”Wood and Other Insulating Members” on page 13-1. Electrodes with relatively large surface areas should be used in order to expedite testing of relatively long booms. Definite test limits have not been established for bucket trucks, but the results may be compared between similar specimens and previous test results. Tests should be performed indoors, or outdoors under favorable atmospheric conditions, with precautions taken to minimize surface leakage.

Overall tests may also be performed between various sections. For example, by energizing the controls in the bucket at 10 kV and measuring the current and watts-loss to the grounded truck chassis.

The hydraulic fluid may be checked for both power factor and dielectric-breakdown strength. It is not unusual to obtain relatively high power factor for hydraulic fluids, primarily due to the effects of additives.

16. Frequently Asked Questions (FAQs)

Technical Support

You can contact your Doble Engineer at 617-393-2900, or by email, or by FAX at 617-926~0528. If he or she cannot resolve your problem, other technical support staff will be available to help you. Doble also maintains an e-mail discussion list for DTA related questions. Contact your Doble engineer if you'd like to subscribe to this e-mail discussion list (requires that the user have Internet email capability).

Optional DTA Software

1. I loaded the software onto my laptop, but I can't run a test.

- The comport may be incorrectly chosen. Select Configuration from the Tools menu, go to the Instrument tab, and select the correct comport for your computer (usually Comm1).
- Another program is grabbing your comport. Turn off all other programs that might grab your comport upon startup.

1. What is an XML file?

- This is the new file structure replacing the old Compressed Data Set (CDS). Each time DTA opens a file with the old file structure, it will save it in the new XML file structure. The new files enable the user to name them in a way so as to be easily identified when viewed with Windows Explorer.

2. How do I temporarily unapprove a dataset?

- This function is no longer available. All datasets are now "unlocked" and accessible.

3. How do l back up my DTA data files (XML)?

- XML files should be backed up periodically to avoid loss of test data. They should be backed up using the DTA Office System. The DTA Office System is a relational database program that is be used to create a database of all XML's. This database can be easily backed up, and is the central repository from which all CDS should be managed.

4. The apparatus that l 'm testing is not listed in the DTA choice lists. What should l do?

- If you are using the DTA system for evaluating the condition of apparatus only, then it is not necessary to enter the complete variation of the type in the type field. DTA evaluates the condition of the apparatus based on generic types only. Additional type information is superfluous in the eyes of DTA. For example, the GE breaker types FK-115, FK-115-10000, FK-1 15-10000-l, and FK-115-10000-2 are all the same in the eyes of DTA, so the user can simply enter FK-115 as the breaker type.
- If however you are using DTA as an inventory control system, then you may wish to enter the entire type designation. If the entire type designation is not in the choice list, then select other as the type and enter the necessary information into the notepad. Notify your Doble Engineer that you have additional information that needs to be added to the DTA limit files. When the new limit files have been created, you will be sent another diskette with updated limit files.

5. I used to send Doble paper copies of test data for review and storage. How do I send Doble copies of electronic test data?

- Diskettes should be sent via postal mail to the attention of your Doble engineer. You can also compress and attach data to an e-mail message and send it to Doble. Contact your Doble engineer for instructions about how to do this.

6. Does Doble have a web site from which I can download files?

- Yes; our World Wide Web site is http://www.doble.com.

Test Procedures

1. How do I set up the test set with a resonator?

- See Chapter 2– ”Using A Resonator” on page 2-1.

2. How do I test in the manual mode?

- Select Configuration, from the Tools menu. Then, click the System tab and select “Manual Set Voltage” as the Ramp Mode, and click the OK button.

NOTE

Make sure to return the setting to automatic when finished.

3. Can I use the M4000 to do a turns ratio test?

- Yes; see ”Turns Ratio Tests With The Doble Capacitor” on page 5-170.

4. How do I save the same clipboard screen multiple times (as I add more lines of test data)?

- Click the diskette icon to save a test (or File/Save As...). You will be prompted to select a directory and a file name for the clipboard screen. Use the default directory (for example, C:\Doble\Dta\Data), and choose an alphanumeric filename with no more than eight letters. Click the OK button. All subsequent saves of the same screen will result in the message, “This file already exists. Do you want to replace it?”. Select “Yes” to save. It is OK to overwrite the previous “save”, since each subsequent “save” includes the previously saved data. If you select “No”, the data you had previously saved will remain, but your new data will not be saved. Then when you turn off the test set, it will be lost.
- Each screen full of data must be given its own name, so when you fill up a clipboard screen and must start on a new one, the new one MUST BE GIVEN A NEW NAME.

5. How can I disable the Beeper? What if I don't want to use the strobe light?

- From the View menu, select Configuration, and select the “Instrument” tab. Under Safety Settings, you can disable the beeper, or chose that the strobe not be required for a test.

6. I want to use an inverter as a power supply. What does Doble suggest?

- A 2400 watt inverter is sufficient to run the M4200c. Be sure to use one designed for use with electronic equipment, so it can handle the switching needs of the M4100. If the inverter is mounted in a vehicle, be sure the vehicle is properly grounded, and that the inverter/vehicle ground is the same as the M4000/specimen ground. Be mindful of vehicle exhaust if you are keeping the vehicle running.

7. I can't test using a voltage higher than seven kV.

- Make sure your input voltage is above 105 volts (on a 120/208Y system). Below that you may not be able to test at full voltage. It may also be that your specimen draws more current than the test set can supply at a higher voltage than seven.

8. My test results contain negative watts resulting in negative percent power factor.

- Be sure this isn't merely due to the negative watts effect, described in the 1987 Doble Minutes, pg. 2-501. This can affect bushing C_1 measurements, transformer CHL measurements, and Rotating Machinery end turn measurements, for example. Negative watts can also be obtained when measuring very low capacitance specimens with surface contamination. Clean the surfaces involved and retest

- Run a Calibration Verification Test (under the Diagnostics menu). If the results show a GST watts loss failure, follow the procedure under "Interpreting Results Of Diagnostic Tests" in Chapter Seven.

General

1. I loaded the M4000 software on my PC, and now whenever I turn on my PC, it automatically starts up with the M4000 software.

- When loading the software, it loaded a shortcut icon into the windows startup folder. If running Windows 95 or higher, right-click on the Start button, open the Programs folder, open the Startup folder, and delete the M4000 icon.

2. I have a problem with my M4000 and it has to be replaced. I can't get my test data off the unit's hard drive. Can Doble save it for me?

- As a matter of routine, Doble saves, whenever possible, the data on an incoming M4200c's hard drive, using MS-DOS Backup command. If notified, Doble will send this data to you, and it can be restored using the MS-DOS Restore command.

3. The M4200c pointer device (mouse) has no right and left buttons. How do I adjust column widths?

- First, move the mouse near the column header or divider line you wish to move.
- When the cursor becomes a double arrow, double-tap the pointer device's pad, but keep your finger on the pad after the second tap, freezing the double arrow.
- Move the double arrow to its new position, and when the new position is achieved, lift your finger off the pad. Then move the mouse off the divider to break the drag.

4. The M4200c pointer device (mouse) has no right and left buttons. How can I select an entire field to replace the contents?

- Place the cursor in the field you wish to select, and double-tap the pointer pad.

5. The M4200c pointer device (mouse) has no right and left buttons. How can I display a right-button menu?

- Place the cursor in the desired field, and tap the different-colored triangle in the upper right-hand corner of the pointer device's pad.