AVTM 672001
Rev. B
October 2001

Instruction Manual
for
DELTA-2000
10-kV Automated Insulation Test Set
Catalog No. 672001

High-Voltage Equipment
Read the entire manual before operating.

Aparato de Alto Voltaje
Antes de operar este producto lea este manual enteramente.

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DELTA-2000
10-kV Automated Insulation Test Set
Instruction Manual

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Section 1
Introduction

Receiving Instructions

Check the equipment received against the packing list to ensure that all materials are present. Notify AVO International of any shortage. Telephone (610) 676-8500 and ask for the Customer Service Department.

Examine the instrument for damage received in transit. If damage is discovered, file a claim with the carrier at once and notify AVO International, giving a detailed description of the damage.

This instrument has been thoroughly tested and inspected to meet rigid specifications before being shipped. It is ready for use when set up as indicated in this manual.

General Information

The DELTA-2000 is used for shop and field testing of high-voltage electrical insulating systems at test voltages up to 12 kV. Test results can be used to evaluate the nature and quality of electrical insulating materials and manufacturing processes to reveal contamination, fractures, punctures, and other defects that accompany the aging of insulation. The test set comprises a control unit, a high-voltage unit, cables, and a canvas carrying bag. Refer to the Specifications section for a list of included accessories.

Tests are made by measuring the capacitance, power factor (dissipation factor) and dielectric losses of a specimen. The values measured will change when undesirable conditions exist, such as moisture on or in the insulation; shorts or opens in windings or insulation; the presence of conductive contaminants in insulating oil, gas or solids; and the presence of internal partial discharges.

The test set measures the capacitance, power factor (dissipation factor) and dielectric losses of electrical insulation on high-voltage power equipment such as cables, bushings, insulators, circuit breakers, transformers, rotating machines, capacitors, and surge (lightning) arresters.

The test set measures changes of capacitance and dielectric loss due to variations of voltage level and ambient conditions, for example, changes in temperature, humidity, pressure, mechanical shock, vibration, and stress. Dielectric constant and transformer excitation current can also be measured. The test set makes all standard UST and GST tests on high-voltage apparatus; seven front-panel test mode switches set up test configuration.

- Ungrounded specimen test (UST), three positions
- Grounded specimen test (GST), one position
- Grounded specimen test using guard connection (GST), three positions

Features include:

- Automatic balance control by high-performance microprocessor.
- User-friendly operation.
- Automatic self-checking of test set calibration and operation.
- Large, easy-to-read LCD shows alphanumeric and graphic data.
- Front-panel MENU switches select operating mode.
- Dual low-voltage input cables simplify measurements on multi-winding transformers and circuit breakers containing inboard and outboard bushings.
- Automatic interference suppression circuit ensures trouble-free operation in switchyards (up to 765 kV) under electrostatic and magnetic interference conditions. The interference suppressor circuit is turned on and off using MENU switches. When the interference suppressor circuit is turned on, the level of interference is shown on the display.
- Direct reading of the following quantities:
  Voltage
  Capacitance
  Current at 2.5 kV or 10 kV
  Percent power factor
  Percent dissipation factor
  Watts at 2.5 kV or 10 kV
- External printer records test data.
- External personal computer (PC) or laptop can be connected instead of a printer to transfer test results.
- Data key stores 127 tests for retrieval and analysis. Stored data can be transferred to a PC.
- Optional bar code wand records equipment identification and temperature.
- Two safety interlocks (hand switch or foot switch).
- Built-in interface to the optional Resonating Inductor provides extended range of capacitive measurements.
- Two-piece design makes the test set easy to transport.
- Meets the requirements of both the European EMC and Low Voltage Directives.

Precautions

The test set and the specimen to which it is connected are a possible source of high-voltage electrical energy and all persons making or assisting in tests must use all practical safety precautions to prevent contact with energized parts of the test equipment and related circuits. Persons actually engaged in the test must stand clear of all parts of the complete high-voltage circuit, including all connections, unless the test set is de-energized and all parts of the test circuit are grounded. Persons not directly involved with the work must be kept away from test activities by suitable barriers, barricades, or warnings. An interlock circuit is provided on the control unit of the test set to enable the operator to enclose all parts of the complete high-voltage circuit within a secure area. The interlock circuit should be used to shut off input power automatically upon unauthorized entry into the high-voltage area or for any other safety reasons.

Treat all terminals of high-voltage power equipment as a potential electric shock hazard. There is always the potential of voltages being induced at these terminals because of proximity to energized high-voltage lines or equipment. Always use a safety ground stick to ground the high-voltage conductor. A safety ground jumper must then be installed between all terminals of apparatus under test and ground. Always disconnect test leads from power equipment before attempting to disconnect them at the test set. The ground connection must be the first made and the last removed. Any interruption of the grounding connection can create an electric shock hazard.

This instrument operates from a single-phase power source. It has a three-wire power cord and requires a two-pole, three-terminal, live, neutral, and ground type connector. The voltage to ground from the live and neutral poles of the power source must be within the following rated operating voltage:

For Cat. No. 672001	120 V ±10%, 60 ±2 Hz
For Cat. No. 672001-44	120 V ±10%, 50 ±2 Hz
For Cat. No. 672001-45	230 V ±10%, 60 ±2 Hz
For Cat. No. 672001-47	230 V ±10%, 50 ±2 Hz

Before making connection to the power source, determine that the instrument rating matches the voltage of the power source and has a suitable two-pole, three-terminal grounding connector.

The power input plug must be inserted only into a mating receptacle with a ground contact. Do not bypass the grounding connection. Any interruption of the grounding connection can create an electric shock hazard. Determine that the receptacle is properly wired before inserting the plug.

For test sets energized with 230 V input, the neutral terminal of the input supply cord (white or blue lead) must be connected to the neutral pole of the line power source. The ground terminal of the input supply cord (green or yellow/green lead) must be connected to the protective ground (earth) terminal of the line power source. The black or brown cord lead is the live (hot) lead.

To avoid electric shock hazard, operating personnel must not remove the instrument from the case or remove the protective cover from the power supply. Component replacement and internal adjustment must be performed by qualified service personnel.

The control circuits in all test sets are protected by two mains circuit fuses. These fuses are not replaceable by the operator. Refer fuse replacement to qualified service personnel only. To avoid electric shock and fire hazard, use only the fuse specified in Section 3, Specifications, that is identical in respect to type, voltage rating and current rating.

AVO International has made formal safety reviews of the initial design and any subsequent changes. This procedure is followed for all new products and covers areas in addition to those included in applicable standards. Regardless of these efforts, it is not possible to eliminate all hazards from electrical test equipment. For this reason, every effort has been made to point out in this instruction manual the proper procedures and precautions to be followed by the user in operating this equipment and to mark the equipment itself with precautionary warnings where appropriate. It is not possible to foresee every hazard which may occur in the various applications of this equipment. It is therefore essential that the user, in addition to following the safety rules in this manual, also carefully consider all safety aspects of the test before proceeding.

- Safety is the responsibility of the user.
- Misuse of this high-voltage equipment can be extremely dangerous.
- The purpose of this equipment is limited to use as described in this manual. Do not use the equipment or its accessories with any device other than specifically described.
- Never connect the test set to energized equipment.
- Operation is prohibited in rain or snow.
- Do not use the test set in an explosive atmosphere.
- A qualified operator should be in attendance at all times while the test equipment is in operation.
- Observe all safety warnings marked on the equipment.
- Corrective maintenance must only be performed by qualified personnel who are familiar with the construction and operation of the test set and the hazards involved.

- Refer to IEEE 510 - 1983, "IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing," for information.

If the test equipment is operated properly and all grounds correctly made, test personnel need not wear rubber gloves. As a routine safety procedure, however, some users require that rubber gloves be worn, not only when making connections to the high-voltage terminals, but also when manipulating the controls. AVO International considers this an excellent safety practice.

High-voltage discharges and other sources of strong electric or magnetic fields may interfere with the proper functioning of heart pacemakers. Persons with heart pacemakers should obtain expert advice on the possible risks before operating this equipment or being close to the equipment during operation.

Warning and Caution Notices

Warning and caution notices are used throughout this manual where applicable and should be strictly observed. These notices appear in the format shown below and are defined as follows:

WARNING
Warning, as used in this manual, is defined as a condition or practice which could result in personal injury or loss of life.

CAUTION
Caution, as used in this manual, is defined as a condition or practice which could result in damage to or destruction of the equipment or apparatus under test.

Section 3
Specifications

Electrical

Input Power

Cat. No. 672001	120 V ac, 60 Hz, 12 A continuous, IEC 1010-1 installation category II
Cat. No. 672001-44	120 V ac, 50 Hz, 12A continuous, IEC 1010-1 installation category II
Cat. No. 672001-45	230 V ac, 60 Hz, 6 A continuous, IEC 1010-1 installation category II
Cat. No. 672001-47	230 V ac, 50 Hz, 6 A continuous, IEC 1010-1 installation category II

Protective Devices

Circuit breaker: 230 V models: 230 V, 15 A, double pole
120 V models: 230 V, 30 A, double pole

Fuses (2): IEC designation: Type T, 230 V, 3.15 A

Output Voltage and Current

Output voltage range: 0 to 12 kV

Maximum continuous current: 100 mA @ 10 kV, 83 mA @ 12 kV
Maximum intermittent current: 200 mA @ 10 kV, 167 mA @ 12 kV
15 minutes on, 15 minutes off, maximum eight test cycles.

The power supply capacity can be extended to 4 A using the optional Resonating Inductor (Cat. No. 670600).

Test Frequency

Same as line frequency.

Measuring Ranges

Voltage: 250 V to 12 kV, 10 V resolution.
Minimum recommended voltage is 500 V.

Current: 0 to 5 A, in 5 ranges, 1µA maximum resolution on low range
The measurement can be corrected to 2.5 kV and 10 kV equivalents.

Capacitance: 1 pF to 1.1µF, 0.01 pF maximum resolution on low ranges

Dissipation factor: 0 to 200%, 0.01% DF maximum resolution

Power factor: 0 to 90%, 0.01% PF maximum resolution

Watts loss: 0 to 2 kW, actual power
0 to 100 kW when corrected to 10 kV equivalent
0.1 mW maximum resolution
The measurement can be automatically corrected to 2.5 kV and 10 kV equivalents.

Accuracy

Voltage (rms): ±(1% of reading + 1 digit)

Current (rms): ±(1% of reading + 1 digit)

Capacitance: ±(0.5% of reading + 2 pF) in UST mode
±(0.5% of reading + 6 pF) in GST mode

Dissipation factor: ±(2% of reading + 0.05% DF)

Power factor: ±(2% of reading + 0.05% PF)

Watts loss at 10 kV: ±(2% of reading + 1 mW)

Measuring Time

10 to 45 seconds depending on mode of operation

Test Modes

UST; Ground Red, Measure Blue
UST; Ground Blue, Measure Red
UST; No Ground, Measure to both Red and Blue
GST; Ground Red and Blue
GST; Guard Red and Blue, No Grounding
GST; Guard Red, Ground Blue
GST; Guard Blue, Ground Red

Cancellation Range and Maximum Interference Conditions

Automatic interference cancellation circuit ensures trouble-free operation of test set in switchyards up to 765 kV, when operated directly under or adjacent to energized lines or bus work.

Magnetic at line frequency: 1000 μT in any direction.

Available Methods

- Operator selectable automatic forward/reverse measurement averaging.
- Operator selectable automatic tracking interference cancellation

Maximum Measurable Specimen Capacitance

Table 1 shows the maximum measurable specimen capacitance. This can be increased up to 1.1 μF at 10 kV test voltage using the optional Resonating Inductor.

Table 1: Maximum Measurable Specimen Capacitance at 50/60 Hz

Test Volts (kV)	Maximum Capacitance (μF) (100 mA continuous service)		Maximum Capacitance (μF) (200 mA for 15 minutes)	
	60 Hz	50 Hz	60 Hz	50 Hz
2.5 & less	0.11	0.11	0.11	0.11
4.0	0.066	0.080	0.11	0.11
5.0	0.052	0.062	0.11	0.11
6.0	0.044	0.053	0.088	0.106
8.0	0.033	0.040	0.066	0.080
10.0	0.026	0.031	0.052	0.062
12.0	0.022	0.026	0.044	0.053

Safety/EMC/Vibration Qualifications

Meets the requirements of the European EMC and Low Voltage Directives and ASTM D999.75.

Environmental Conditions

Operating temperature range: 32° to 122°F (0 to 50C)

Storage temperature range: -58° to 140°F (-50 to 60C)

Relative humidity: 0 to 90% noncondensing (operating)
0 to 95% noncondensing (storage)

CAUTION

Storage for extended periods of time at high temperature and relative humidity may cause degradation of the LCD.

Physical Data

Dimensions and Weight

Control unit: 15 x 22 x 16 in. (381 x 559 x 406 mm) (H x W x D)
74 lb (33 kg)

High-voltage unit: 15 x 22 x 16 in. (381 x 559 x 406 mm) (H x W x D)
63 lb (29 kg)

Cables (in bag): Refer to “Accessories Supplied” for individual cable lengths.
40 lb (16 kg) max

Measuring Circuit

Based on principle of opposing ampere-turn balance using adjustable transformer ratio arm bridge.

Reference Capacitor

Fixed loss-free capacitor (fully shielded): 100 pF ±0.5%, 12 kV.

High-Voltage Transformer

Double-shielded construction.

Guarding

Cold guard type circuit encloses power transformer, reference capacitor, entire high-voltage circuit and output test cables.

Display

LCD 256 x 128 dot pixels (W x H)
120 x 60 mm viewing area

Printer

A battery/line-powered printer prints results of the present test or test results stored on the data key. A separate manual is supplied with the printer.

Data Keys

Two data keys are provided; each stores 127 test results. Data can be transferred to a PC using the interface box and PC program supplied. Refer to Appendix A for a description of the data-key data downloader program.

Terminals

High-voltage
Low-voltage (2) marked RED and BLUE
Interconnection (2)
Resonating Inductor Return
Supply power
External interlock (2)
Ground
Printer / RS-232
Bar code wand
Data key

Safety Features

- Zero start for output voltage.
- Two external hand interlock switches (supplied) must be closed to energize high-voltage circuit.
- Double ground required to energize high-voltage circuit.
- Circuit breaker for short-circuit protection.
- All controls at ground potential.
- Overvoltage protective devices prevent damage to test set in the event of specimen breakdown.
- Low-voltage inputs are grounded when the test set is turned off or between measurements.

Accessories Supplied

- High-voltage lead: 70 ft (21.4 m), double shielded, interchangeable hook or clip terminations
- Low-voltage leads: two, 70 ft (21.4 m), shielded, (color-coded red and blue)
- Ground lead: 15 ft (4.6 m)
- Power cord: 8 ft (2.5 m)
- Safety hand switch interlock #1: 70 ft (21.4 m)
- Safety hand switch interlock #2: 8 ft (2.5 m)
- Two 5 ft. (1.5 m) interconnect cables for connecting the control unit to power unit
- Two protective caps for the HV cable connectors
- Canvas carrying bag for carrying test leads
- Battery/line-powered serial thermal printer

- Printer interface cable for connecting printer to control unit.
- PC interface cable for connection of data key box to PC
- Two data keys with interface box, cable, and download software
- Two, heavy-duty, foam-padded; transit cases for test set
- Instruction Manual

Optional Accessories

- Bar code wand and software (Cat. No. 34705) The bar code generator program BAR-ONE is a purchased software package from Vertical Technologies, Inc. This program is used to create bar code identification labels for the DELTA-2000. The program generates bar codes in the Code 39 format. Refer to the User's Guide accompanying the software for installation and operation.
- Bushing tap connectors (3) (Cat. No. 670506)
- Calibration standard (Cat. No. 670500-1)
- Hot-collar belts (3) (Cat. No. 670505)
- Oil Test Cell (Cat. No. 670511)
- Resonating Inductor (Cat. No. 670600)
- RS232 cable (Cat. No. 34675)
- Safety interlock foot switch (Cat. No. 10229-5)
- Transit case for cables (Cat. No. 218744-1)
- Transit case for standard (Cat. No. 670635)
- High-voltage lead 25 ft (7.6 m) (Cat. No. 30012-8)

Section 4
Controls, Indicators, and Connectors

Control Unit Front Panel (Fig. 1)

1. GROUND

   This wing nut is for connecting the test set to earth ground.

2. OPEN GROUND

   When lit, this yellow lamp indicates an open in double ground system or defective grounding of test set.

3. MENU

   Three membrane-type switches select main menu, move cursor up or down, select setup for operating mode, send test results to printer, store test results in data key, and enter equipment ID NO. and temperature from the optional bar code wand.

4. LCD

   Graphic display guides the operator through menu-selected setup, test, and calibration procedures; displays test results and indicates status of setup and operating procedures. It also gives indication of the presence of high voltage at the high-voltage output cable.

WARNING

High voltage is present at the high-voltage output cable whenever the two lightning bolt symbol is displayed.

5. CONTRAST

   This control changes the contrast and viewing angle of the LCD when turned clockwise or counterclockwise.

6. DATA KEY

   This receptacle provides capability to store test results when a data key is inserted. One data key stores 127 test results. Two data keys are supplied. Data can then be transferred to a PC using the data key RS232C interface box.

7. LOW VOLTAGE LEAD CONFIGURATION

   Seven membrane-type switches select the ungrounded specimen test (UST) or grounded specimen test (GST) operating mode. Color bars next to switch positions identify connection of test leads as to measurement, guarding or grounding.

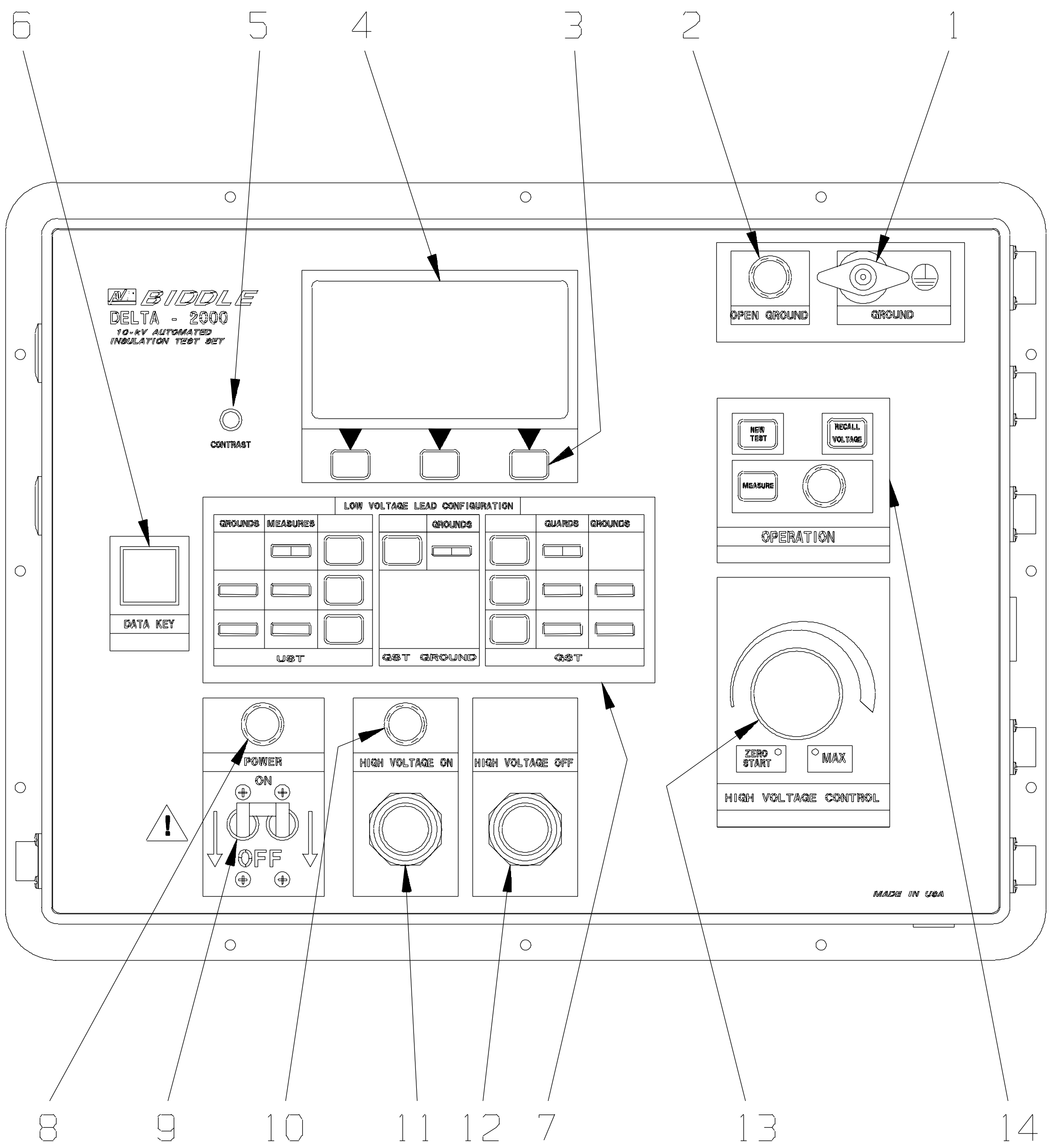


Figure 1: Control Unit Front Panel

UST; Ground Red, Measure Blue
UST; Ground Blue, Measure Red
UST; No Ground, Measure to both Red and Blue
GST; Ground Red and Blue
GST; Guard Red and Blue, No Grounding
GST; Guard Red, Ground Blue
GST; Guard Blue, Ground Red

8. POWER

This white lamp when lit indicates that the main circuit breaker is set to ON and the test set is energized.

9. ON/OFF

This two-pole, magnetic main circuit breaker controls power to the test set and provides short-circuit and overload protection.

10. HIGH VOLTAGE ON

This red lamp when lit indicates that the high-voltage output circuit is enabled.

11. HIGH VOLTAGE ON

This white push-button switch, when pressed, energizes the high-voltage output circuit and red HIGH VOLTAGE lamp when the HIGH VOLTAGE CONTROL is set to ZERO START and the external interlock switches are closed.

12. HIGH VOLTAGE OFF

This red push-button switch, when pressed, immediately de-energizes high-voltage output. It may be used as an emergency stop. It turns off the red MEASURE and red HIGH VOLTAGE ON lamps and clears display test results.

13. HIGH VOLTAGE CONTROL

Variable-ratio autotransformer adjusts output voltage by controlling the primary voltage of the high-voltage transformer. This control must be set to ZERO START to activate high-voltage output.

14. OPERATION

Three membrane-type switches and one red lamp function as follows:

NEW TEST— After completing a test, the operator can choose to conduct another test by pressing this button; this will bring up a test screen in which the operator can choose a different lead configuration, and recall voltage. It also clears display test results.

MEASURE — When pressed, initiates a measurement test. When completed, test voltage is removed from the specimen and the test results are displayed on the LCD.

Red lamp — When lit, indicates that a measurement is being made and high voltage is being applied to the test specimen.

WARNING

High voltage may still be applied to the test specimen even when this lamp is not lit. Check for the presence of the two lightning bolt symbol on the graphics display for confirmation.

RECALL VOLTAGE — This switch is only active after the final results from a measurement test are shown on the LCD and the NEW TEST button is pressed. When pressed, high-voltage can be reapplied to the test specimen without a zero restart of the high-voltage circuit. This time-saving feature allows the operator to repeat tests or make tests using a different LOW VOLTAGE LEAD CONFIGURATION switch setting (7) without readjustment of the output voltage setting.

Internal beeper (not shown)

Beeps to confirm that a membrane switch has been pressed.

Control Unit Connector Panels (Fig. 2, 3, 4)

15, 16. SAFETY INTERLOCK 1 and 2

Two plug receptacles for connecting external interlock switches. Two hand interlock switches are supplied; however, in the event that a hand interlock is replaced with a test area interlock, the system must be constructed so that the interlock switches are closed when the test area gate or gates are closed. The interlock wiring must be run as a twisted pair to minimize electromagnetic coupling into the system. This interlock system should be wired such that connection is made to the A and B sockets of the SAFETY INTERLOCK receptacle. When the interlock loop is opened the test is automatically terminated.

17. AC POWER

Receptacle for connecting the test set to an ac power source as marked on panel.

18. INDUCTOR RETURN

Receptacle for connecting the test set to an optional Resonating Inductor (Cat. No. 670600) for extended capacitance range.

19,20. INTERCONNECT 1 and 2

Two plug receptacles for connecting the control unit to the high-voltage unit.

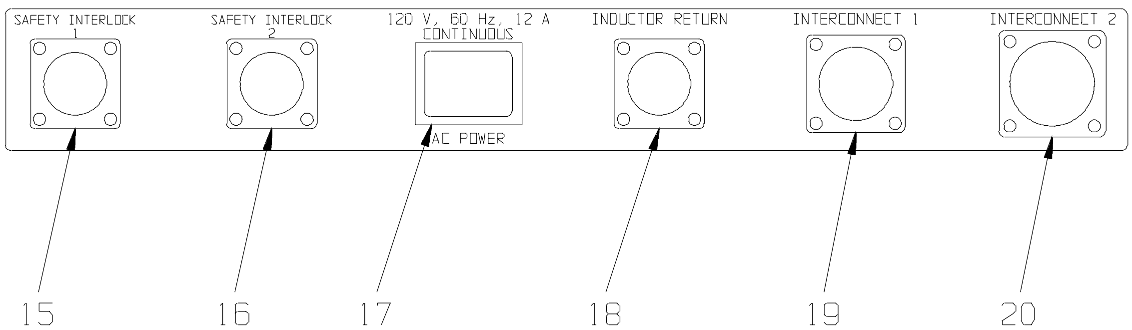


Figure 2: Control Unit Connector Panel (Right)

21. LOW VOLTAGE RED

Plug receptacle for connecting the red low-voltage test lead.

22. LOW VOLTAGE BLUE

Plug receptacle for connecting the blue low-voltage test lead.

23. PRINTER/RS-232 Port

Plug receptacle for connecting the printer or RS-232 port of a PC.

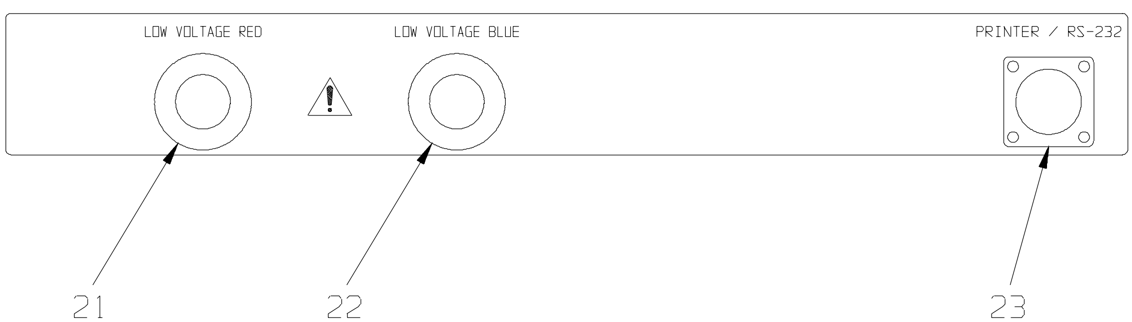


Figure 3: Control Unit Connector Panel (Left)

24. BAR CODE WAND

This receptacle is for connecting the optional bar code wand used to enter equipment identification and temperature to be included in test results.

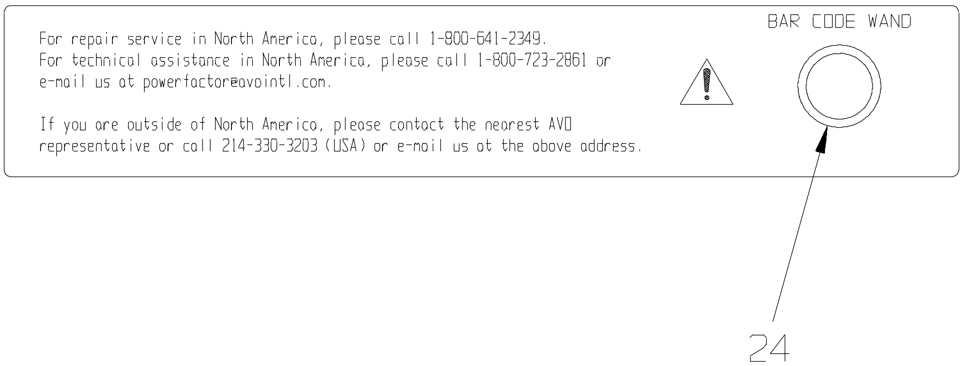


Figure 4: Control Unit Connector Panel (Front)

High-Voltage Unit Connector Panel (Fig. 5)

The following connectors are situated behind the door in the front of the high-voltage unit.

25,26. INTERCONNECT 1 and 2

Two plug receptacles for connecting the control unit to the high-voltage unit.

27. HV OUTPUT

Plug receptacle for connecting the high-voltage output cable.

28. Ground

Wing nut terminal for connecting the ground pigtail lead of the high-voltage output cable.

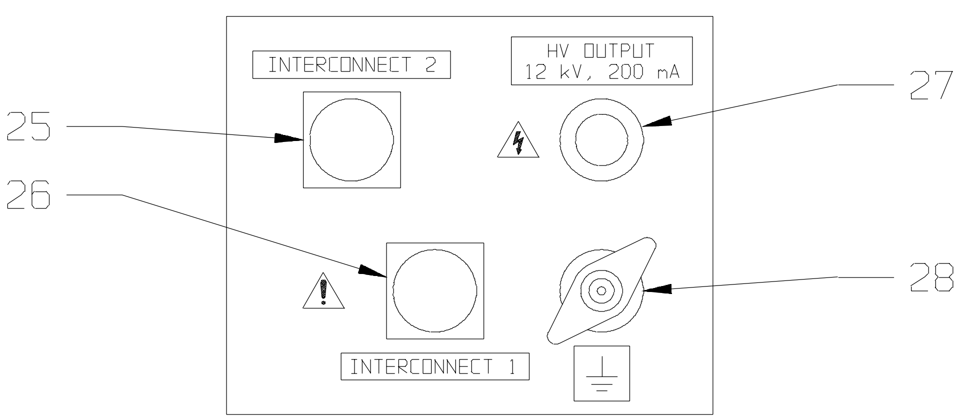


Figure 5: Connector Panel, High-Voltage Unit

Section 5
Setup and Operation

Safety Precautions

The output of this test set can be lethal. As with any high-voltage equipment, caution must be used at all times and all safety procedures followed. Read and understand Section 2, Safety, before proceeding. Be sure that the test specimen is de-energized and grounded before making connections. Isolate power equipment to be tested from the high-voltage busbars and attach necessary grounds to floating busbars in accordance with standard company policy, observing all safety procedures. Make certain that no one can come in contact with the high-voltage output terminal or any material energized by the output. Be aware that when testing power cables high voltage will be present at the remote end of the cable. Use protective barriers if necessary. Locate the control unit and high-voltage unit in an area which is as dry as possible.

Maintain adequate clearances between energized conductors and ground to prevent arc-over. Such accidental arc-over may create a safety hazard or damage the equipment being tested. A minimum clearance of 1 ft (30 cm) is recommended.

Setup

The following steps are a general guide for setting up the test set. Figure 6 shows a typical setup for testing inter-winding and ground capacitance on a three-phase delta-wye power transformer; Figure 7 shows a typical setup for making excitation current measurements on the same transformer. The test set controls and connectors are identified in Figures 1 through 5. Refer to the Application Guide for specific instructions on connecting this and other power equipment to the test set.

WARNING

There is always the possibility of voltages being induced at the terminals of a test specimen because of proximity to energized high-voltage lines or equipment. A residual static voltage charge may also be present at these terminals. Ground each terminal to be tested with a safety ground stick, then install safety ground jumpers, before making connections.

CAUTION

To ensure proper functioning of the DELTA-2000, it is important to avoid exposure of the unit to excessive heat. When performing tests on days when there is high temperature, keep the DELTA-2000 in the shade whenever possible. Although the DELTA-2000 is rated for operation up to 50°C, in direct sunlight the interior of the control unit can exceed that temperature, reducing the amount of time that the instrument can be used. Turn the DELTA-2000 off when not in use.

1. Locate the test set at least 6 ft (1.8 m) from the specimen to be tested.

2. Connect the wing thumb-nut ground terminal (1) of the test set to a low impedance earth ground using the 15 ft (4.5 m) ground cable supplied. This should always be the first cable connected.

3. Connect the control unit receptacle (19, 20) to the high-voltage receptacle (25, 26) using the two 5 ft (1.52 m) interconnection cables. Make sure that the bayonet type plugs are fully locked on the receptacles.

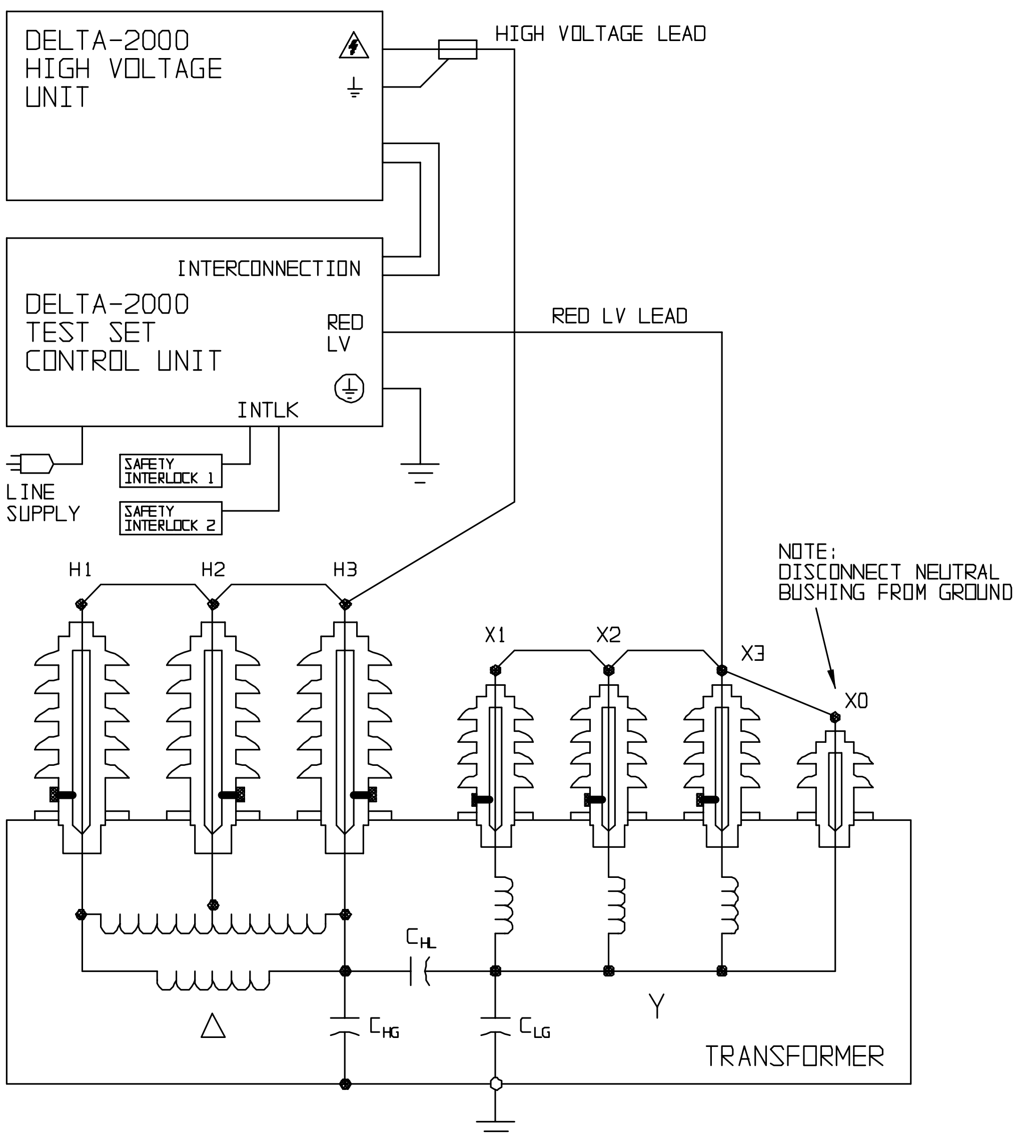


Figure 6: Typical Test Setup for Ac Insulation Testing of a Three-Phase Power Transformer

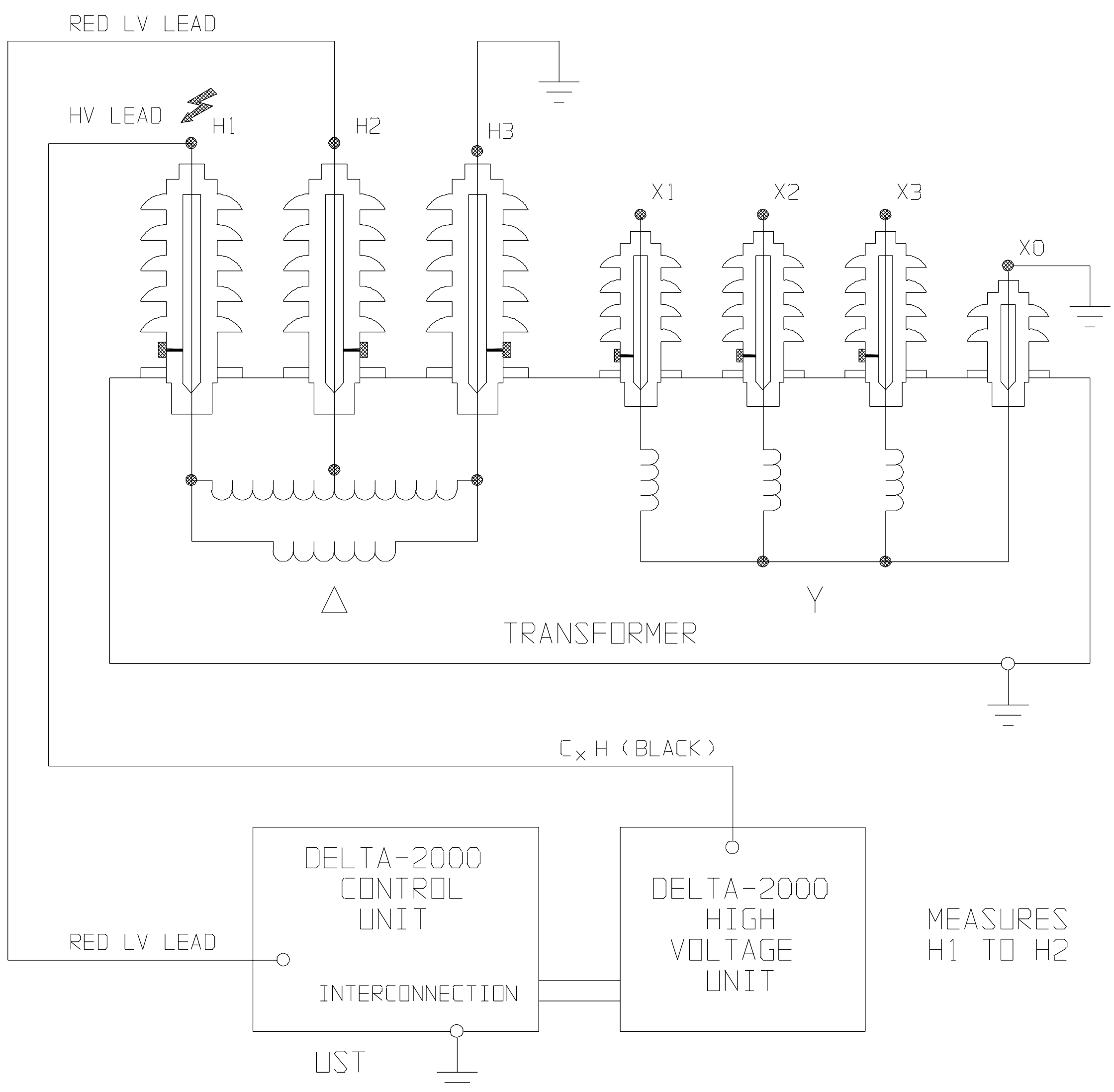


Figure 7: Typical Test Setup for Transformer Excitation Current Measurements

4. Connect the low-voltage cable with the red colored boot to the LOW VOLTAGE RED receptacle (21). Make sure the connector locks to the receptacle. If required, connect the low-voltage cable with the blue colored boot to the LOW VOLTAGE BLUE receptacle (22).

5. Connect the external interlock cables or a test area interlock system to the SAFETY INTERLOCK receptacles (15, 16). Make sure the bayonet type plugs are fully locked on the receptacles.

6. Connect the printer to the PRINTER/ RS-232 receptacle (23) of the test set if desired. Make sure the bayonet type plug is fully locked on the receptacle. Make sure the dip switches on the bottom of the printer are set as shown in Figure 8:

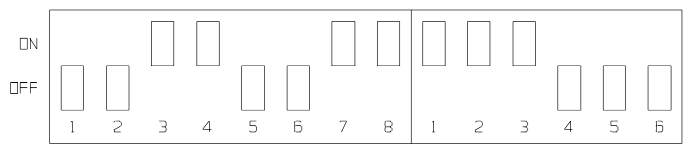


Figure 8: Printer Dip Switch Settings

7. Connect the bar code wand (optional) to its receptacle (24) of the test set if desired.

8. Connect the high-voltage cable to the high-voltage terminal (27) of the high-voltage unit (be sure that the connector locks in place). Connect the pigtail for the outer shield to the wing nut terminal (28) (ground) on the high-voltage unit.

Note: The exposed metal shield ring nearest the hook on the outboard end of the high-voltage cable is at guard potential. The inner metal ring is ground. Both rings are undercut so that a battery or alligator clip may be attached to them for convenience in connection of short jumper leads to guard or ground. Keep the insulation at each end of this cable, as well as the high-voltage plug and receptacle, free from moisture and dirt during installation and operation. Clean as required with a clean, dry cloth or one moistened sparingly with alcohol.

9. With the main breaker OFF, plug the input power cord into the test set power receptacle (17) and into a three-wire grounded power receptacle having the appropriate voltage and current ratings.

When using a generator as a power source for the DELTA-2000, note the following:

- The generator itself should be grounded to a suitable earth ground. If this is not done properly, the high-voltage circuit of the DELTA-2000 will be disabled.
- The voltage supplied to the DELTA-2000 should be 120 V ±10% (108 to 132 V). For the -47 model, the voltage should be 230 V ±10% (207 to 253 V). Frequency stability should be higher than ±2 Hz. Variations of the output voltage shall be less than 2 V during any 5-min time interval.

10. Connect the crocodile clip of the low-voltage test cable to the desired terminal of the test specimen.

11. Connect the hook (or clip) of the high-voltage test cable to the desired terminal of the test specimen.

When making capacitance measurements on transformer windings, always short each winding on itself with a jumper lead to eliminate winding inductance effect. When making transformer excitation current measurements, conduct all tests on high-voltage windings only. This reduces the required charging current. In load tap changers, set to fully raised or fully lowered position for routine tests.

Description of Menus and Test Screens

The test set is operated by using the controls and switches on the front panel and on the LCD. On power up, a beep will sound, the test set will run a complete RAM check, and will initialize all the hardware and software variables.

Opening Display Screen (Fig. 9)

The LCD then displays the opening screen (Fig. 9). This display is followed by a beep sound as the test set performs a diagnostic self-check of the electronics. If no errors are detected, the message "IN PROGRESS" at the bottom of the screen is replaced with the message "SUCCESSFUL."

AVO

AVO INTERNATIONAL
BIDDLE
DELTA-2000
SELF-DIAGNOSTIC
AND
CALIBRATION CHECK

IN PROGRESS

Figure 9: Opening Display Screen

Self-Diagnostic Results Screen (Fig. 10)

If there are any errors, the "self-diagnostic results" screen (Fig. 10) will appear and will list the specific failure(s). Refer to the Maintenance and Calibration section.

SELF-DIAGNOSTIC RESULTS:

....
....
....

PLEASE REFER TO THE INSTRUCTION
MANUAL FOR HELP.

Figure 10: Self-Diagnostic Results Screen

First Test Screen (Fig. 11)

After a successful self-diagnostic check, the first test screen appears.

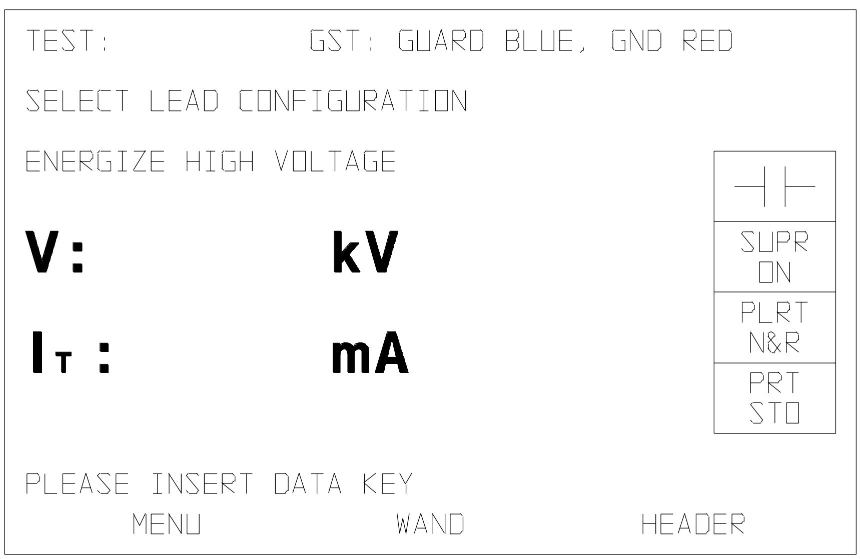


Figure 11: First Test Screen

TEST: — This message shows the number of each test.

GST: GUARD BLUE, GND RED — This message indicates the low voltage lead configuration chosen.

SELECT LEAD CONFIGURATION — This message prompts the operator to choose the appropriate low voltage lead configuration, which can be selected via membrane switch push buttons on the front panel.

ENERGIZE HIGH VOLTAGE — This message prompts the operator to energize the high voltage circuit (via push-button switch on front panel) before conducting a test.

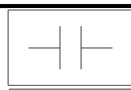
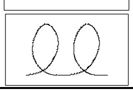
V: kV — The voltage applied to the specimen is displayed on this line when high voltage is energized.

I_T: mA — The total output current is displayed on this line when high voltage is energized.

PLEASE INSERT DATA KEY — This message prompts the operator to insert a data key if storage of test results is desired.

The status blocks shown on the right side of the screen give continuous indication (status) of the activated operating functions. This feature allows the operator to make an initial setup and then make repetitive measurements without going back into the menu. The status blocks are further defined as follows:

Table 2: Definition of Status Blocks on Test Screens

Status Block	Definition
	Ac insulation test
	Transformer excitation test
SUPR ON	Interference suppressor: turned on
SUPR OFF	Interference suppressor: turned off
PLRT N&R	Voltage polarity: normal/reverse
PLRT NORM	Voltage polarity: normal only
PRT STO	Print and store readings: print and store
PRT	Print and store readings: print readings
STO	Print and store readings: store readings
	Print and store readings: none

The bottom line on the screen (command line) displays the function of the three buttons immediately below the display. On the initial screen, with the PRINT/STORE option selected, these selections are MENU, WAND, and HEADER.

MENU — displays the first of two menu screens. Menu operations allow the operator to change test parameters. Pressing the button below MENU will cause the first menu screen (Fig. 12) to be displayed.

WAND — pressing the button below WAND displays three options on the command line: ID NO., CANCEL, and TEMP.

Pressing the button below ID NO. allows the operator to enter the test identification number via the bar code wand.

Pressing the button below CANCEL allows cancellation of an entry if a mistake has been made.

Pressing the button below TEMP allows the operator to enter the temperature in °C via the bar code wand.

HEADER — sends a header record to the printer.

First Menu Screen (Fig. 12)

From the first menu screen, the operator can choose the desired test parameters. The item selected is shown in reverse video and the command line shows the options available. The center and right buttons display UP and DOWN on the screen, respectively. These buttons allow the operator to highlight the desired line. The selection sequence allows the display to wrap from the first line to the last line and vice versa. The display above the left button shows the function of this button and changes as different items are selected; either ENTER or CHANGE is displayed.

```
EXIT TO TEST                        11/26/96      10:27

MEASUREMENT:       AC INSULATION TEST (or)
                   XFMR EXCITATION TEST

CORRECTION:        NONE (or) 10 kV (or) 2.5 kV

LOSS DISPLAY: POWER FACTOR (or) DISSIPATION FACTOR

INTERFERENCE SUPPRESSOR:     ON (or) OFF

HV POLARITY: NORMAL/REVERSE (or) NORMAL ONLY

NEXT MENU

ENTER (OR) CHANGE            UP                DOWN
```

Figure 12: First Menu Screen

EXIT TO TEST— returns the display to the first test screen (Fig. 11).

MEASUREMENT— toggles between AC INSULATION TEST (for routine power factor testing) and XFMR EXCITATION TEST (for measuring transformer excitation current).

CORRECTION— toggles between NONE, 10 kV, and 2.5 kV. Allows the operator to view actual values of current and watts and their 10 kV or 2.5 kV equivalents (calculated).

LOSS DISPLAY — toggles between POWER FACTOR and DISSIPATION FACTOR. Allows operator to view either value. Refer to Appendix B, Applications Guide, for an explanation of the difference between these two values.

INTERFERENCE SUPPRESSOR — toggles between ON and OFF. Select ON for conducting tests in areas prone to interference, such as energized substations. Select OFF for conducting tests in areas where there is little or no interference, such as an indoor shop or lab. Refer to Appendix B, Applications Guide, for information on the effects of electrostatic interference.

HV POLARITY — toggles between NORMAL/REVERSE and NORMAL ONLY. Select NORMAL/REVERSE to cancel the effects of electrostatic interference currents. Refer to Appendix B. Select NORMAL ONLY when interference is not present.

NEXT MENU — when selected, displays the second menu screen (Fig. 13).

Second Menu Screen (Fig. 13)

```
PRINT/STORE READINGS: PRINT & STORE        11/26/96
10:11
                      (or) PRINT (or) STORE (or) NONE

OPERATION MODE:  SINGLE (or) CONTINUOUS

RECALL READINGS

SET CLOCK

FULL CALIBRATION:  LAST CHECKED 11/18/96

SAVE SETTINGS

PREVIOUS MENU

ENTER (or) CHANGE        UP                DOWN
```

Figure 13: Second Menu Screen

PRINT/STORE READINGS — toggles among PRINT&STORE, PRINT, STORE, an NONE.

Select PRINT&STORE to send the test results to the printer and to store the test results on the data key.

Select PRINT to send results to the printer.

Select STORE to store test results on the data key.

Select NONE if test results are not to be stored or printed.

OPERATION MODE — toggles between SINGLE and CONTINUOUS.

Select SINGLE to display test results on the screen after a single test.

Select CONTINUOUS to continue to have the test set make measurements until testing is stopped (by releasing interlock, pressing HV OFF push button, or pressing the center key) and display the test results on screen after each test is performed.

RECALL READINGS — when selected displays a submenu (Fig. 14).

SET CLOCK — allows the operator to change the date and time. When this function is selected, the operator is asked if he wants to use the optional bar code wand for input. A YES response allows the operator to enter the date and time one character at a time. All characters must be entered, including any zeros. The cursor blinks under the character to be entered and moves as the characters are received. Only the numbers need to be entered as the cursor skips the /, space, and : characters. A NO response means that the date and time will be updated by the buttons below the LCD panel. The command line displays from left to right: OK, RAISE, and LOWER, corresponding to the buttons below the display. The two characters of the month are shown in reverse video. Use the RAISE and LOWER buttons to select the correct month. The numbers will wrap from 01 to 12 and vice versa. When the month is correct, press the OK button. The display will then show the day field in reverse video. Perform the same functions for each field in the display. After entering OK after the minutes, the display returns to the menu screen. The date and time will automatically be updated.

FULL CALIBRATION — shows the date on which the last calibration check was performed. Select this line to perform a calibration check of the test set. This requires removing the control unit from its case (refer to Maintenance and Calibration section).

SAVE SETTINGS — saves the desired test parameters.

PREVIOUS MENU — returns to the first menu screen (Fig. 12).

Recall Readings Submenu (Fig. 14)

When a data key is inserted in its receptacle on the control unit, RECALL READINGS may be selected on the second menu screen (Fig. 13), and the following submenu is then displayed.

DISPLAY READINGS
PRINT READINGS
CLEAR ALL READINGS
CLEAR LAST READING
RETURN TO MENU

Figure 14: Recall Readings Submenu

DISPLAY READINGS and PRINT READINGS — requests the operator to enter the start test number and then the number of tests to be displayed or printed.

Press the center (RAISE) and right (LOWER) buttons to increase or decrease the test number displayed.

Press the left button (OK) to select the value.

When DISPLAY READINGS is selected and both prompts are answered, the LCD will display the test results for the first test and the command line will display NEXT and EXIT above the left and right buttons, respectively. Press the left button to display the next test or the right button to exit back to the submenu.

CLEAR ALL READINGS and CLEAR LAST READING — prompts the operator with the message “ARE YOU SURE?”

To enter a YES response, press the right button.

To enter a NO response, press the left button.

RETURN TO MENU — returns to the second menu screen (Fig. 13).

Second Test Screen (Fig. 15)

After choosing all desired test parameters from the first and second menu screens, the operator may select EXIT TO TEST from the first menu screen (Fig. 12). This will return the operator to the first test screen (Fig. 11).

If STORE was selected from the second menu screen, the HEADER message will not be displayed. If NONE was selected, only the MENU message is displayed. If PRINT/STORE or STORE were selected, the test set checks to see if a data key is present and, if not, asks the operator to PLEASE INSERT DATA KEY. To store data, the data key must be inserted and turned one quarter turn to the right. Again, the HEADER function sends a header record to the printer. The WAND function presents another command line with ID. NO., CANCEL, and TEMP above the arrow buttons. The WAND function displays three additional options on the command line (ID NO., CANCEL, and TEMP) and requests that the operator enter the identification number and temperature in °C of the equipment being tested, using the optional bar code wand. Pressing the button below CANCEL cancels an entry if a mistake was made.

From the first test screen (Fig. 11), the operator can choose the desired lead configuration by pressing the appropriate LOW VOLTAGE LEAD CONFIGURATION button. The operator may then energize high voltage by pressing the white HIGH VOLTAGE ON push button, when the VOLTAGE CONTROL is set to ZERO START.

WARNING
High voltage is now present at the terminals of the test specimen.

After energizing high voltage, a second test screen will appear (Fig. 15). The test number (when data key is inserted) and lead configuration are displayed on the first line. The two lightning bolt symbol will appear, indicating that high voltage is present.

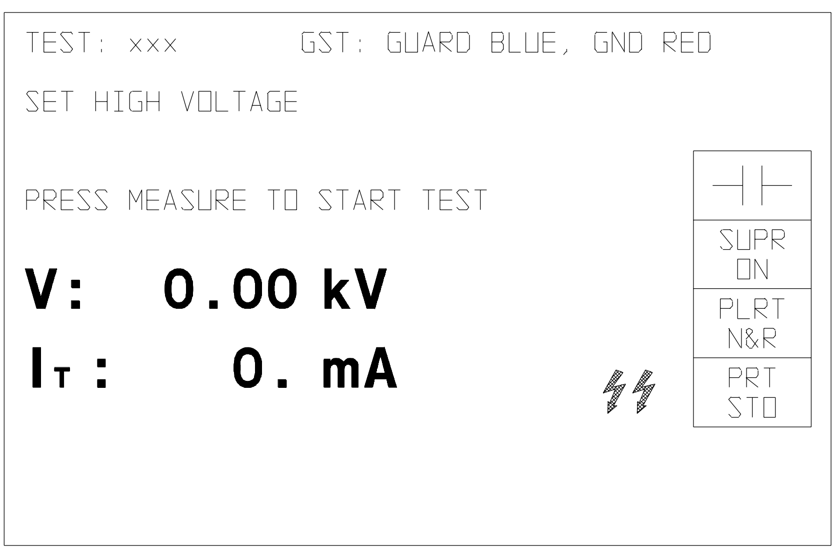


Figure 15: Second Test Screen

Third Test Screen (Fig. 16)

The operator may now set the desired test voltage using the HIGH VOLTAGE CONTROL. the test voltage and total current are displayed. To start the test, press the MEASURE button.

A third test screen will appear (Fig. 16). The message "MEASUREMENT IN PROGRESS" will appear. The test voltage and current will hold their last value.

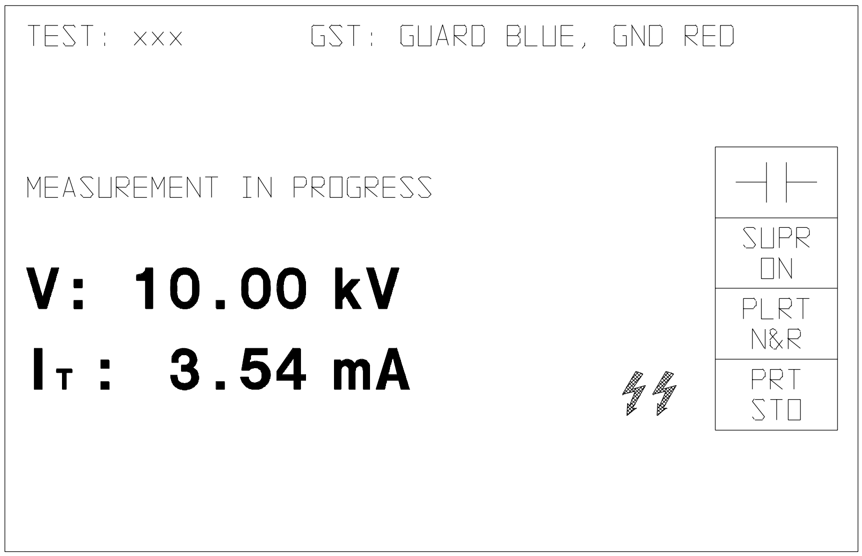


Figure 16: Third Test Screen

Typical Test Results Screen (Fig. 17)

When the test is completed, the high voltage is removed from the specimen and the test results are displayed as shown in Figure 17, including test voltage, calculated watts, power factor, and capacitance. To view 10 kV and 2.5 kV equivalents of current and watts, press the CORRECTION button.

The red HIGH VOLTAGE lamp will remain lit, indicating that the high-voltage circuit is still enabled. The two lightning bolt symbol shown in Figures 15 and 16 is not displayed, indicating that the test voltage has been removed from the specimen.

The red testing lamp next to the MEASURE button is extinguished, indicating that the test is completed.

The operator may send a header record (to the printer) by pressing the button directly beneath the word HEADER on the screen.

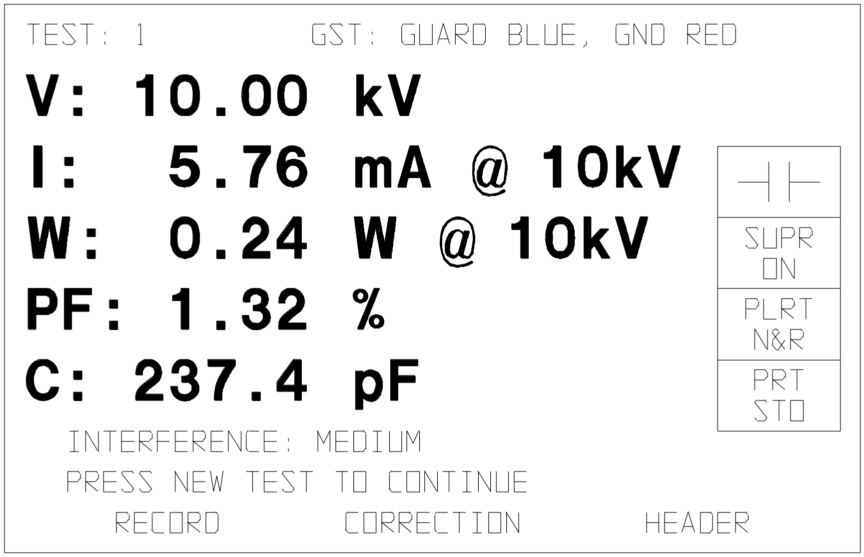


Figure 17: Typical Test Results Screen

If the PRINT AND STORE option is on, the test results can be stored on the data key and printed out to the external printer by pressing the button directly beneath the word RECORD.

When the interference suppressor is turned on, the relative level of interference (low, medium, high, or severe) is measured and displayed.

New Test Screen (Fig. 18)

To continue testing, select the “PRESS NEW TEST TO CONTINUE” message from the screen shown in. Figure 17. If either of the safety interlocks have been released (opened), pressing the NEW TEST button will bring up the first test screen (Fig. 11). If the safety interlocks have been kept closed, the following screen will appear (Fig. 18)

The operator may now select another lead configuration by pressing the appropriate LOW VOLTAGE LEAD CONFIGURATION button. The new lead configuration will appear on the top line of the screen.

Pressing the RECALL VOLTAGE button will bring up the second test screen (Fig. 15). The test voltage will be the same as that of the last test performed. If desired, the operator may change the test voltage.

WARNING

High voltage is now present at the terminals of the test specimen.

The next test can then be performed by pressing the MEASURE button.

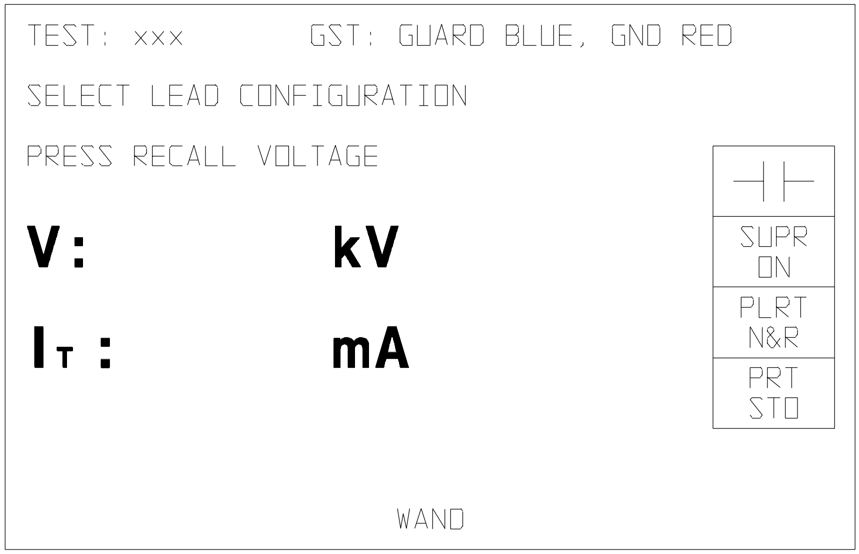


Figure 18: "New Test" Test Screen

Test Screens if Resonating Inductor Is Connected (Fig. 19 and 20)

If a Resonating Inductor (Cat. No. 670600) is connected to the test set, the first test screen will appear as shown in Figure 19. The second test screen after energizing high voltage will appear as shown in Figure 20.

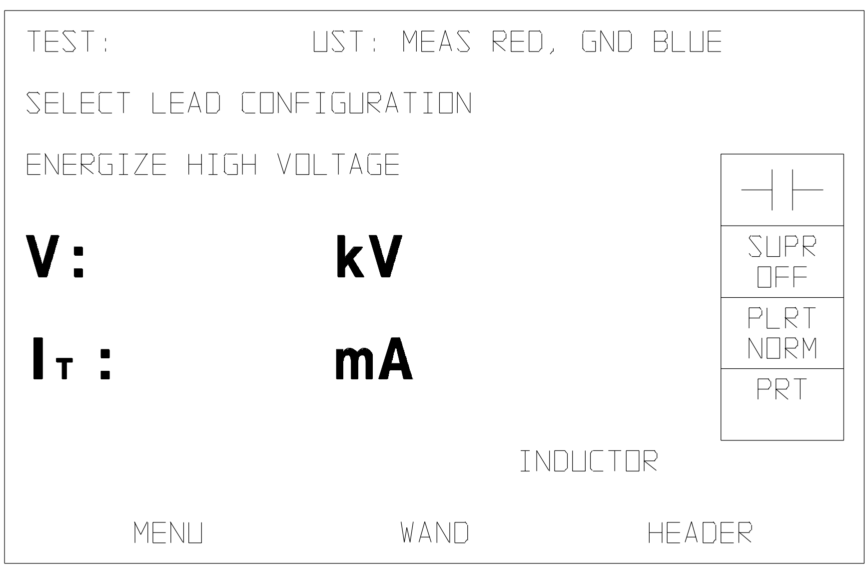


Figure 19: First Test Screen if Resonating Inductor Is Connected

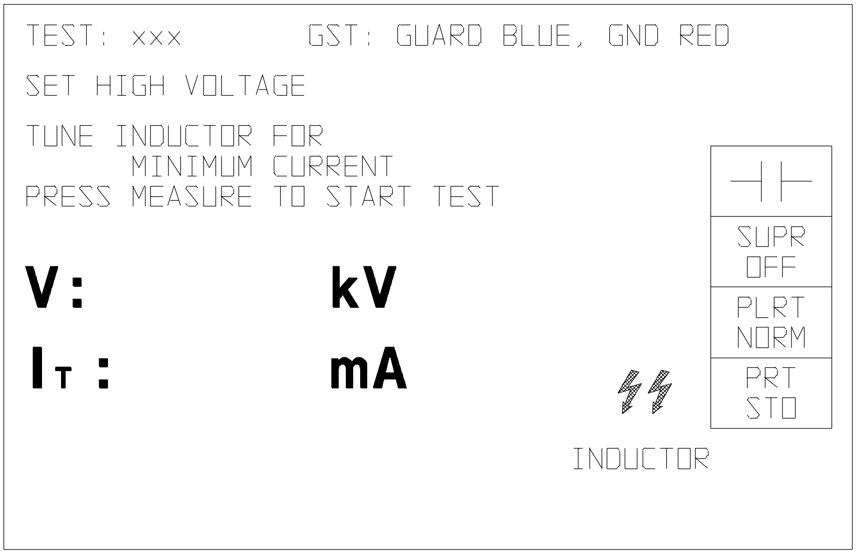


Figure 20: Second Test Screen if Resonating Inductor Is Connected

Ac Insulation Test Procedure

Proceed only after fully understanding Section 2, Safety, and setting up the test set as described in Section 5. An operator who is familiar with the contents of this manual, the test setup, and the operation of the test set may follow the condensed operating procedure in the lid of the test set. The LCD panel and the front panel controls and switches are the means by which the operator controls the operation of the test set. Refer to Section 4, Controls, Indicators and Connectors, and to “Description of Main Menu and Test Screens” in Section 5. Following are the normal procedures for conducting a test with print and store functions enabled.

1. Remove all safety grounds from the specimen to be tested.

2. To store data, insert a data key into the receptacle on the front panel and turn it one quarter turn clockwise.

3. Close the main breaker. The white POWER lamp should light. The opening display screen (Fig. 9) appears, and after diagnostic self-check, the test screen is displayed.

4. Adjust the CONTRAST control for desired viewing angle of screen.

5. Examine the operation status blocks on the first test screen (Fig. 11) to see if the test set is set up to make measurements in the desired manner. If necessary, press the MENU button to make required changes.

6. At this time, the operator can print a header or enter the equipment ID NO. and/or temperature using the optional bar code wand. Entry can also be made after a test has been completed. Press the HEADER button to send a header record to the printer.

Press the ID NO. button to enter a test ID NO. The operator will then be requested to enter a test ID NO. on the message line via the bar code wand. If the ID NO. button is pressed inadvertently, the operator may exit by pressing the button directly beneath the word CANCEL on the screen. Press the TEMPERATURE button to enter temperature. The operator will then be requested to enter temperature via the bar code wand. If the TEMPERATURE button is pressed inadvertently, the operator may exit by pressing the button directly beneath the word CANCEL on the screen.

7. Select the desired LOW VOLTAGE LEAD CONFIGURATION by pressing the appropriate UST/GST switch button. The lead configuration selected will appear on the top line of the test screen.

8. Close the external interlock switches.

9. Set the HIGH VOLTAGE CONTROL to ZERO START.

10. Press the white HV ON push-button switch when ready to energize the high-voltage circuit. The red HIGH VOLTAGE ON lamp should light, and the two lightning bolt symbol should appear on the screen.

WARNING

High voltage is now present at the terminals of the test specimen.

11. Adjust the HIGH VOLTAGE CONTROL to obtain the desired test voltage. The test voltage and total current values are shown on the screen.

Note: If 200 mA is exceeded, the message "MAXIMUM KVA REACHED - USE INDUCTOR TO TEST" will appear. If current exceeds 210 mA, the high voltage will shut down and the message "OVERCURRENT TRIP OUT - PRESS ENTER TO CONTINUE" will appear. If the setting of the HIGH VOLTAGE control is accidentally changed during a measurement, the error message "SETTING OF HIGH VOLTAGE CONTROL HAS CHANGED, PRESS ENTER TO CONTINUE" will appear on the screen.

12. Press the MEASURE button when ready to make a measurement. This will light the red operation lamp (to the right of the MEASURE button) and initiate a measurement test. When the test is completed, test voltage is removed from the specimen and test results are displayed on the screen (see Fig. 17 for typical test screen). The red HIGH VOLTAGE ON lamp will remain lit, indicating that the high voltage circuit is still enabled. The red operation lamp will be extinguished.

13. At this point, the operator may send a header record to the printer by pressing the button directly beneath the word HEADER on the screen. The operator may also choose to record the test results to the data key by pressing the button directly beneath the word RECORD on the screen (if PRINT & STORE option is on, results will also be sent to the printer). See Figure 21 for a sample printout of header and test results.

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DELTA - 2000
10 kV AUTOMATED INSULATION TEST SET

INSTRUMENT SERIAL NO.:____________________________
OPERATORS NAME:________________________________
EQUIPMENT IDENTIFICATION:_________________________
EQUIPMENT SERIAL NO.:____________________________
AMBIENT TEMPERATURE:____________________________
RELATIVE HUMIDITY:_______________________________
COMMENTS/NOTE:

DATE: 11/22/96 10:28
TEST ID NO.: XFMR - 123 - SS 3
TEMPERATURE (°C): 18
TEST MODE: UST: MEAS RED, GND BLUE
MEASUREMENT: AC INSULATION TEST
VOLTAGE: 12.03 kV
CURRENT: 9.04 mA
7.51 mA @ 10 kV
WATTS: 0.024 W
XXX @ 10 kV
POWER FACTOR: 0.02%
DISSIPATION FACTOR: 0.02%
CAPACITANCE: 1993.3 pF
INTERFERENCE: MEDIUM

Figure 21: Sample Printout (Header and Test Results) Ac Insulation Test Measurement

14. The operator may now choose to conduct another test. If either of the safety interlocks have been released (opened), pressing the NEW TEST button will bring up the first test screen (Fig. 11). In this case, return to step 5 and repeat the procedure from there. If the interlocks have been kept closed, pressing the NEW TEST button will bring up the "new test" test screen (Fig. 18). If this is the case, the operator may then select another lead configuration by pressing the appropriate LOW VOLTAGE LEAD CONFIGURATION button (the new lead configuration will appear on the top line of the screen).

15. Press the RECALL VOLTAGE button to reapply high voltage (same voltage as that of the last test conducted) to the specimen without a zero restart of the high voltage circuit (if necessary, readjust the HIGH VOLTAGE CONTROL to obtain the desired test voltage). Pressing the RECALL VOLTAGE button will bring up the second test screen (Fig. 15).

WARNING

High voltage is now present at the terminals of the test specimen.

16. Press the MEASURE button to start the next test. New test results will be displayed. The test number will increment for each test performed when the data key is inserted.

17. Repeat steps 14 through 16 as many times as desired to repeat tests or select different UST/GST test modes (low voltage lead configuration), or change test voltage.

18. When the tests have been completed, return the HIGH VOLTAGE CONTROL to the ZERO START position, press the red HIGH VOLTAGE OFF push-button or open the external interlock switch, then switch the main breaker to OFF.

IN CASE OF EMERGENCY

High-voltage power can be interrupted immediately by pressing the red HIGH VOLTAGE OFF push-button, opening one or both of the external interlock switches, or switching the main breaker OFF.

WARNING

Discharge specimen terminals with a safety ground stick to ground all live parts, then solidly ground these parts with safety ground jumpers before disconnecting the instrument leads. Always disconnect test cables from the specimen under test before attempting to disconnect them at the test set. The test set ground cable should be the last cable disconnected.

Transformer Excitation Current Test Procedure

Proceed only after fully understanding Section, 2, Safety, and setting up the test set as described (see Fig. 8). An operator who is familiar with the contents of this manual, the test setup, and the operation of the test set may follow the condensed operating procedure in the lid of the test set. The LCD and the front panel controls and switches are the means by which the operator controls the operation of the test set. Refer to Section 4- Controls, Indicators and Connectors and to Section 5, Description of Menu and Test Screens.

To reduce the required charging current, conduct all tests on high-voltage windings only. Shorted turns will still be detected in the low-voltage windings. Low-voltage windings which are grounded in service (such as X_o) should be grounded for this test.

Always apply the exact same test voltage to each phase of a three-phase transformer winding. This will minimize errors due to any nonlinearity between voltage and current. For this same reason, subsequent tests on transformer windings, whether single or three-phase, should always be repeated at the exact same test voltage. On three-phase transformers, the excitation current is generally similar for two phases and noticeably lower for the third phase which is wound on the center leg of the core.

On single-phase transformers, the winding is normally energized alternately from opposite ends. This should also be done on delta windings of three-phase transformers if the excitation current is abnormal. The residual magnetism in the magnetic core will seldom affect routine tests; however, the probability should be considered if the excitation currents are abnormally high. Care should be exercised when energizing transformer windings so as not to exceed the voltage rating of the winding.

Load tap changers should be set to fully raised or fully lowered position for routine tests.

The following instructions are the normal procedures for conducting a transformer excitation current test, with print and store functions enabled.

1. Remove all safety grounds from the specimen to be tested.

2. To store data, insert data key in the key receptacle and turn one-quarter turn clockwise.

3. Close the main breaker. The white POWER lamp should light. The opening display screen appears for approximately 5 seconds, and after diagnostic self-check, the test screen is displayed.

4. Adjust the CONTRAST control for desired viewing angle of screen.

5. Examine the status blocks on the test set screen to see if test set is set up to make transformer excitation current measurements and in the desired manner. For example, do you want to make measurements with NORMAL/REVERSE or NORMAL ONLY voltage polarity? If necessary, press the MENU button and make required changes.

6. At this time, the operator can print a header or enter the equipment ID NO. and/or temperature using the optional bar code wand. Press the HEADER button to send a header record to the printer. Press the ID NO. button to enter a test ID NO. The operator will then be requested to enter a test ID NO. on the message line via the bar code wand. If the ID NO. button is pressed inadvertently, the operator may exit by pressing the button directly beneath the word CANCEL on the screen. Press the TEMPERATURE button to enter temperature. The operator will then be requested to enter temperature via the bar code wand. If the TEMPERATURE button is pressed inadvertently, the operator may exit by pressing the button directly beneath the word CANCEL on the screen.

7. Select the desired LOW VOLTAGE LEAD CONFIGURATION by pressing the appropriate UST/GST button (UST: Measure Red, Ground Blue, when making initial test in accordance with Fig. 7). The lead configuration selected will appear on the top line of the test screen (UST: MEAS RED, GND BLUE).

8. Close the external interlock switches.

9. Set the HIGH VOLTAGE CONTROL to ZERO START.

10. Press the white HIGH VOLTAGE ON push button when ready to energize the high-voltage circuit. The red HIGH VOLTAGE ON lamp should light, and the two lightning bolt symbol should appear on the screen.

WARNING
High voltage is now present at the terminals of the test specimen.

11. Adjust the HIGH VOLTAGE CONTROL to obtain the desired test voltage. The test voltage and measurement current values are shown on the test screen.

12. Press the MEASURE button when ready to make a measurement. This will light the red operation lamp (to the right of the MEASURE button) and initiate a measurement test (either single or continuous, depending on which OPERATION MODE was selected in second menu screen). When the test is completed, test voltage is removed from the specimen and test results are displayed on the screen. A typical test result is shown in Figure 22. The red HIGH VOLTAGE ON lamp will remain lit, indicating that the high-voltage circuit is still enabled. The red operation lamp will be extinguished.

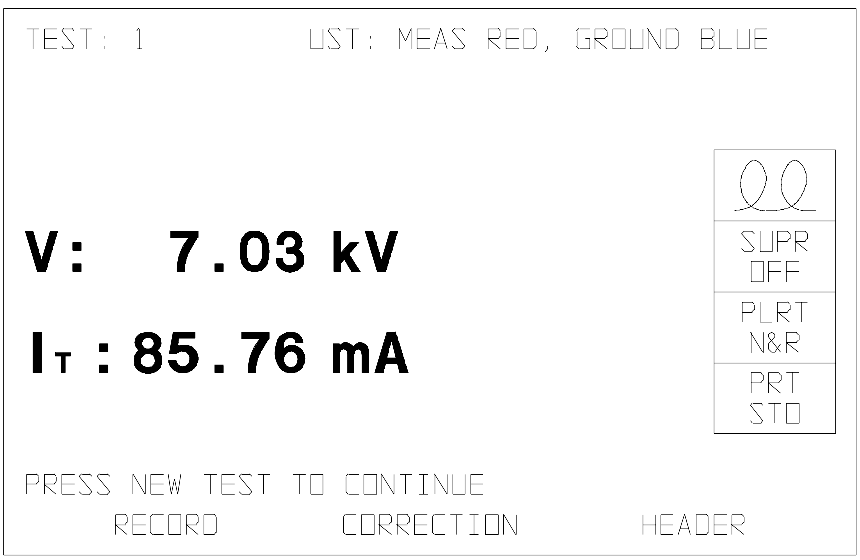


Figure 22: Test Results, Transformer Excitation Test

*Note: The interference suppressor is **always** turned OFF when making transformer excitation current measurements.*

Note: If the total current exceeds 210 mA with a measurement current below the maximum, the error message "OVERCURRENT TRIP OUT - PRESS ENTER TO CONTINUE" will appear. This may happen when tests are conducted on a high-voltage delta winding with the junction between the two other windings grounded as shown in Figure 7.

13. Press the HEADER button to send a header record to the printer. Press the RECORD button to store test results and send test results to the printer. The test number appears on the top line of the test screen. See Figure 23 for a sample printout of test results.

14. To repeat a measurement, press the NEW TEST button, then press the RECALL VOLTAGE button which will reapply high-voltage to the transformer winding without a zero restart of the high-voltage circuit (test voltage will be the same as that of the last test conducted; if necessary readjust the HIGH VOLTAGE CONTROL to obtain the desired test voltage).

WARNING
High voltage is now present at the terminals of the test specimen.

15. Press the MEASURE button to start the next test. When completed, the new test results will be shown on the display. The test number will increment for each test.

16. Press the RECORD button to both store and print out the new test results.

17. Repeat steps 14 through 16 as many times as desired to repeat a measurement.

18. When the tests have been completed, return the HIGH VOLTAGE CONTROL to ZERO START, press the red HIGH VOLTAGE OFF push button or open the external interlock switch, then switch the main breaker OFF.

IN CASE OF EMERGENCY
High-voltage power can be interrupted immediately by pressing the red HIGH VOLTAGE OFF push button, opening one or both of the external interlock switches, or switching the main breaker OFF.

WARNING
Discharge transformer terminals with a safety ground stick to ground all live parts, then solidly ground these parts with safety ground jumpers before disconnecting the instrument leads. Always disconnect test cables from the transformer under test before attempting to disconnect them at the test set. The test set ground cable should be the last cable disconnected.

```
DATE:  11/22/96     10:28
TEST ID NO.:  XFMR - 123 - SS 3
TEMPERATURE (°C): 27.6
TEST MODE:   UST: MEAS RED, GND BLUE
MEASUREMENT:  XFMR EXCITATION TEST
VOLTAGE:   7.03 kV
CURRENT:  85.76 mA
              122 mA @ 10 kV
```

Figure 23: Sample Printout of Excitation Current Measurement

Section 6
Maintenance and Calibration

Maintenance

Maintenance should be performed only by qualified persons familiar with the hazards involved with high-voltage test equipment. Read and understand Section 2, Safety, before performing any service.

Routine maintenance is all that is required for these test sets. The cables and connector panel should be inspected frequently to be sure all connections are tight and all ground connections intact.

The appearance of the test set can be maintained by occasional cleaning of the case, panel and cable assemblies. The outside of the carrying case can be cleaned with detergent and water. Dry with a clean, dry cloth. The control panel can be cleaned with a cloth dampened with detergent and water. Do not allow water to penetrate panel holes, because damage to components on the underside may result. A household all-purpose spray cleaner can be used to clean the panel. Polish with a soft, dry cloth, taking care not to scratch the display screen cover. The cables and mating panel receptacles can be cleaned with isopropyl or denatured alcohol applied with a clean cloth.

Contamination of some parts of the high-voltage circuit, in particular the high-voltage cable terminations and its mating panel receptacle, may show up as a residual PF(DF) meter reading. Cleaning of these sensitive parts will remove the leakage paths which cause the unwanted leakage current. Treat the high-voltage cable with care. Keep it clean and do not subject it to abuse, such as dropping or crimping.

Calibration

During the warranty period, no calibration should be necessary. Contact the factory if there is any suspected problem. A complete operation and calibration check as described in the following is recommended at least once every year. This will ensure that the low-voltage measuring circuit of the test set is functioning and calibrated properly.

The overall accuracy of capacitance and power factor (dissipation factor) at 10 kV should also be checked at least once a year against AVO International's Capacitance and Dissipation Factor Standard (Cat. No. 670500-1). This will ensure that the entire high-voltage circuit is functioning and calibrated properly.

To perform the following calibration checks, loosen and remove the screws securing the control panel. Set the unit on a bench with the latch side down. Then slide the control panel out of the case a few inches to allow access to the push-button switch situated at the top left side of the PC board cage. Calibration potentiometers, labeled R1 through R10, are accessible through the long cut-out in the top of the PC board cage.

1. The analog PCB potentiometers will be precisely set in this step and a complete overall test/calibration sequence performed on the control unit. The control unit must be allowed to warm-up for at least 5 minutes before attempting to adjust the potentiometers.

2. To initiate the Test/Calibration sequence, which is controlled by the microprocessor, press the MENU button then go to the Second Menu Screen. Enter FULL CALIBRATION.

3. Follow the Table 3 Test/Calibration sequence, steps 1 through 20 to check Analog PCB operation and to adjust potentiometers precisely. Table 3 also contains an abbreviated troubleshooting guide in the event of a malfunction. Press the push button at the top left side of the PC board cage when ready to advance to the next step.

4. Steps 21 through 24 of Table 3 check the Analog Relay and Range/Mode PCB operation. Step 25 initiates an automatic sequence of 73 self check steps on the Relay and Range/Mode PCB. The entire self-check sequence is performed within 38 seconds. Countdown appears on the graphic screen.

For an approved calibration check there should be no diagnostic error messages appearing on the LCD at the end of countdown (00). Absence of an error message indicates all measurements within tolerance.

A diagnostic error for the Relay and Range/Mode PCB will appear on the LCD in the following typical format.

DIAGNOSTIC ERROR TEST #03 12
DIAGNOSTIC ERROR TEST #06 08
DIAGNOSTIC ERROR TEST #18 22
DIAGNOSTIC ERROR TEST #56 14

The first number indicates the Table 4 test number step. The second number indicates the number of bits error measured by the A/D converter (1 bit = 4.8828 mV).

Table 4 indicates the instrument setup for each of the 73 self-check steps as well as the possible faulty component for a malfunction on the Relay and Range/Mode PCB.

Table 5 tabulates the function of all relays (K numbers) and CMOS switches (U numbers).

5. Switch the MAIN breaker OFF, then disconnect all cables from the control unit. This completes Preliminary Operation and Calibration Checks.

Table 3: Analog PCB Calibration Checks

Test/Calibration Check Sequence	Adjustment/Check Display Indication	Malfunction Checks or Possible Defective Component on Analog PCB
(1) "0 Cross" Detector check	Will skip to next step if check is OK Displays "No 0 crossing Detector" for malfunction	Recheck +15 V, -15 V, +10 V, - 10 V, and +5 V supply voltages Check for +5V 1/2 cycle square wave at TP35
(2) "Phase locked loop" check	Will skip to next step if check is OK Displays "No Phase Locked Loop" for malfunction	Voltage at TP36 will be +5V if locked and <6 V if unlocked Defective U35 or U44
(3) A/D OFFSET	Adjust R9 to between -9.995 and -10.004 (should trigger between H&L limits)	Defective U3, U11, U10, U15, U12 Check for -10 V at TP6
(4) A/D GAIN Adjust R10	Adjust R10 to between 9.990 and 10.000 (should trigger between H&L limits)	Defective U3, U11, U10, U15, U12 Check for +10 V at TP6
(5) A/D ZERO Check	Should be 0.000 ±0.050 V	Defective U3, U11, U10, U15 Check for 0 V at TP6
(6) C DAC OFFSET Adjust R7	Adjust R7 to 0.000 ±0.010 V	Defective U3, U29, U45, U46, U47, U48, U49 Check for 0 V at TP26 and TP6
(7) C DAC GAIN Adjust R3	Adjust R3 to 9.982 ±0.020 V	Defective U3, U29, U45, U46, U47, U48, U49 Check for 9.982 V at TP26 and TP6
(8) C DAC MINUS GAIN Check	Should be -9.982 ±0.020 V	Defective U3, U29, U45, U46, U47 U48, U49 Check for -9.982 V at TP26 and TP6
(9) DF DAC OFFSET Adjust R8	Adjust R8 to 0.000 ±0.010 V	Defective U3, U29, U45, U55, U56, U57, U58 Check for 0 V at TP43 and TP6
(10) DF DAC GAIN Adjust R4	Adjust R4 to 9.982 ±0.020 V	Defective U3, U29, U45, U55, U56, U57, U58 Check for 9.982 V at TP43 and TP6
(11) DF DAC MINUS GAIN Check	Should be -9.982 ±0.020 V	Defective U3, U29, U45, U55, U56, U57, U58 Check for --9.982 V at TP43 and TP6
(12) C SUPP DAC OFFSET Adjust R6	Adjust R6 to 0.000 ±0.010 V	Defective U3, U29, U39, U40, U41, U42, U54 Check for 0 V at TP25 and TP6
(13) C SUPP DAC GAIN Check	Should be 9.689 ±0.20 V	Defective U3, U29, U39, U40, U41, U42, U54 Check for 9.689 V at TP25 and TP6
(14) C SUPP DAC MINUS GAIN Check	Should be -9.689 ±0.20 V	Defective U3, U29, U39, U40, U41, U42, U54 Check for -9.689 V at TP25 and TP6
(15) DF SUPP DAC OFFSET Adjust R5	Adjust R5 to 0.000 ±0.010 V	Defective U3, U29, U54, U60, U61, U62, U63 Check for 0 V at TP46 and TP6
(16) DF SUPP DAC GAIN Check	Should be 9.689 ±0.20 V	Defective U3, U29, U54, U60, U61, U62 U63 Check for 9.689 V at TP46 and TP6
(17) DF SUPP DAC MINUS GAIN Check	Should be -9.689 ±0.20 V	Defective U3, U29, U54, U60, U61, U62, U63 Check for -9.689 V at TP46 and TP6
(18) VOLTAGE CHANNEL Check	Should be 8.000 ±0.10 V	Defective U1, U3, U4, U6, U7, U12, U34 Check for 10.0 V P-P square wave at TP4; 16.0 V P-P square wave at TP24 and TP7;

Table 3: Analog PCB Calibration Checks

Test/Calibration Check Sequence	Adjustment/Check Display Indication	Malfunction Checks or Possible Defective Component on Analog PCB
		+8.0 V dc at TP11 and TP6
(19) MEAS CURRENT CHANNEL Check	Should be 8.000 ±0.10 V	Defective U1, U3, U5, U6, U7, U12, U34 Check for 10.0 V P-P square wave at TP4; 16.0 V P-P square wave at TP3; +8.0 V dc at TP5 and TP6
(20) TOTAL CURRENT CHANNEL Check	Should be 5.000 ±0.10 V	Defective U1, U3, U6, U7, U12, U27, U34 Check for 10.0 V P-P square wave at TP4; +5.0 V dc at TP19 and TP6
(21) FILTER PHASE Adjust R2	Adjust R2 to 0.000 ±0.050 V	Defective U3, U17, U34, U45, U59 Check for nom 27 V P-P square wave at TP33; 0 V dc at TP2 and TP6 Check for nom 6.0 V rms at TP45
(22) C PHASE RECTIFIER Check	Should be -1.150 ±0.30 V	Defective U3, U23, U34, U45, U59 Check for nom 27 V P-P square wave at TP38; 1.15 V dc nom at TP20 and TP6
(23) DF PHASE RECTIFIER Adjust R1	Adjust R1 to 0.000± 0.050 V	Defective U3, U17, U34, U45, U59 Check for nom 27 V P-P square wave at TP33; 0 V dc at TP2 and TP6
(24) C PHASE RECTIFIER Check	Should be -1.150 ±0.30 V	Defective U3, U23, U34, U45, U59 Check for nom 27 V P-P square wave at TP38; -1.15 V d c nom at TP20 and TP6
(25) Overall check of complete Analog PCB, Relay PCB, and Range/Mode PCB	Instrument makes 73 diagnostic self-checks within 38 seconds. At end of countdown, there should be no diagnostic error.	Refer to Table 4 for explanation of PCB and diagnostic error test number and magnitude of error.

Table 4: Relay and Range/Mode PCB Calibration Checks

Test No.	Meas Chan C/DF	N_X Winding (Turns)	N_S Winding (Turns)	Multiplier DAC & Range Settings	Analog U14 Gain	Error Allowed A/D Bits	Possible Defective Component (R) Relay PCB (R/M) Range/Mode PCB
01	C	0T	0T	All 4 DACs set to 0	10	10	See steps 21 - 24 of Table 3.
02	C	10T	10T	All 4 DACs set to 0	10	10	K12, U9, U3 (R) K18, U8, Q9, (R/M)
03	C	10T	10 x 1T	All 4 DACs set to 0	10	10	K30, U9, U6 (R) K18, U8, Q9 (R/M)
04	C	100T	100T	All 4 DACs set to 0	10	10	K2, U9, U1 (R) K19, U8, Q11 (R/M)
05	C	100T	10 x 10T	All 4 DACs set to 0	10	10	K20, U9, U4 (R) K19, U8, Q11 (R/M)
06	C	1T	1T	All 4 DACs set to 0	10	10	K22, U9, U5 (R) K16, U8, Q12 (R/M)
07	C	1T	1T	All 4 DACs set to 0	100	102	K22, U9, U5 (R) K16, U8, Q12 (R/M)
08	C	1T	2T	C DAC -0.5 FS	100	61	K22, U9, U5 (R) K16, U8, Q12 (R/M)
09	C	1T	0T	C DAC +0.5 FS	100	61	K21, U9, U5 (R) K16, U8, Q12 (R/M)
				C, DF, and DF SUPP DACs set to 0 (steps 10, 11, 12)			
10	C	0T	0T	C SUPP DAC+FS range 1	10	82	U15, U21, U27 (R)
11	C	0T	0T	C SUPP DAC+FS range 2	1	82	K39, U9, U7 (R)
12	C	0T	0T	C SUPP DAC+0.2 FS range 3	1	164	K40, U9, U4 (R)
				C, DF, and C SUPP DACs set to 0 (steps 13, 14, 15)			
13	DF	0T	0T	DF SUPP DAC+FS range 1	10	82	U12, U18, U24 (R)
14	DF	0T	0T	DF SUPP DAC+FS range 2	1	82	K31, U9, U6 (R)
15	DF	0T	0T	DF SUPP DAC+0.2 FS range 3	1	164	K32, U9, U6 (R)
16	C	0T	0T	All 4 DACs set to 0	1	10	See steps 21 - 24 of Table 3.
17	C	0T	100T	All 4 DACs set to 0	1	61	Open ckt if error >41 bits K2, U1, U9 (R)
17	C	0T	200T	All 4 DACs set to 0	1	4	K3, U9, U1 (R)
18	C	0T	300T	All 4 DACs set to 0	1	4	K4, U9, U1 (R)
19	C	0T	400T	All 4 DACs set to 0	1	4	K5, U9, U1 (R)
20	C	0T	500T	All 4 DACs set to 0	1	4	K6, U9, U1 (R)
	C	0T	500T	C SUPP DAC set to -2176 bits on range 3	1	—	K39, K40, U9, U7 (R)
	C	0T	600T	New ref value meas in this step	1	—	K42, U9, U1 (R)
21	C	0T	700T	C SUPP DAC set to -2176 bits on range 3	1	4	K41, U9, U1 (R)

Table 4: Relay and Range/Mode PCB Calibration Checks

Test No.	Meas Chan C/DF	N_X Winding (Turns)	N_S Winding (Turns)	Multiplier DAC & Range Settings	Analog U14 Gain	Error Allowed A/D Bits	Possible Defective Component (R) Relay PCB (R/M) Range/Mode PCB
22	C	0T	800T	C SUPP DAC set to -2176 bits on range 3	1	4	K8, U9, U2 (R)
23	C	0T	900T	C SUPP DAC set to -2176 bits on range 3	1	4	K9, U9, U2 (R)
24	C	0T	1000T	C SUPP DAC set to -2176 bits on range 3	1	4	K10, U9, U2 (R)
25	C	0T	0T	All DACs set to 0	10	10	See steps 21 - 24 of Table 3.
26	C	0T	10T	All 4 DACs set to 0	10	61	Open ckt if error >41 bits K12, U9, U3 (R)
26	C	0T	20T	All 4 DACs set to 0	10	10	K13, U9, U3 (R)
27	C	0T	30T	All 4 DACs set to 0	10	10	K14, U9, U3 (R)
28	C	0T	40T	All 4 DACs set to 0	10	10	K15. U9, U3 (R)
29	C	0T	50T	All 4 DACs set to 0	10	10	K16, U9, U3 (R)
	C	0T	50T	C SUPP DAC set to -2176 bits on range 2	10	—	K39, U9, U7 (R)
	C	0T	60T	New ref value meas in this step	10	—	K17, U9, U3 (R)
30	C	0T	70T	C SUPP DAC set to -2176 bits on range 2	10	10	K7, U9, U3 (R)
31	C	0T	80T	C SUPP DAC set to -2176 bits on range 2	10	10	K18, U9, U4 (R)
32	C	0T	90T	C SUPP DAC set to -2176 bits on range 2	10	10	K19, U9, U4 (R)
33	C	0T	100T	C SUPP DAC set to -2176 bits on range 2	10	10	K20, U9, U4 (R)
	C	0T	1T	All 4 DACs set to 0 New ref value meas	10	—	K22, U9, U5 (R)
34	C	0T	2T	All 4 DACs set to 0	10	10	K23, U9, U5 (R)
35	C	0T	3T	All 4 DACs set to 0	10	10	K24, U9, U5 (R)
36	C	0T	4T	All 4 DACs set to 0	10	10	K25, U9, U5 (R)
37	C	0T	5T	All 4 DACs set to 0	10	10	K26, U9, U5 (R)
38	C	0T	6T	All 4 DACs set to 0	10	10	K33, U9, U5 (R)
39	C	0T	7T	All 4 DACs set to 0	10	10	K27, U9, U5 (R)
40	C	0T	8T	All 4 DACs set to 0	10	10	K28, U9, U6 (R)
41	C	0T	9T	All 4 DACs set to 0	10	10	K29, U9, U6 (R)
42	C	0T	10T	All 4 DACs set to 0	10	10	K30, U9, U6 (R)
				C, C SUPP, DF SUPP DACs set to 0 (steps 43-47)			
43	DF	0T	0T	DF DAC +FS range 3	1	10	K34, K35, U9, U7 (R)
44	DF	0T	100T	DF DAC +FS range 3	1	61	Open ckt if error >41 bits K2, U9, U1 (R)
44	DF	0T	200T	DF DAC +FS range 3	1	4	K3, U9, U1 (R)
45	DF	0T	300T	DF DAC +FS range 3	1	4	K4, U9, U1 (R)
46	DF	0T	400T	DF DAC +FS range 3	1	4	K5, U9, U1 (R)
47	DF	0T	500T	DF DAC +FS range 3	1	4	K6, U9, U1 (R)
	DF	0T	500T	C & DF SUPP DACs set to	1	—	K39, K40, U9, U7 (R)

Table 4: Relay and Range/Mode PCB Calibration Checks

Test No.	Meas Chan C/DF	N_X Winding (Turns)	N_S Winding (Turns)	Multiplier DAC & Range Settings	Analog U14 Gain	Error Allowed A/D Bits	Possible Defective Component (R) Relay PCB (R/M) Range/Mode PCB
				-2176 bits on range 3			
	DF	0T	600T	New ref value in this step	1	—	K42, U9, U1 (R)
					1		
48	DF	0T	700T	C & DF SUPP DACs set to		4	K41, U9, U1 (R)
				-2176 bits on range 3	1		
49		0T	800T	C & DF SUPP DACs set to		4	K8, U9, U2 (R)
	DF			-2176 bits on range 3	1		
50		0T	900T	C & DF SUPP DACs set to		4	K9, U9, U2 (R)
	DF			-2176 bits on range 3	1		
51		0T	1000T	C & DF SUPP DACs set to		4	K10, U9, U2 (R)
	DF			-2176 bits on range 3			
				C, C SUPP, and DF SUPP DACs set to 0 (steps 52-56)			
52	DF	0T	0T	DF DAC +FS range 3	10	10	See steps 21-24 of Table 3.
							K30, K35, U9, U7 (R)
53	DF	0T	10T	DF DAC +FS range 3	10	61	Open ckt if error >41 bits
							K12, U9, U3 (R)
53	DF	0T	20T	DF DAC +FS range 3	10	10	K13, U9, U3 (R)
54	DF	0T	30T	DF DAC +FS range 3	10	10	K14 ,U9, U3 (R)
55	DF	0T	40T	DF DAC +FS range 3	10	10	K15, U9, U3 (R)
56	DF	0T	50T	DF DAC +FS range 3	10	10	K16, U9, U3 (R)
	DF	0T	50T	C SUPP and DF SUPP DACs set to -2176 bits on range 2 (steps 57 to 60)	10	—	K39, K40, U9, U7 (R)
	DF	0T	60T	New ref value meas in this step	10	—	K17, U9, U3 (R)
57	DF	0T	70T	—	10	10	K7, U9, U3 (R)
58	DF	0T	80T	—	10	10	K18, U9, U4 (R)
59	DF	0T	90T	—	10	10	K19, U9, U4 (R)
60	DF	0T	100T	—	10	10	K20, U9, U4 (R)
	DF	0T	0T	Set C, C SUPP, DF SUPP DACs to 0 (steps 61-69)	—	—	See steps 21 - 24 of Table 3.
	DF	0T	1T	DF DAC +FS range 3	10	—	K34, K35, U9, U7 (R)
61	DF	0T	2T	DF DAC +FS range 3	10	10	K23, U9, U5 (R)
62	DF	0T	3T	DF DAC +FS range 3	10	10	K24, U9, U5 (R)
63	DF	0T	4T	DF DAC +FS range 3	10	10	K25, U9, U5 (R)
64	DF	0T	5T	DF DAC +FS range 3	10	10	K26, U9, U5 (R)
65	DF	0T	6T	DF DAC +FS range 3	10	10	K33, U9, U5 (R)
66	DF	0T	7T	DF DAC +FS range 3	10	10	K27, U9, U5 (R)
67	DF	0T	8T	DF DAC +FS range 3	10	10	K28, U9, U6 (R)
68	DF	0T	9T	DF DAC +FS range 3	10	10	K29, U9, U6 (R)
69	DF	0T	10T	DF DAC +FS range 3	10	10	K30, U9, U6 (R)
				C, C SUPP, DF SUPP DACs set to 0 (steps 70-73)			See steps 21-24 of Table 3.
70	DF	0T	0T	DF DAC +FS range 3	10	10	K34, K35, U9, U7 (R)
71	DF	0T	50T	DF DAC +FS range 3	10	102	K34, K35, U9, U7 (R)
72	DF	0T	50T	DF DAC +0.1 FS range 4	10	102	K34, K35, K36, U9, U7 (R)
73	DF	0T	50T	DF DAC +FS range 2	10	41	K34, U9, U7 (R)

Table 5: Function of Relays and CMOS Switches

Relay	Function	Relay	Function
—	Power breaker (top panel)	K11	N_S 10 turn 0 (Relay PCB)
K1	Line relay (Input PCB)	K12	N_S 10 turn 1 (Relay PCB)
K11	HV ON relay (Input PCB)	K13	N_S 10 turn 2 (Relay PCB)
K3, K14	HV OUTPUT relay (Input PCB)	K14	N_S 10 turn 3 (Relay PCB)
K5, K6, K13	Reverse polarity (Input PCB)	K15	N_S 10 turn 4 (Relay PCB)
K10	Open ground (Input PCB)	K16	N_S 10 turn 5 (Relay PCB)
K9	Over V & I relay (Input PCB)	K17	N_S 10 turn 6 (Relay PCB)
K7	Measure lamp relay (Input PCB)	K7	N_S 10 turn 7 (Relay PCB)
K4	Triac control (Input PCB)	K18	N_S 10 turn 8 (Relay PCB)
K2, K8	Short triac (Input PCB)	K19	N_S 10 turn 9 (Relay PCB)
K12	LV lead short (Input PCB)	K20	N_S 10 turn 10 (Relay PCB)
K15, K17	Nx 0T (Range/Mode PCB)		
K16	Nx 1T (Range/Mode PCB)	K21	N_S 1 turn 0 (Relay PCB)
K18	Nx 10T (Range/Mode PCB)	K22	N_S 1 turn 1 (Relay PCB)
K19	Nx 100T (Range/Mode PCB)	K23	N_S 1 turn 2 (Relay PCB)
		K24	N_S 1 turn 3 (Relay PCB)
K3, K9	Red LV 1 (Range/Mode PCB)	K25	N_S 1 turn 4 (Relay PCB)
K1, K7	Red LV 2 (Range/Mode PCB)	K26	N_S 1 turn 5 (Relay PCB)
K4, K10	Blue LV 1 (Range/Mode PCB)	K33	N_S 1 turn 6 (Relay PCB)
K2, K8	Blue LV 2 (Range/Mode PCB)	K27	N_S 1 turn 7 (Relay PCB)
K6, K12	GST (Range/Mode PCB)	K28	N_S 1 turn 8 (Relay PCB)
K5, K11	UST (Range/Mode PCB)	K29	N_S 1 turn 9 (Relay PCB)
K22	Nx CALIB (Range/Mode PCB)	K30	N_S 1 turn 10 (Relay PCB)
K13	Cs SHORT (Range/Mode PCB)		
K14	Nx CALIB (Range/Mode PCB)	K34	% DF range 2 (Relay PCB)
		K35	% DF range 3 (Relay PCB)
K1	Ns 100 turn 0 (Relay PCB)	K36	% DF range 4 (Relay PCB)
K2	Ns 100 turn 1 (Relay PCB)	K37	C fine bal range 2 (Relay PCB)
K3	Ns 100 turn 2 (Relay PCB)	K38	C fine bal range 3 (Relay PCB)
K4	Ns 100 turn 3 (Relay PCB)	K39	C SUPP range 2 (Relay PCB)
K5	Ns 100 turn 4 (Relay PCB)	K40	C SUPP range 3 (Relay PCB)
K6	Ns 100 turn 5 (Relay PCB)	K31	DF SUPP range 2 (Relay PCB)
K42	Ns 100 turn 6 (Relay PCB)	K32	DF SUPP range 3 (Relay PCB)
K41	Ns 100 turn 7 (Relay PCB)	K25	Range CT, sec (Range/Mode PCB)
K8	Ns 100 turn 8 (Relay PCB)	K21, K24	Range CT, pri (Range/Mode PCB)
K9	Ns 100 turn 9 (Relay PCB)	K20, K23	Range CT tap (Range/Mode PCB)
K10	Ns 100 turn 10 (Relay PCB)		
		CMOS Switches	Analog PCB
		U34	Measure/calibrate
		U32	Gain 1 (always) A1 Logic LO A2, A3, A4 Logic HI
		U20	Gain 1, 10, 100, 1000
		U3	Multiplexer 0 V initial
		U59	Line ref V/test ref V
		U45	Measurement/DAC cal
		U54	Measurement/DAC cal

Troubleshooting

General Guidelines

This section provides general guidelines for basic troubleshooting of the DELTA-2000. The DELTA-2000 undergoes rigorous testing before being shipped from the factory; however, when it is subjected to various field conditions, there is always the possibility of damage being done to the instrument or its cables. This troubleshooting section does not attempt to cover all possibilities, but does list suggestions that can be carried out in the field. There may be problems that require the unit to be returned to the factory for repair.

If any error messages appear during self-diagnostic check, refer to "Maintenance" and "Calibration."

If questionable readings are obtained, the first step is to check the calibration of the DELTA-2000 using AVO's Capacitance and Dissipation Factor Standard (Cat. No. 670500-1). If the standard is not available, the next step is to test a specimen with a known value (a specimen that is known to be good). If such a specimen is not available, then perform the following procedure for an "Open Air Test."

Open Air Test

The purpose of this test is to check the overall functionality of the DELTA-2000, including the high-voltage cable. The readings obtained show the stray signal losses of the high-voltage cable.

1. Connect the wing nut ground terminal of the test set to a low impedance earth ground using the 15 ft (4.6 m) ground cable supplied.

2. Connect the control unit receptacles (INTERCONNECT 1 and 2) to the high-voltage (power supply) receptacles using the two 5 ft (1.5 m) interconnection cables.

3. Connect the external interlock cables to the SAFETY INTERLOCK receptacles.

4. Connect the high-voltage cable to the HV OUTPUT terminal of the high-voltage unit (power supply). Be sure that the connector locks in place. Connect the pigtail for the outer shield to the wing nut terminal (ground).

5. With the main breaker OFF, plug the input power cord into the test set AC POWER receptacle and into a three-wire grounded power receptacle having the appropriate voltage and current ratings.

6. Suspend the outboard end of the high-voltage cable in free air so that it is clear of all surrounding objects by at least 3 ft (0.91 m). Use dry nylon rope if available.

7. Close main breaker. Refer to the instructions in Section 5 (Setup and Operation) “Description of Menus and Test Screens.” From the first menu screen, choose:
   Measurement: “AC Insulation Test”; HV Polarity: “Normal/Reverse.”
   Then choose “EXIT TO TEST.”

8. Set LOW VOLTAGE LEAD CONFIGURATION to GST GROUND (grounds red and blue). Energize high voltage.

9. Set high voltage to approximately 5 kV. Press MEASURE to start test.

10. When test is completed, observe test results. The results should be as follows:

Capacitance:	between 4.0 and 8.0 pF
%DF or %PF:	between -1.0 to +2.0%
Watts @ 10 kV:	between -0.002 to +0.006
mA @ 10 kV:	between 0.015 to 0.030

Note: The %DF and %PF readings can be affected by high humidity.

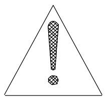
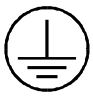
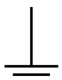
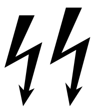
Repair

AVO International offers a complete repair service and recommends that its customers take advantage of this service in the event of equipment malfunction. Please indicate all pertinent information including problem, symptoms, and attempted repairs. Pack the DELTA-2000 in its transit case and include all cables that came with the instrument. Equipment returned for repair must be shipped prepaid and insured and marked for the attention of the Repair Department.

Section 7
Spare Parts List

Description	Part Number
Bag, canvas for cables	34460-010
Cable, ground (hook lug)	4702-7
Cable, high-voltage	30012-5
Cable, interconnect	27978
Cable, interconnect	27979
Cable, PC interface	29017
Cable, printer interface	29016
Data key	30603
Data key interface box	30606
Data key interface box (for 672001-47)	30606-1
Knob (CONTRAST control)	4690-31
Knob (HIGH VOLTAGE CONTROL)	4690-28
Lead, low-voltage (red)	25572-1
Lead, low-voltage (blue)	25572-2
Line cord (for Cat. No. 672001)	17032-4
Line cord (for Cat. No. 672001-47)	17032-2
Pilot light, white (1 per unit)	27931-3
Pilot light, yellow (1 per unit)	27931-4
Pilot light, red (2 per unit)	27931-5
Printer	29015
Printer (for Cat No. 672001-47)	29015-1
Safety interlock hand switch 8 ft (2.4 m)	34460-020
Safety interlock hand switch 70 ft (21 m)	34460-0

Glossary

	Use only in accordance with instruction manual.
	Protective conductor terminal is the wing nut for connecting the test set to earth ground.
	Earth terminal
	This two lightning bolt symbol, shown on the Second and Third Test Screens (Fig. 15 and 16), indicates that high voltage is present.
arc-over	A disruptive discharge in the form of an arc or spark between two electrical conductors or between a conductor and earth (also sparkover or flashover).
bridge symbols	Bridge symbols used are: R = red, B = blue, and G = green.
CAP	Capacitance
dissipation factor	The ratio of energy dissipated to the energy (DF) stored in an element for one cycle.
GST	Grounded specimen test
hot collar	A conductive band used to test for dielectric losses in bushings.
LCD	Liquid crystal display
LED	Light-emitting diode
permittivity	The ability of a dielectric to store electrical potential energy under the influence of an electric field.
pothead	A device that seals the end of a cable and provides insulated egress for the conductor or conductors.
power factor	(PF) the ratio of total watts to the total rms volt-amperes.

safety ground jumper	A temporary connection, not supplied, made between the terminals of the apparatus under test and ground.
safety ground stick	An insulated stick (sometimes called a hot stick) with a hook type electrode connected to ground via an insulated cable. In some designs, frequently known as high voltage discharge sticks, a resistor is connected between the electrode and the ground cable. Both are used to discharge capacitive specimens by providing a low impedance path to ground. They must be suitably rated for the voltage and capacitance of the specimen to be discharged.
UST	Ungrounded specimen test

Warranty

Products supplied by AVO International are warranted against defects in material and workmanship for a period of one year following shipment. Our liability is specifically limited to replacing or repairing, at our option, defective equipment. Equipment returned to the factory for repair must be shipped prepaid and insured. This warranty does not include batteries, lamps, or other similar items, where the original manufacturer's warranty shall apply. We make no other warranty. The warranty is void in the event of abuse (failure to follow recommended operating procedures) or failure by the customer to perform specific maintenance as indicated in this manual.

Appendix A
Data Key Data Downloader Program

If you do not have access to Windows 95 or Windows NT, and if your computer does not meet system requirements, please contact AVO International technical support. Download software is available that does not require use of Windows 95 and Windows NT.

DXDKEY -- Data Downloader Program

Latest revision: 1998-02-02

Help Topics

Introduction

DXDKEY is a simple utility program for downloading data from the AVO Delta-2000 test instrument's EEPROM data key. The program communicates with the PKS-232 Interface Module to retrieve test results from a data key. Once downloaded, the data can be saved in a comma- or tab-delimited text file for use with database or spreadsheet software. DXDKEY runs under Windows 95 or Windows NT.

You can also use DXDKEY to view data files and edit them in simple ways. DXDKEY can erase data keys for re-use in the Delta-2000 instrument.

DXDKEY was developed by Delta-X Research for free distribution and use with the AVO Delta-2000 insulation test set. Because DXDKEY is free software, technical support is limited to information and occasional updates provided through our Internet web site.

Disclaimer: DXDKEY is not guaranteed or warranted in any manner, and you may acquire, install, and use it strictly at your own risk. The documentation is not guaranteed to be free of errors, and Delta-X Research reserves the right to modify the software or documentation at any time without notice.

We hope that you will find DXDKEY reliable and easy to use. We want you to be happy with this software, and we very much appreciate your suggestions and bug reports.

Acknowledgments

Computer system requirements

Note: To run DXDKEY under Windows NT 4.0, you must have Windows NT Service Pack 2 installed. Service packs for updating Windows NT are available from Microsoft Corp.

•486 or Pentium-type PC with Windows 95 or Windows NT 4.0.
•Up to 3 MB of hard disk space for installed files.
•VGA display or better.
•Mouse or equivalent.
•Serial communications port for downloading data.
•PKS-232 data key reader and cable.

DXDKEY installation

To install DXDKEY, run SETUP.EXE and follow instructions.

To remove DXDKEY from your system, use the Add/Remove Programs feature in your Windows Control Panel. Data files are not deleted when you un-install DXDKEY.

Serial port options

Run DXDKEY and choose the Options menu.

•Enter the number of the serial port you will use for downloading data (usually 1 or 2).
•The Data Rate is 9600 unless you have changed the internal setting in the PKS-232.
•Likewise, Parity is normally None.
•Data Bits and Stop Bits are displayed for your reference, but you cannot change them.

Data file options

Run DXDKEY and choose the Options menu.

Select or enter a Delimiter (usually Tab or comma), a Text Qualifier (single or double quotes, or none), and a Date Format.

The Delimiter and the Text Qualifier are used for both saving and loading data files. The Date Format is used to format dates when you download data from a data key or when you load a data file.

The Also Save Raw Data option should normally remain un-checked. It saves downloaded data to a text file in hexadecimal format for troubleshooting.

How to download data

To download data from a data key, you must connect the interface module, insert the data key, designate a data file, and start the download. After inspecting, editing, and saving the file, you can repeat the process as many times as you wish to create more files or download from other data keys.

Set up the PKS-232 interface module

•Connect the PKS-232 interface module to a free serial port on the PC using the communications cable supplied with the module.
•Connect the PKS-232 to a power source and turn it on. The power cable connector and switch are on the back of the module.

Create or open a data file

•If you want to create a new data file, choose New in the File menu. The data grid is emptied, and the standard DXDKEY column headings are displayed.
•If you want to append data to an existing data file, choose Open in the File menu and open the file before downloading data. The data grid is emptied, column headings are read from the first row of the file, and the data records are displayed in the rows of the grid.

Start the download

•Insert a data key into the front of the PKS-232 module and turn it.
•Choose Read Data Key in the File menu. A dialog box should appear informing you that the serial port is open. If the port number is invalid or the port cannot be opened for some reason, cancel the dialog and remedy the problem before trying again. You may need to change the port number (see Serial port options above).
•If the serial port is open, click the Download Data button in the dialog box. If there is an error, cancel the download dialog, correct the problem (e.g. loose cable, key not inserted), and retry.
•The download takes about 10 seconds. Then a message box announces the number of records downloaded, and the records are displayed in the DXDKEY main window.
•Inspect and edit the data (see How to view and edit data below).
•Choose Save As in the File menu to save the file.

How to erase a data key

CAUTION: This procedure destroys all information stored in the data key. After erasure, the data key must be re-initialized by the Delta-2000 test instrument before it can be used for data logging.

•Connect the PKS-232 interface module, turn it on, and insert the data key to be erased. •Choose Erase Data Key in the File menu.
•After you confirm that you do wish to erase the key, a dialog box is displayed showing that the serial port is open.
•Click the Erase Data Key button to erase the data key. The process takes about two seconds and cannot be interrupted.

How to view and edit data

View

You can use DXDKEY to inspect data, whether downloaded from a data key or loaded from a data file. The main DXDKEY window contains a data grid which can be scrolled vertically and horizontally with the mouse or the keyboard. The window can be resized or maximized for your convenience.

If you double-click any row in the data grid, the Test Data Record window opens for viewing individual formatted records. The Test Data Record window is resizable and has a toolbar with "navigation" buttons, a Copy button, a Delete button, and a Font Size button.

Edit non-measurement data

The Equipment ID and Temperature fields in the data grid are editable. For example, to enter or correct the Equipment ID in a record, click the Equipment ID column in that row and type the information. Press Esc to cancel the edit, or press Ctrl-Z to start over if you make a mistake. Move to a different column or row to accept what you typed and stop editing.

Any non-DXDKEY data fields which may be present in your data file are also editable.

All of the DXDKEY data fields representing instrument measurement data are protected and cannot be edited.

Adjust or hide columns

You can adjust the width of any column by clicking the column boundary with the left mouse button and dragging it.

NOTE: If you shrink a column to zero or near-zero width, that column is omitted when printing or saving the file.

Print

Select the Print command in the File menu to print the data shown in the grid, using column widths similar to the ones shown in the grid. There are no options available for printing other than the ones offered in the Print dialog.

Delete

Highlight one or more rows of data and press the Del key or choose Delete from the Edit menu to delete data.

Cut, Copy, and Paste

Highlight one or more rows of data and choose Copy from the Edit menu to copy the highlighted data to the Windows Clipboard in a format which can be pasted directly into a spreadsheet or text file. If you choose Cut instead of Copy, the selected rows are copied into the Clipboard and deleted from the grid.

If you click the Copy button in the Test Data Record window, the displayed record as shown in the window is copied into the Windows Clipboard in tab-delimited text format, one data item per row. It can be pasted into a spreadsheet or text file.

Save and Save As

The Save command in the File menu saves the data grid contents in a text file using the delimiter and quotation character specified in the Data File Options. Data items in zero-width columns are not saved. The Save As command allows you to specify a new file name and directory before saving the data.

For your convenience, some basic editing functions can be performed in DXDKEY. To do more complex editing, such as rearranging columns or sorting, you must use a spreadsheet or database program.

How to add more data to a data file

Choose Open File in the File menu and open the file you want to modify. The DXDKEY data file options must agree with the delimiter and text qualifier (if any) used in the data file. You may be asked to change the options if the data file is not in a format compatible with your selected options.

If you download data from a data key (see How to download data above) while DXDKEY already has a file loaded, the data key records are appended at the bottom of the list.

CAUTION: Only columns with names identical to standard DXDKEY data columns receive data. Any data key item whose column is missing is discarded.

After editing or deleting data, you can save the file under its original name or choose Save As in the File menu to save it under a new name.

Software support

Because DXDKEY is free software, Delta-X Research does not provide telephone support for it. There is a DXDKEY Home Page in the Delta-X Research web site

http://www.hydracen.com/dx

where you can find helpful material such as:

•Answers to frequently asked questions,
•A form for asking questions or reporting problems,
•A form for obtaining the latest version of DXDKEY or files needed for operating DXDKEY in other languages.

Your AVO representative may be able to assist you with some questions or problems.

Appendix B
Applications Guide

Table of Contents

Section **Page**

List of Illustrations

Figure **Page**

List of Tables

Table

Section 1
Introduction

General

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

> WARNING
> Specific instructions in the operation of the test set, making connection to the apparatus under test, and safety precautions to be observed are not included.

Before performing any test with this apparatus, read and understand Section 2, Safety, and observe all safety precautions indicated throughout this manual. In addition, before performing any field tests, refer to IEEE 510 - 1983, “IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing” for more information.

Principle of Operation

Most physical capacitors can be accurately represented as a two or three-terminal network as shown in Figure 1. The direct capacitance between the terminals H and L is represented by C_{HL} while the capacitances between each respective terminal and ground are represented by C_{HG} and C_{LG}. In the two-terminal capacitor the L terminal is connected to ground.

An example of a two-terminal capacitor is an apparatus bushing. The center conductor is one terminal and the mounting flange (ground) is the second terminal. An example of a three-terminal capacitor is an apparatus bushing which has a power factor or capacitance tap. The center conductor is one terminal, the tap is the second terminal, and the mounting flange (ground) is the third terminal.

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

Figure 2 shows a simplified measuring circuit diagram of the DELTA-2000 test set when operating in the UST test mode. The basic bridge circuit uses a three-winding differential current transformer. The ampere-turns due to the current i_X through the test specimen (C_{HL}) are balanced by the ampere-turns due to the current i_s passing through the reference capacitor (C_S). The same voltage is applied to the two capacitors by the power supply. An ampere-turn balance is obtained for the quadrature (capacitance) component of current by automatic adjustment of the N_X and N_S turns. The value of the capacitance is then displayed on the LCD.

Since the specimen current includes both an in-phase component (leakage) and a quadrature component (capacitive) of current, a residual difference current will appear in the third winding after the capacitance has been balanced. This represents the leakage (loss) component of current. This current component is also automatically balanced to produce a dissipation factor (power factor/watts/milliwatts) balance. The % dissipation factor/power factor/watts/milliwatts is displayed on the LCD.

Figure 2 also shows how guarding is accomplished in the UST test mode. The bridge measures the capacitance C_{HL} which is shown by the heavy solid line. All internal and external stray capacitance between the high-voltage H terminal and guard (ground) shunts the power supply, where it affects only the supply loading and does not influence the measurement. All stray capacitance between the L terminal and guard (ground) shunts the N_X bridge winding and also does not influence the measurement. In practice the transformer winding resistance and leakage inductance is very small so that a large value of capacitance (>2000 pF) can be allowed to shunt the N_X bridge winding before there is a noticeable error in the measurement.

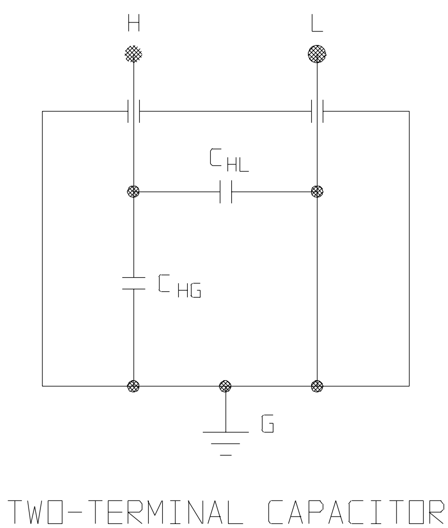


Figure 1: Two and Three Terminal Capacitors

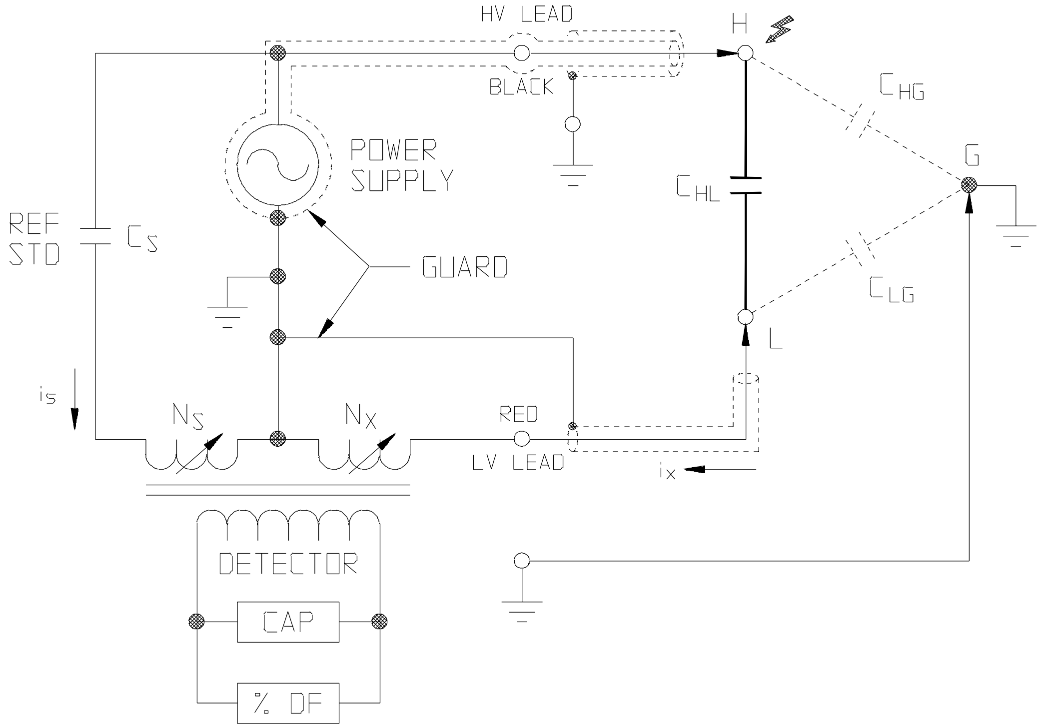


Figure 2: Simplified Measuring Circuit Diagram, UST MEASURE RED Test Mode

Figure 3 shows the measuring circuit and guarding for the GST GROUND RED test mode. In this test the L terminal of the specimen is grounded (two-terminal specimen). The bridge measures the two capacitances shown by the heavy solid lines (C_{HL} + C_{HG}). All internal stray capacitance between the high-voltage lead and guard shunts the power supply, whereas the stray capacitance between guard and ground shunts the N_X bridge winding, therefore, both internal stray capacitances are excluded from the measurement for the same reasons as for the UST test method.

Figure 4 shows the measuring circuit and guarding for the GST GUARD RED test mode. The bridge measures the capacitance shown by the heavy solid line (C_{HG}). All internal and external stray capacitance between the high-voltage H terminal and guard shunts the power supply, whereas all internal and external stray capacitance between guard and ground shunts the N_X bridge winding; therefore, both stray capacitances are excluded from the measurement.

Current, Capacitance and Dissipation Factor Relationship

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

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

The power factor is defined as:

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

and the dissipation factor is defined as:

$$Dissipation\ factor = \cot\Theta = \tan\delta = \frac{I_r}{I_c}$$

The DELTA-2000 test set is calibrated for direct reading in terms of capacitance and dissipation factor (tan δ).

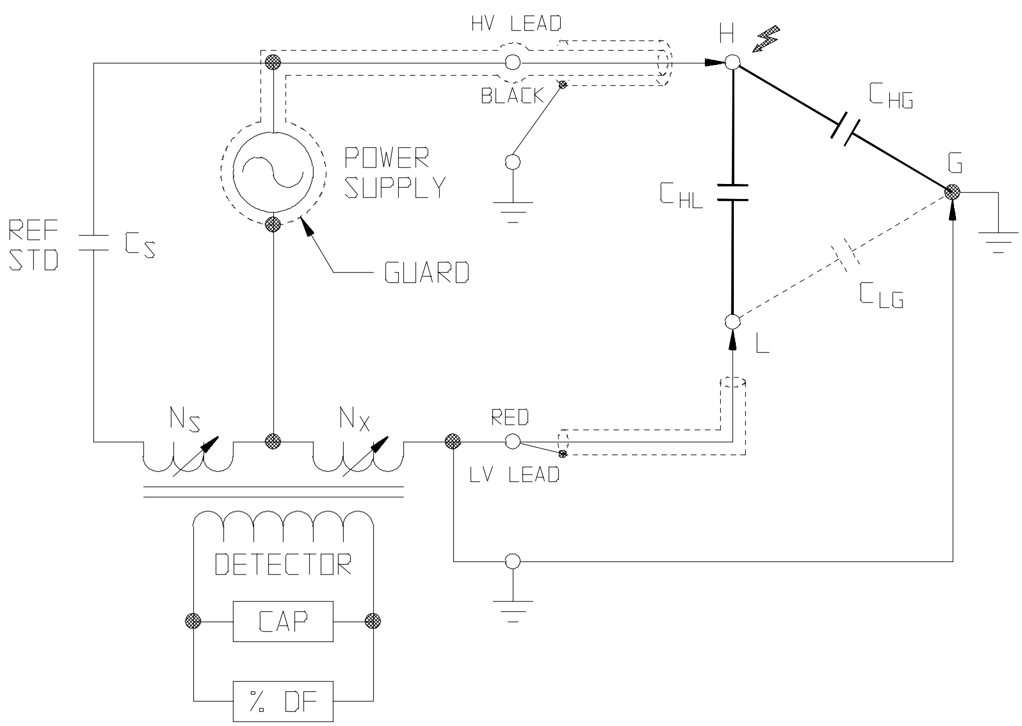


Figure 3: Simplified Measuring Circuit Diagram, GST GROUND RED Test Mode

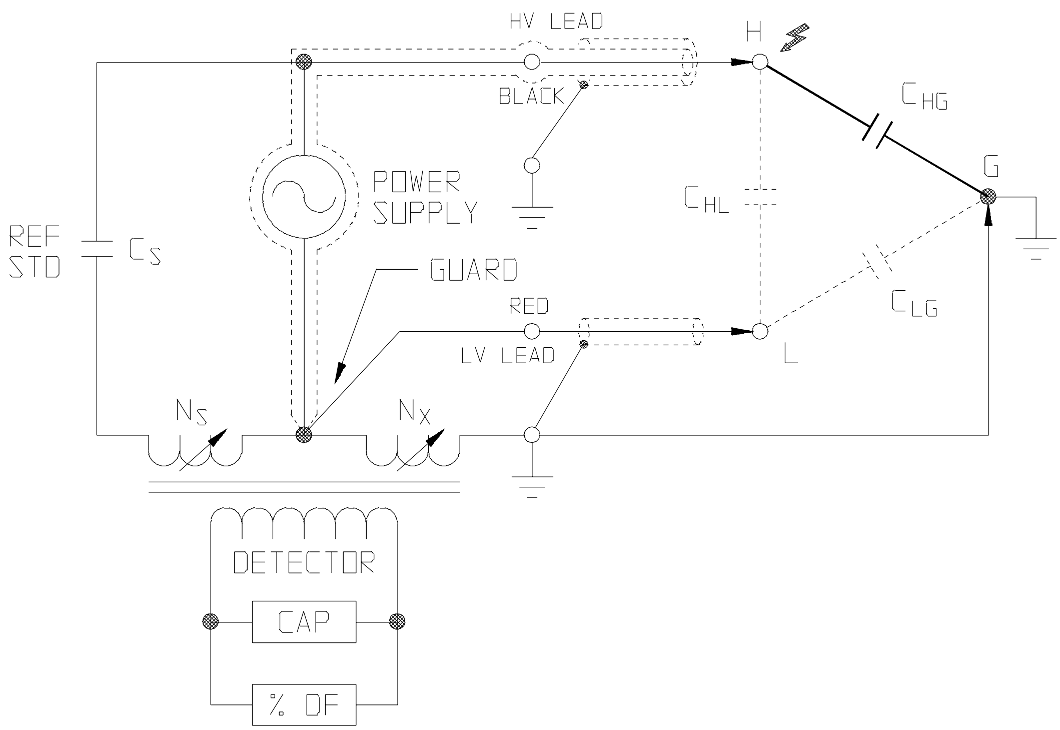


Figure 4: Simplified Measuring Circuit Diagram, GST GUARD RED Test Mode

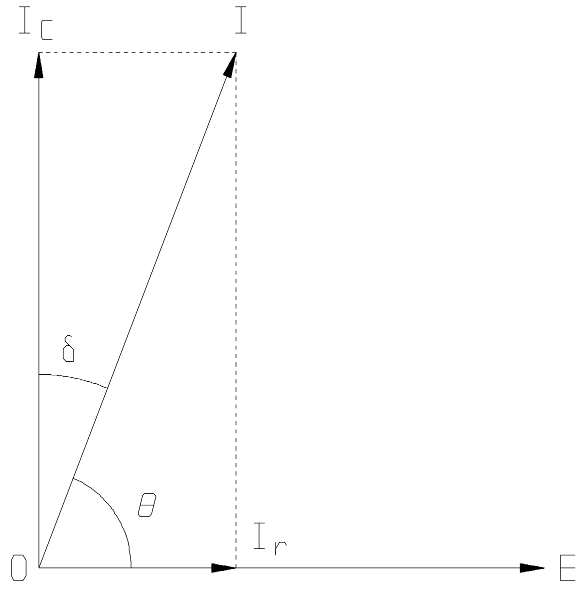


Figure 5: Vector Diagram Insulation System

$$\tan\delta = \frac{R}{X_c} = R\omega C$$

$$X_c = \frac{1}{\omega C}$$

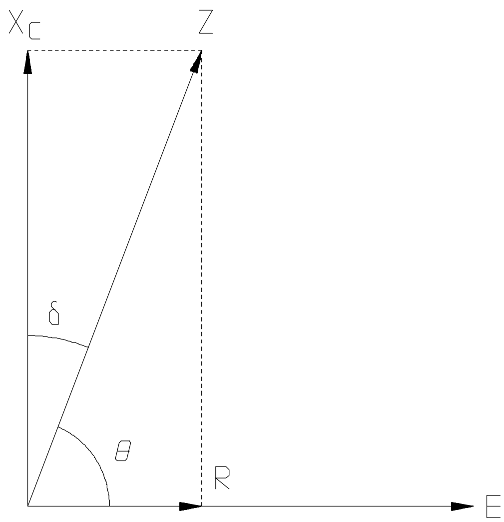


Figure 6: Vector Diagram Showing Resistance and Reactance

The important characteristic of a capacitor is the ratio of its loss resistance to its reactance, which is the dissipation factor. This relationship is shown in the vector diagram of Figure 6.

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

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

If it is desired to find the value of the charging current I_c at a given test voltage and frequency, it may be determined from the following relationship:

$$I_c = V\omega C$$

In reality, a capacitor possesses both a series and parallel loss resistance as shown in Figure 7. The frequency of the applied voltage determines which loss dominates, however, at low frequencies (50/60 Hz) only the parallel losses R_p, predominately generated in the dielectric, are generally measured. For a particular frequency, any loss can be expressed in terms of either a series or parallel equivalent circuit with equal accuracy. The choice is a matter of convenience. The dissipation factor (tan δ) for the series equivalent circuit is defined as:

$$\tan\delta = R_s\,\omega\,C_s$$

To find the equivalent parallel impedance C_p and R_p, use the conversion formulas shown in Figure 8.

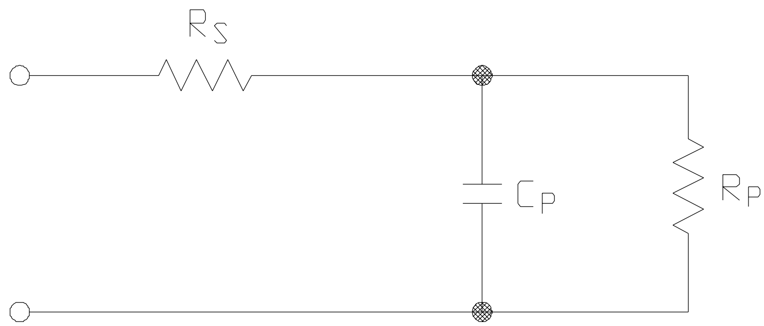


Figure 7: Equivalent Circuit for Capacitor Losses

$$\tan\ \delta = \frac{1}{R_p \omega C_p}$$

$$C_p = \frac{C_s}{1 + \tan^2 \delta_s} = \frac{C_s}{1 + (R_s \omega C_s)^2}$$

$$R_p = R_s \left(1 + \frac{1}{\tan^2 \delta_s}\right) = R_s \left(1 + \frac{1}{(R_s \omega C_s)^2}\right)$$

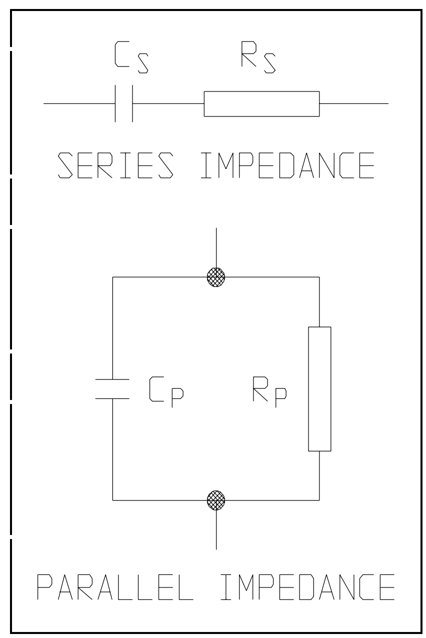


Figure 8: Series - Parallel Equivalent Circuit

Conversion Formulas

Note: Capacitance, dissipation factor, power factor, watts, watts at 10 kV, watts at 2.5 kV, current, current at 10 kV, and current at 2.5 kV can all be read directly from the DELTA-2000 test set. These formulas are provided for informational purposes only.

Use the following formulas and the chart in Figure 9 to compare the capacitance reading obtained on the DELTA-2000 test set against the milliampere reading as well as the DELTA-2000 test set dissipation factor reading versus the watts loss reading. The mA and mW readings, even if obtained at reduced test voltages, are generally recorded in terms of equivalent 2.5 kV values (2.5 kV test set) or equivalent 10 kV values (10 kV test set).

Conversion Formulas for Test at 2.5 kV, 60 Hz

(based on equivalent 2.5 kV values)

$C_{pF} = mA \times 1061$

$mA = C_{pF} \times 94.3 \times 10^{-5}$

$$\%DF = \frac{W_{loss} \times 40}{mA}$$

Applicable when DF (PF) is less than 20 percent

$W_{loss} = C_{pF} \times \%DF \times 23.6 \times 10^{-6}$ — No limitation

Conversion Formulas for test at 10 kV, 60 Hz

(based on equivalent 10 kV values)

$C_{pF} = mA \times 265$

$mA = C_{pF} \times 377 \times 10^{-5}$

$$\%DF = \frac{W_{loss} \times 10}{mA}$$

Applicable when DF (PF) is less than 20%

$W_{loss} = C_{pF} \times \%DF \times 377 \times 10^{-6}$ — No limitation

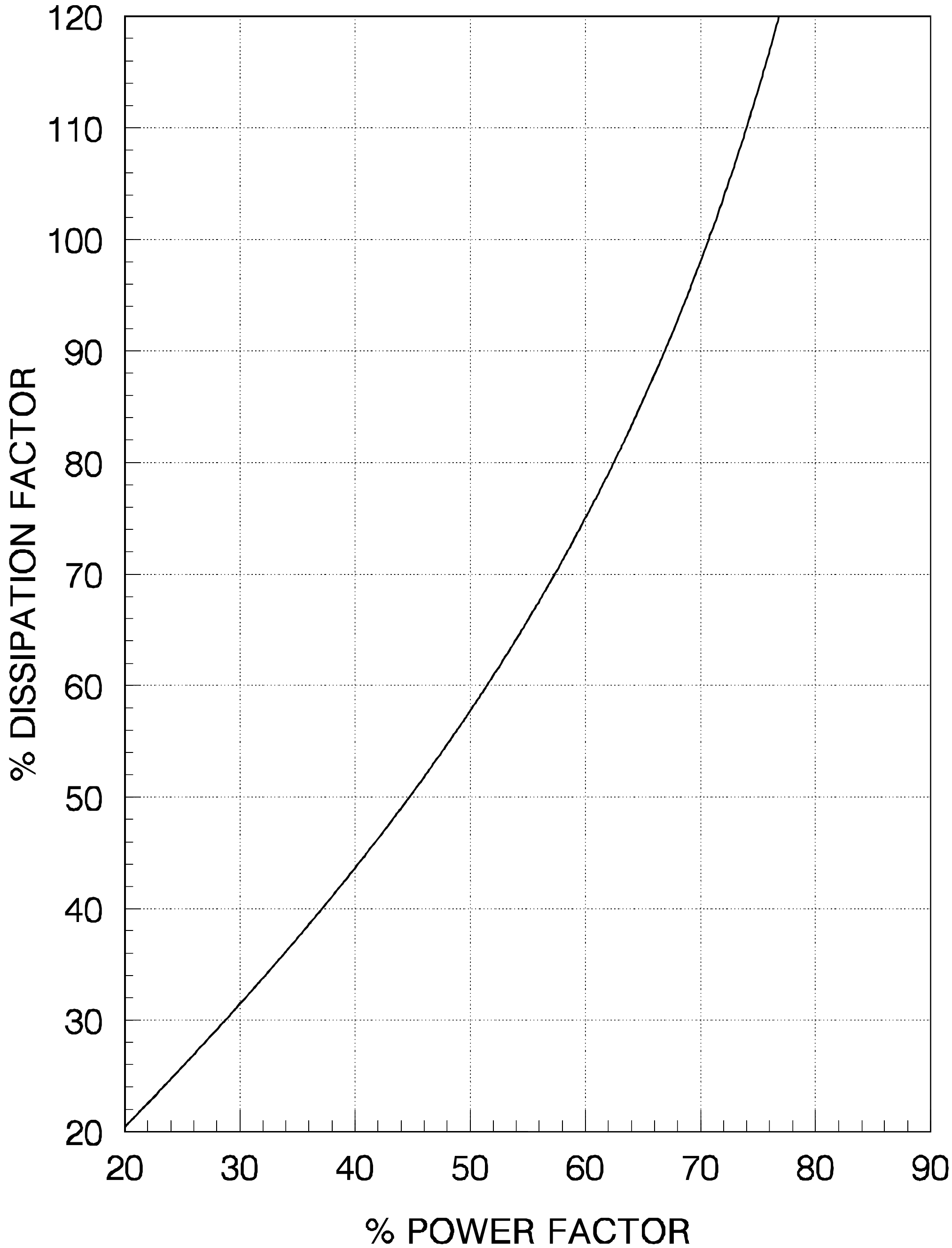


Figure 9: Graph for Converting Power Factor vs. Dissipation Factor Above 20%

Conversion Formulas for test at 2.5 kV, 50 Hz

(based on equivalent 2.5 kV values)

$C_{pF} = mA \times 1273$

$mA = C_{pF} \times 78.6 \times 10^{-5}$

$$\%DF = \frac{W_{loss} \times 40}{mA}$$

Applicable when DF (PF) is less than 20%

$W_{loss} = C_{pF} \times \%DF \times 19.6 \times 10^{-6}$

No limitation

Conversion Formulas for test at 10 kV, 50 Hz

(based on equivalent 10 kV values)

$C_{pF} = mA \times 318$

$mA = C_{pF} \times 314 \times 10^{-5}$

$$\%DF = \frac{W_{loss} \times 10}{mA}$$

Applicable when DF (PF) is less than 20%

$W_{loss} = C_{pF} \times \%DF \times 314 \times 10^{-6}$

No limitation

General Conversion Formulas

$$C_{pF} = \frac{mA \times 10^{6}}{\varpi\ kV}$$

$$C_{pF} = \frac{mA \times 2650}{kV} \quad @\ 60\ Hz$$

$$C_{pF} = \frac{mA \times 3180}{kV} \quad @\ 50\ Hz$$

$mA = kV\ \omega\ C_{pF} \times 10^{-6}$

$mA = kV \times C_{pF} \times 377 \times 10^{-6}$ @ 60 Hz

$mA = kV \times C_{pF} \times 314 \times 10^{-6}$ @ 50 Hz

$$\%DF = \frac{W_{loss} \times 100}{kV \times mA}$$

Applicable when DF (PF) is less than 20%

$W_{loss} = kV^2 \times C_{pF} \times \%DF \times 3.77 \times 10^{-6}$ @ 60 Hz

$W_{loss} = kV^2 \times C_{pF} \times \%DF \times 3.14 \times 10^{-6}$ @ 50 Hz

No limitation

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

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

No limitation

where:

C_{pF}	=	capacitance, picofarads
DF	=	dissipation factor
mA	=	milliamperes
PF	=	power factor
kV	=	kilovolts
ω	=	$2\pi f$
W_{loss}	=	watts loss
f	=	frequency

Connections for UST/GST Low Voltage Lead Configuration

Figures 10 through 13 show the connections between the test set and specimen for each of the UST/GST low voltage lead configurations. The following chart shows the connections of the low voltage red and blue test leads for a measurement and to either guard or ground in the bridge circuit. It also provides cross-reference to the existing AVO Biddle test sets. The component measured is shown by the heavy solid line in Figures 10 through 13. Measurements are always made between the black high-voltage lead and the lead in the MEASURES column. For the GST test mode, measurement is also made between the high voltage lead and ground.

DELTA-2000 Test Set (Cat. No. 672001)		TEST MODE POSITION (Cat. No. 670025, 670065, 670070 & 672000)
UST		
GROUNDS	MEASURES	
—	RED & BLUE	1
BLUE	RED	3
RED	BLUE	2
GST GROUND		
	GROUNDS RED & BLUE	4
GST		
GUARDS	GROUNDS	
RED & BLUE	—	5
RED	BLUE	7
BLUE	RED	6

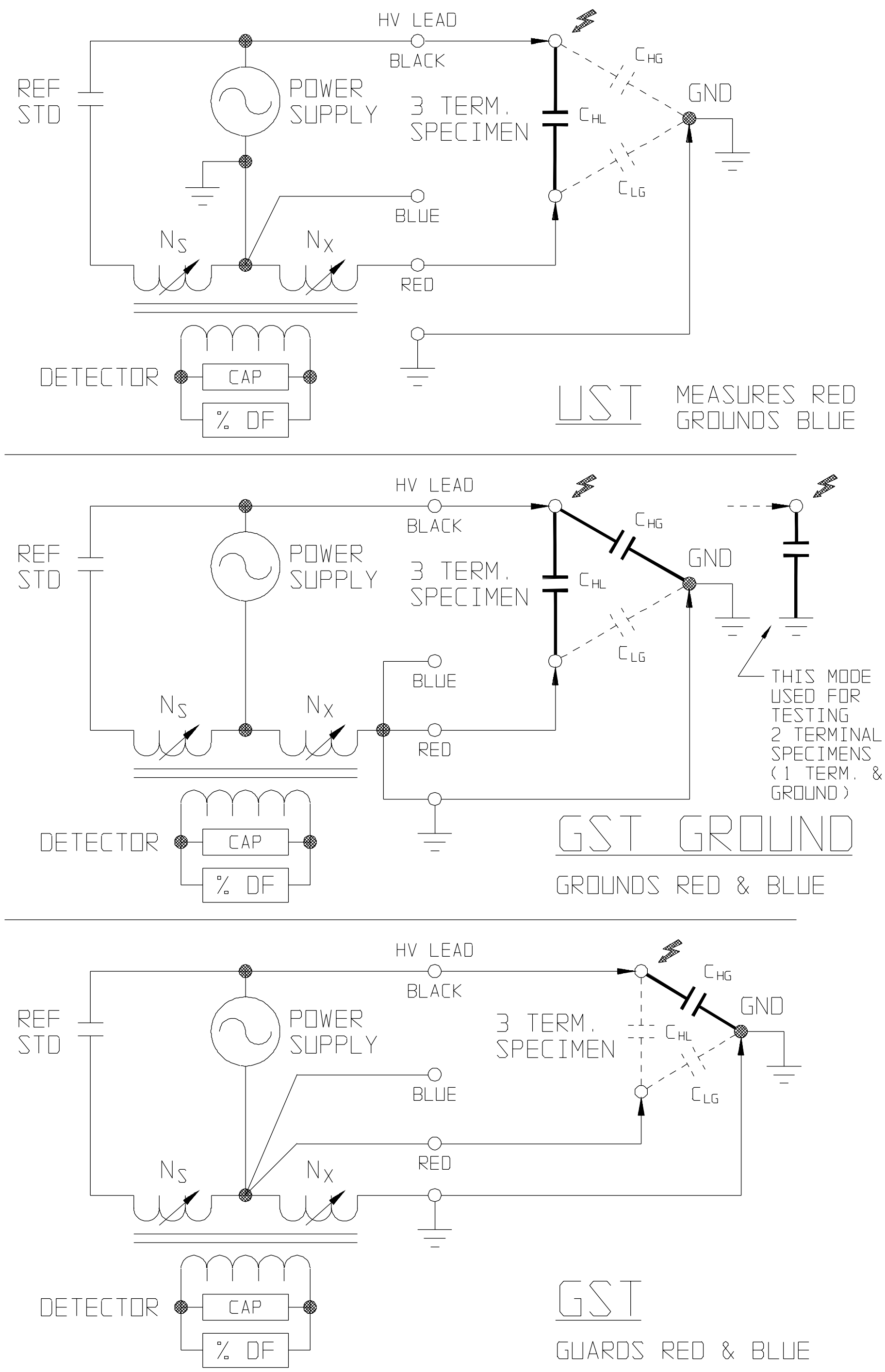


Figure 10: Connection for Three-Phase Specimens

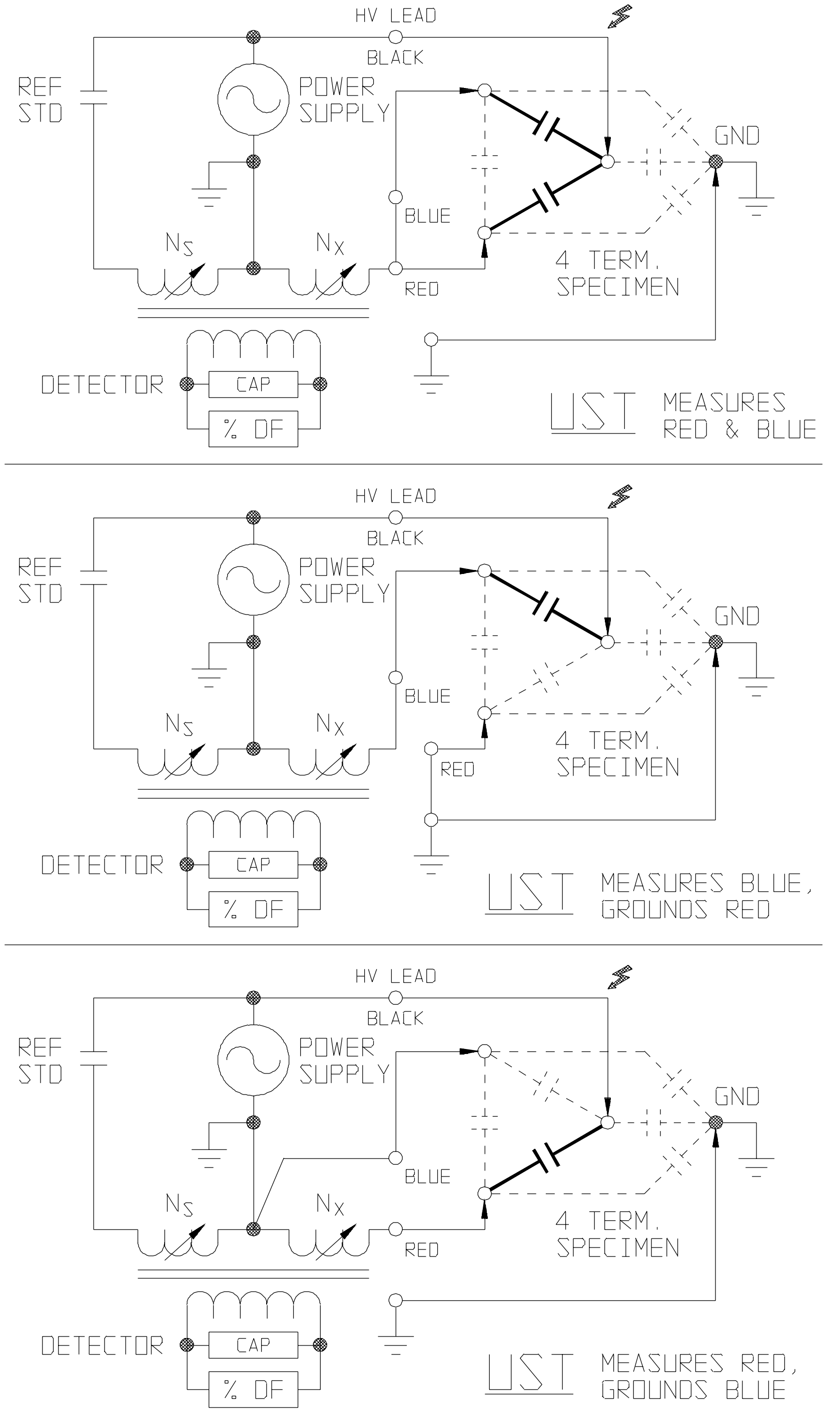


Figure 11: Connection for Four-Terminal Specimens, UST Test Modes

8

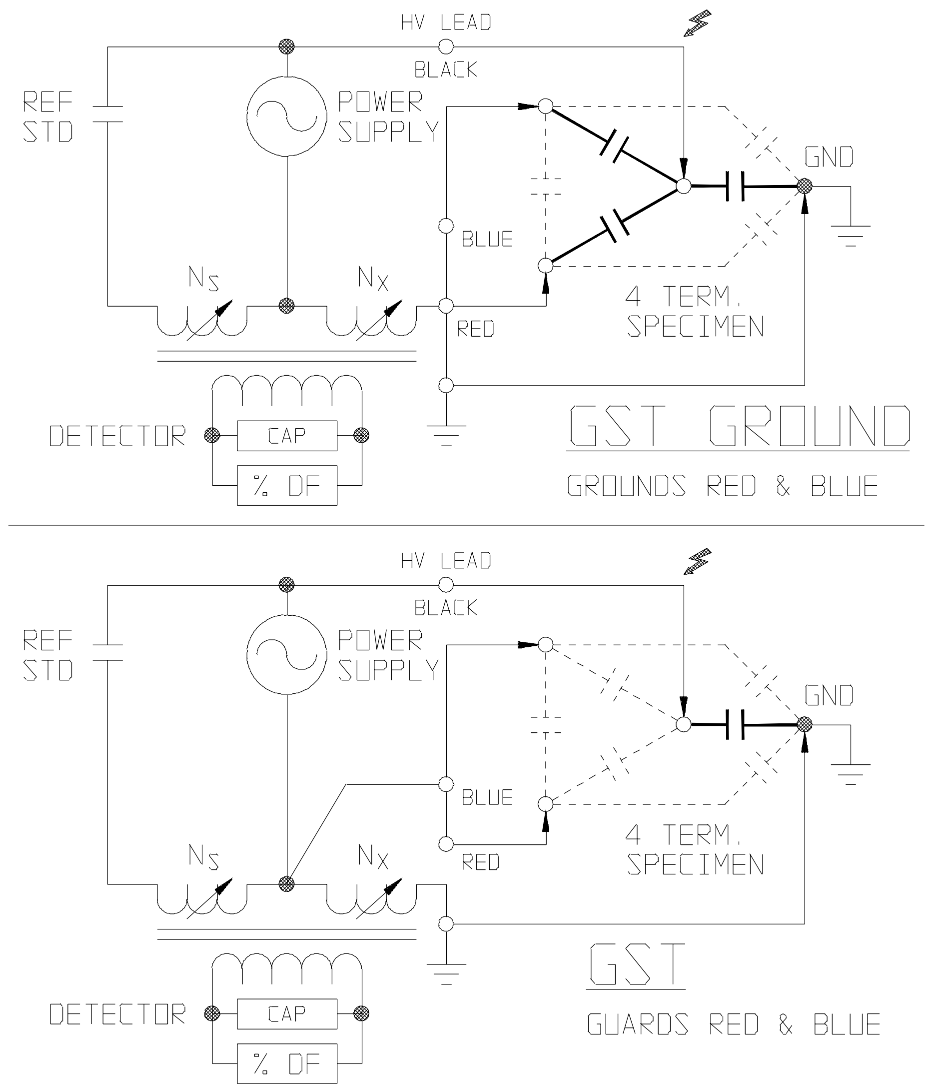


Figure 12: Connection for Four-Terminal Specimens, GST Test Modes

9

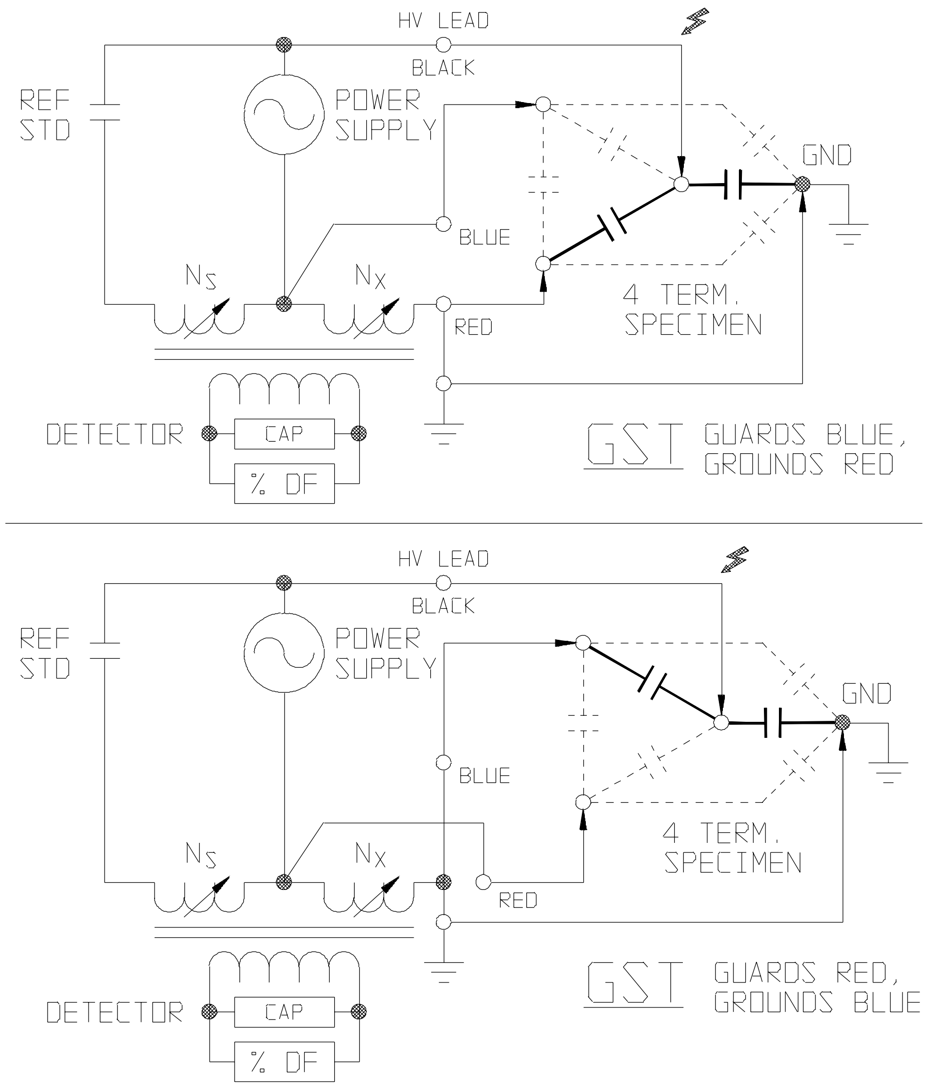


Figure 13: Connection for Four-Terminal Specimen, GST Guard Modes

Section 2
Interpretation of Measurements

Significance of Capacitance and Dissipation Factor

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

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

- Chemical deterioration due to time and temperature, including certain cases of acute deterioration caused by localized overheating.

- Contamination by water, carbon deposits, bad oil, dirt and other chemicals.

- Severe leakage through cracks and over surfaces.

- Ionization.

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

- Between measurements on the same unit after successive intervals of time.

- Between measurements on duplicate units or a similar part of one unit, tested under the same conditions around the same time, e.g., several identical transformers or one winding of a three-phase transformer tested separately.

- Between measurements made at different test voltages on one part of a unit; an increase in slope (tip-up) of a dissipation factor versus voltage curve at a given voltage is an indication of ionization commencing at that voltage.

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

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

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

Dissipation Factor (Power Factor) of Typical Apparatus Insulation

Values of insulation dissipation factor for various apparatus are shown in Table 1. These values may be useful in roughly indicating the range to be found in practice; however, the upper limits are not reliable service values. Dissipation factor has a direct advantage over an equivalent watts value since it is independent of the insulation thickness and area. The dielectric watts loss increases as the amount of insulation under test increases.

Table 1: DF (PF) of Typical Apparatus Insulation

Type Apparatus	% DF (PF) at 20°C
Oil-filled transformer: New, high-voltage (115 kV and up) 15 years old, high-voltage Low-voltage, distribution type	0.25 to 1.0 0.75 to 1.5 1.5 to 5.0
Oil circuit breakers	0.5 to 2.0
Oil-paper cables, “solid” (up to 27.6 kV) new condition	0.5 to 1.5
Oil-paper cables, high-voltage oil-filled or pressurized	0.2 to 0.5
Rotating machine stator windings, 2.3 to 13.8 kV	2.0 to 8.0
Capacitors (discharge resistor out of circuit)	0.2 to 0.5
Bushings: Solid or dry Compound-filled, up to 15 kV Compound-filled, 15 to 46 kV Oil-filled, below 110 kV Oil-filled, above 110 kV and condenser type	3.0 to 10.0 5.0 to 10.0 2.0 to 5.0 1.5 to 4.0 0.3 to 3.0

Permittivity and % DF of Typical Insulating Materials

Typical values of permittivity (dielectric constant) k and 50/60 Hz dissipation factor of a few kinds of insulating materials (also water and ice) are given in Table 2.

Table 2: Permittivity of Typical Insulating Materials

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

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

Significance of Temperature

Most insulation measurements have to be interpreted based on the temperature of the specimen. The dielectric losses of most insulation increase with temperature. In many cases, insulations have failed due to the cumulative effect of temperature, i.e., a rise in temperature causes a rise in dielectric loss which in turn causes a further rise in temperature, etc.

It is important to determine the dissipation factor-temperature characteristics of the insulation under test, at least in a typical unit of each design of apparatus. Otherwise, all tests of the same specimen should be made, as nearly as practicable, at the same temperature. On transformers and similar apparatus, measurements during cooling (after factory heat-run or after service load) can provide the required temperature correction factors. For circuit breakers and other apparatus in which little heating occurs in service, measurements to determine correction factors can be made at different but constant ambient conditions.

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

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

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

Any sudden changes in ambient temperature will increase the measurement error since the temperature of the apparatus will lag the ambient temperature. The capacitance of dry insulation is not appreciably affected by temperature; however, in the case of wet insulation, there is a tendency for the capacitance to increase with temperature.

Dissipation factor-temperature characteristics, as well as dissipation factor measurements at a given temperature, may change with deterioration or damage of insulation. This suggests that any such change in temperature characteristics may be helpful in assessing deteriorated conditions.

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

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

Significance of Humidity

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

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

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

Surface Leakage

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

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

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

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

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

Electrostatic Interference

When tests are conducted in energized substations, the readings may be influenced by electrostatic interference currents resulting from the capacitance coupling between energized lines and bus work to the test specimen. In the shop or low-voltage substations the effects of electrostatic interference currents can be canceled by taking normal and reverse polarity voltage readings. In high-voltage substations the effects of electrostatic interference currents can be canceled by using the interference suppressor circuit. Normal and reverse polarity voltage readings should still be taken to cancel any residual interference currents. Trouble from magnetic fields encountered in high-voltage substations is very unlikely.

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

The measurement difficulty which is encountered when testing in the presence of interference depends not only upon the severity of the interference field but also on the capacitance and dissipation factor of the specimen. Unfavorable weather conditions such as high relative humidity, fog, overcast sky, and high wind velocity will increase the severity and variability of the interference field. The lower the specimen capacitance and its dissipation factor, the greater the difficulty, with possible reduction in accuracy, in making measurements. It is also possible that a negative dissipation factor reading may be obtained so it is necessary to observe the polarity sign for each reading. Specifically, it has been found that some difficulty may be expected when measuring capacitance by the GST test method in 230 through 550 kV low-profile switchyards when the capacitance value is less than 100 pF. This difficulty may be minimized considerably by:

- Using the maximum voltage of the test set if possible.

- Disconnecting and grounding as much bus work as possible from the specimen terminals.

- Making measurements on a day when the weather is sunny and clear, the relative humidity is less than 80 percent, the wind velocity is low, and the surface temperature of exposed insulation is above the ambient temperature.

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

It is not generally recognized that when testing by the GST test method in the vicinity of other energized high-voltage circuits another form of interference is produced which may cause a change in the actual dissipation factor of the specimen. This interference is partial discharge that may occur at the specimen high-voltage terminal, not as a result of the test voltage, but by intense fields between the specimen terminal and the adjacent energized high-voltage circuit. The partial discharge loss resulting from this interference is added to the normal loss in the specimen, thereby increasing its dissipation factor. Since this type of interference is a loss related to the specimen in that particular environment, it cannot be eliminated from the test and cannot be considered as an error in the measurement.

If the test set is energized from a portable generator when conducting tests in an energized substation, the readings may fluctuate over a significant range. This results from the frequency of test set voltage being out of synchronization with the electrostatic interference field. If it is not possible to synchronize the frequency of the two voltage systems, disconnect and ground as much bus work as possible from the specimen terminals. This will decrease both the interference pickup and the reading fluctuation.

Negative Dissipation Factor

In isolated cases, negative dissipation factors are encountered in the measurement of dielectric specimens of low capacitance. This condition is most likely to arise when making UST and GST measurements on specimens which have a capacitance value of a few hundred picofarads or less. Equipment such as bushings, circuit breakers, and low loss surge arresters fall into this category.

It is believed that the negative dissipation factor phenomenon is caused by a complex tee network of capacitance and resistance which exists within a piece of equipment. Error currents may flow into the measuring circuit in instances where phantom multiple terminals or a guard terminal appear in the measurement system. It is also believed that a negative dissipation factor may be produced by error currents flowing into a tee network as a result of space coupling from electrostatic interference fields.

The only time a negative dissipation factor has been observed is in cases where there is incomplete shielding of the measuring electrode or when the specimen itself is defective.

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

There appears to be no clear-cut way of knowing whether an error is significant or what remedies should be taken to overcome an error. The best advice is to avoid making measurements on equipment in locations where negative dissipation factors are known to present a problem when unfavorable weather conditions exist, especially high relative humidity. Make sure the surface of porcelain bushings are clean and dry to minimize the effects of surface leakage. Make sure all items such as wooden ladders or nylon ropes are removed from the equipment to be tested and are brought out of any electrostatic interference fields that could influence a measurement. Additional shielding around the low-voltage terminals of the specimen connected to the measuring and guarded leads of the test set should help to minimize this problem; however, this solution is generally not practical in the field.

Section 3
Types of Apparatus

Transformers

The voltage rating of each winding under test must be considered and the test voltage selected accordingly. If neutral bushings are involved, their voltage rating must be considered in selecting the test voltage. Measurements should be made between each interwinding combination (or set of three-phase windings in a three-phase transformer) with all other windings grounded to the tank (UST test). Measurements should also be made between each winding (or set of three-phase windings) and ground with all other windings guarded (GST test with guarding). In a two-winding transformer, a measurement should also be made between each winding and ground with the remaining winding grounded (GST GROUND test). For a three-winding transformer, a measurement should also be made between each winding and ground with one remaining winding guarded and the second remaining winding grounded (GST test with guarding). This special test is used to isolate the interwindings. A final measurement should be made between all windings connected together and the ground tank. It is also desirable to test samples of the liquid insulation.

Figure 14 shows a typical setup for testing a two-winding transformer, Table 3 outlines the connections between the test set and two-winding transformer for each UST/GST test. Table 4 specifies the connections for three-winding transformers. Each winding should be shorted on itself at its bushing terminals. It is recommended that the Measurement Intercheck calculations, specified in Tables 3 and 4 be performed to validate all measurements. The calculated intercheck values should agree with the direct measurement values within reasonable limits.

Table 5 shows typical setups for making transformer excitation current measurements.

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

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

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

Bushings, if in poor condition, may have their losses masked by normal losses in the winding insulation. Therefore, separate tests should be applied to them. Temperature correcting curves for each design of transformer should be carefully established by measurement in factory or field and should be used to correct all measurements to a base temperature, usually 20°C.

10

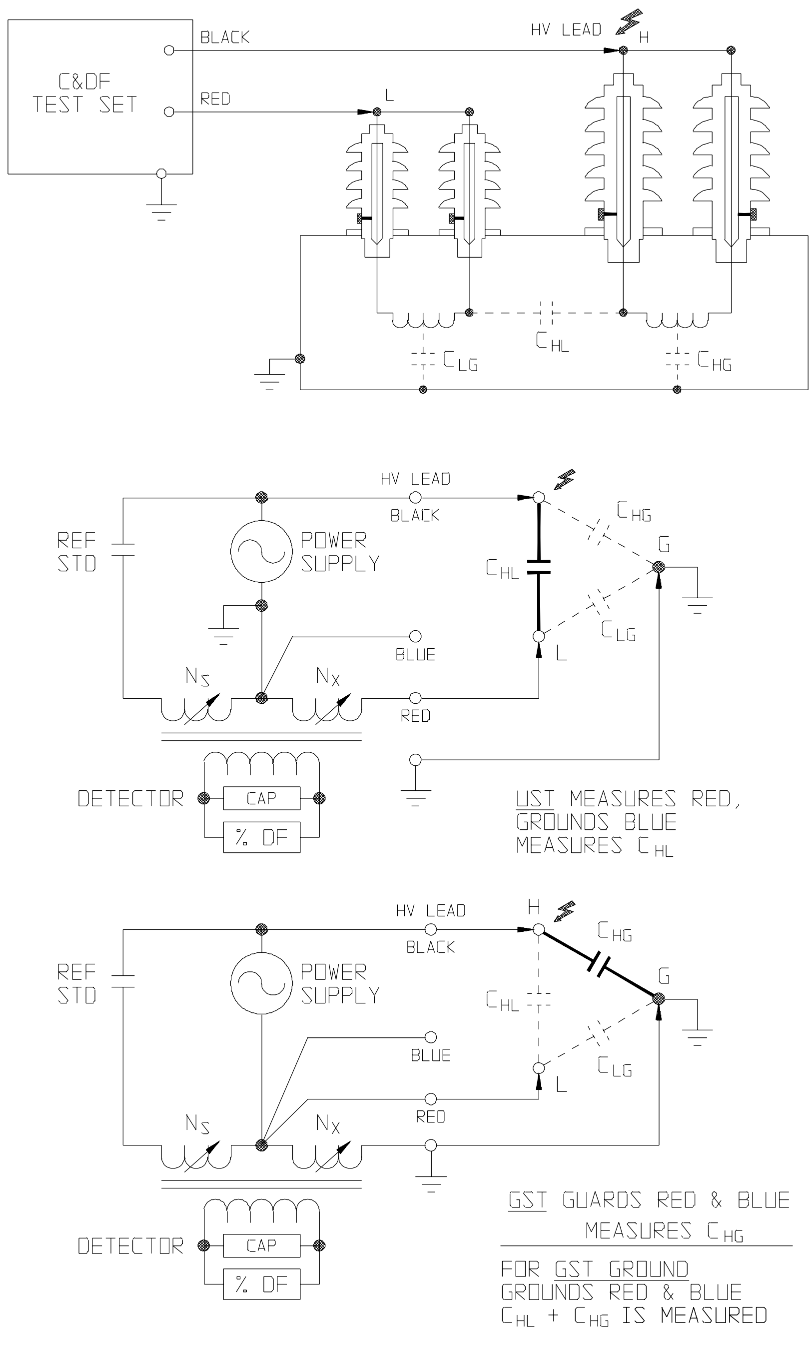
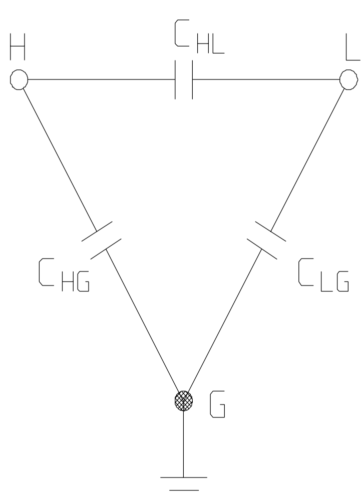


Figure 14: Two-Winding Transformer Tests

Table 3: Two-Winding Transformer Test Connections

Test No.	Insulation Tested	Low Voltage Lead Configuration				Test Connections To Windings			Remarks
		Test Mode	Measures	Grounds	Guards	Black	Red	Blue	
1	$C_{HG} + C_{HL}$	GST GND		Red & Blue		H	L	—	L Grounded
2	C_{HG}	GST			Red & Blue	H	L	—	L Guarded
3	C_{HL}	UST	Red	Blue		H	L	—	
4	C_{HL}	—	Test 1 minus Test 2			—	—	—	Calculated intercheck
5	$C_{LG} + C_{HL}$	GST GND		Red & Blue		L	H	—	H Grounded
6	C_{LG}	GST			Red & Blue	L	H	—	H Guarded
7	C_{HL}	UST	Red	Blue		L	H	—	
8	C_{HL}	—	Test 5 minus Test 6			—	—	—	Calculated intercheck
9									
10									
11									
12									

Equivalent Circuit



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

Note: Short each winding on itself.

Measurement Interchecks (Calculated)

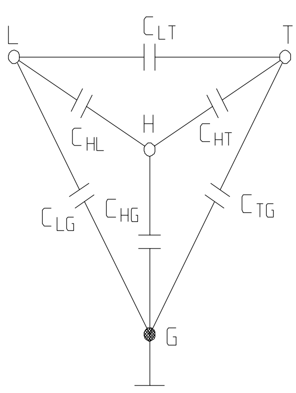
Capacitance	Watts
$C_4 = C_1 - C_2$	$W_4 = W_1 - W_2$
$C_8 = C_5 - C_6$	$W_8 = W_5 - W_6$

Note: Subscripts are test numbers.

Table 4: Three-Winding Transformer Test Connections

Test No.	Insulation Tested	Low Voltage Lead Configuration				Test Connections To Windings			Remarks
		Test Mode	Measures	Grounds	Guards	Black	Red	Blue	
1	$C_{HG} + C_{HL}$	GST		Red	Blue	H	L	T	L Grounded T Guarded
2	C_{HG}	GST			Red & Blue	H	L	T	L & T Guarded
3	C_{HL}	UST	Red	Blue		H	L	T	T Grounded
4	C_{HL}	—	Test 1 minus Test 2			—	—	—	Calculated intercheck
5	$C_{LG} + C_{LT}$	GST		Red	Blue	L	T	H	T Grounded H Guarded
6	C_{LG}	GST			Red & Blue	L	T	H	T & H Guarded
7	C_{LT}	UST	Red	Blue		L	T	H	H Grounded
8	C_{LT}	—	Test 5 minus Test 6			—	—	—	Calculated intercheck
9	$C_{TG} + C_{HT}$	GST		Red	Blue	T	H	L	H Grounded L Guarded
10	C_{TG}	GST			Red & Blue	T	H	L	H & L Guarded
11	C_{HT}	UST	Red	Blue		T	H	L	L Grounded
12	C_{HT}	—	Test 9 minus Test 10			—	—	—	Calculated intercheck

Equivalent Circuit



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

Note: Short each winding on itself.

Measurement Interchecks (Calculated)

Capacitance

$C_4 = C_1 - C_2$

$C_8 = C_5 - C_6$

$C_{12} = C_9 - C_{10}$

Watts

$W_4 = W_1 - W_2$

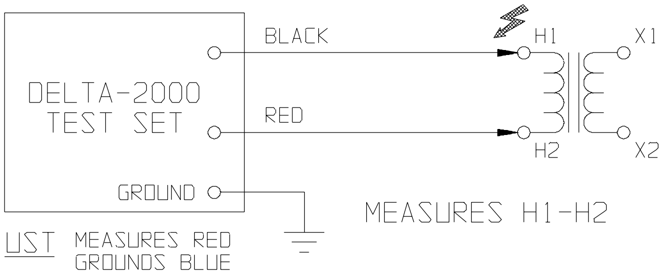
$W_8 = W_5 - W_6$

$W_{12} = W_9 - W_{10}$

Note: Subscripts are test numbers.

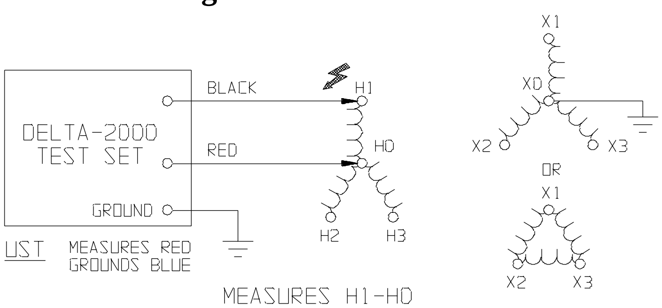
Table 5: Transformer Excitation Current Test Connections

Single Phase



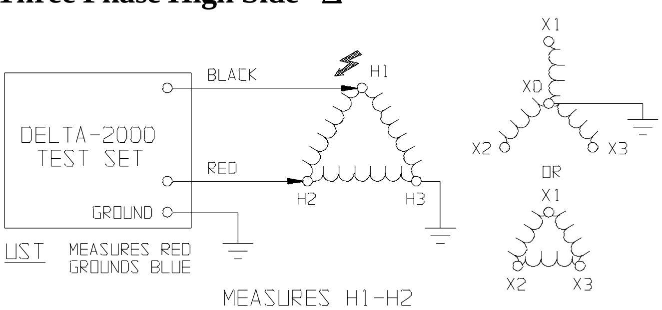
Measures	Test Lead Connections		
Terminal Symbol	Black	Red	Ground
H1-H2	H1	H2	—
H2-H1	H2	H1	—

Three Phase High Side "Y"



Measures	Test Lead Connections		
Terminal Symbol	Black	Red	Ground
H1-H0	H1	H0	—
H2-H0	H2	H0	—
H3-H0	H3	H0	—

Three Phase High Side "Δ"



Measures	Test Lead Connections		
Terminal Symbol	Black	Red	Ground
H1-H2	H1	H2	H3
H2-H3	H2	H3	H1
H3-H1	H3	H1	H2

Circuit Breakers

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

The specific term “tank-loss index” has been developed to assist in evaluating the results of the open and closed oil circuit breaker tests. It is defined for each phase as the difference of the measured open circuit and closed circuit power, in watts. To obtain the open circuit value, the individual values measured on the two bushings of each phase must be summed. Tank-loss index may have values ranging from positive to negative which will give an indication of the possible source of a problem. Positive indexes occur when the closed circuit values are larger than the sum of the open circuit values. Conversely, negative indexes occur when the closed circuit values are smaller than the sum of the open circuit values. The test results should be recorded in terms of equivalent 10 kV watts or 2.5 kV watts/milliwatts regardless of the test voltage used. To obtain watts from a previous measurement of capacitance and dissipation factor, refer to the conversion formulas.

The Oil Circuit Breakers test data form in Appendix C outlines the specific connections between the test set and breaker as well as the series of measurements which should be performed on the breaker.

Table 6, SF6 Dead Tank Circuit Breaker Test Connections, outlines the specific connections between the test set and breaker as well as the series of measurements that should be performed on the breaker.

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

The losses in an oil circuit breaker are different between an open circuit test and a closed circuit test because the voltage stress on the insulating members is distributed differently. Tables 7 and 8 summarize what may be defective based upon the polarity of the tank-loss index. Once a particular section has given indications of deterioration, the test results should be verified by systematically isolating the suspected insulating member before disassembling the unit.

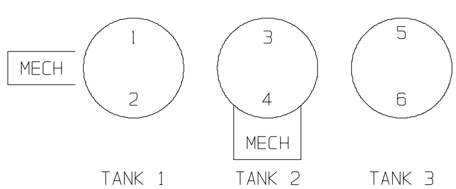
Oil circuit breakers are composed of many different materials each having its own temperature coefficient. For this reason it may be difficult to correct tank-loss indexes for a standard temperature. On this basis, an attempt should be made to conduct tests at approximately the same time of the year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

Air and gas circuit breakers vary so much in construction that specific instructions and interpretation would be too lengthy. This section, however, does contain a detailed test connection chart (Table 9) outlining the normal series of measurements performed on a General Electric Type ATB Air-Blast Circuit Breaker. Table 10 outlines the normal series of measurements performed on a three-column live tank breaker.

Table 6: SF6 Dead Tank Circuit Breaker Test Connections

Test No.	CB	Insulation Tested	Low Voltage Lead Configuration: Test Mode	Measures	Grounds	Guards	Test Connections To Bushings: Black	Red	Blue	Remarks
1		C_{1G}	GST GND		Red & Blue		1			Bushing 2 floating
2		C_{2G}	GST GND		Red & Blue		2			Bushing 1 floating
3	O	C_{3G}	GST GND		Red & Blue		3			Bushing 4 floating
4	P E	C_{4G}	GST GND		Red & Blue		4			Bushing 3 floating
5	N	C_{5G}	GST GND		Red & Blue		5			Bushing 6 floating
6		C_{6G}	GST GND		Red & Blue		6			Bushing 5 floating
7	O	C_{12}	UST	Red	Blue		1	2		
8	P E	C_{34}	UST	Red	Blue		3	4		
9	N	C_{56}	UST	Red	Blue		5	6		
10	C L	$C_{1G} + C_{2G}$	GST GND		Red & Blue		1 or 2			
11	O S	$C_{3G} + C_{4G}$	GST GND		Red & Blue		3 or 4			
12	E D	$C_{5G} + C_{6G}$	GST GND		Red & Blue		5 or 6			

Diagram



Insulation Tested
1 to 6 = Bushing terminals
G = Ground

Note: No. in Black column is bushing energized. Tests 1 through 6, 10, 11, and 12 all other bushings must be floating.

Table 7: Tank-Loss Index of Oil Circuit Breakers (Equivalent to 10 kV Losses)

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

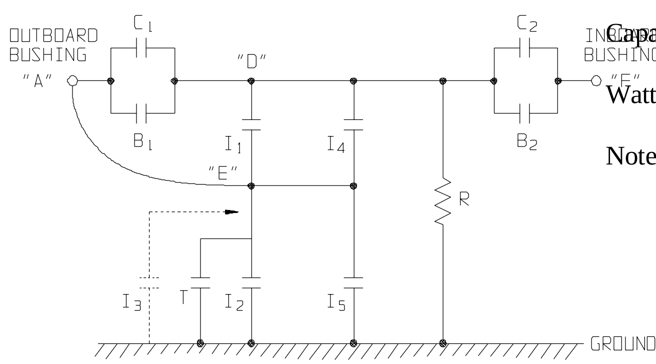
Table 8: Tank-Loss Index of Oil Circuit Breakers (Equivalent to 2.5 kV Losses)

Tank Loss Index	Test Remarks	Probable Problem	Insulation Rating
<±10 mW	Normal results for both open CB tests	None	Good
>+10 mW	Normal results for both open CB tests	1. Tank oil 2. Tank liner 3. Lift rod 4. Auxiliary contact insulation	Investigate
>-10 mW	High losses for both open CB tests Closed CB test near normal	1. Cross guide assembly 2. Isolated cross guide 3. Contact assembly insulation 4. Lift rod upper section (moisture contaminated)	Investigate
<±10 mW	Normal results for one open CB test Other has high losses	1. Bushing with high loss reading 2. Arc interruption assembly	Investigate
<±10 mW	High losses for both open CB tests and closed CB test	1. Bushings 2. Arc interruption assembly 3. Tank oil 4. Tank liner 5. Lift rod 6. Auxiliary contact insulation 7. Cross guide assembly 8. Isolated cross guide 9. Contact assembly insulation	Investigate

Table 9: General Electric Air-Blast Type Circuit Breaker Test Connections

Test No.	Insulation Tested	Low Voltage Lead Configuration: Test Mode	Measures	Grounds	Guards	Test Connections To Breaker: Black	Red	Blue	Remarks
1	$C_2 + B_2$	UST	Red	Blue		D	F	A	A Grounded
2	$C_1 + B_1 + I_1$	UST	Blue	Red		D	F	A	F Grounded
3	$C_2 + B_2 + C_1 + B_1 + I_1$	UST	Red & Blue			D	F	A	
4	R (or $R + I_3$)	GST			Red & Blue	D	F	A	F & A Guarded
5	$I_2 + T$ *	GST		Red	Blue	A	F	D	D Guarded F Grounded

* Test performed only on units with current transformer.



Measurement Intercheck

Capacitance: $C_1 = C_3 - C_2$

Watts: $W_1 = W_3 - W_2$

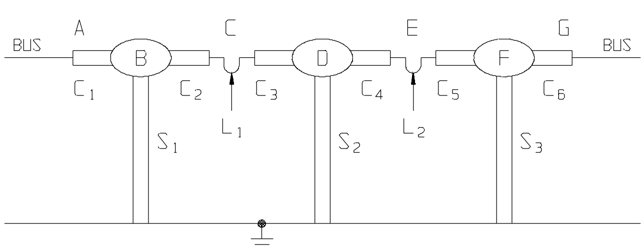
Note: Subscripts are test no.'s.

B_1 & B_2 Entrance bushings
C_1 & C_2 Grading capacitors
D Module live tank
I_1 Upper insulator
I_2 Lower insulator
I_3 Insulator for units without current transformer
R Glass fiber air supply tube, open rods and
wood tie rods
T Current transformer insulation
I_4 and I_5 Protective glass fiber tube that encloses R tube
is slit at "E" with metal guard ring

Table 10: Live Tank Circuit Breaker Test Connections (Typical Three-Column Support Per Phase)

Test No.	Insulation Tested	ϕ	Low Voltage Lead Configuration				Test Connections To Breaker			Remarks
			Test Mode	Measures	Grounds	Guards	Black	Red	Blue	
1	C_1		UST	Red	Blue		B	A	C	C Grounded
2	C_2		UST	Blue	Red		B	A	C	A Grounded
3	S_1		GST			Red & Blue	B	A	C	A & C Guarded
4	C_3		UST	Red	Blue		D	C	E	E Grounded
5	C_4		UST	Blue	Red		D	C	E	C Grounded
6	S_2		GST			Red & Blue	D	C	E	C & E Guarded
7	C_5		UST	Red	Blue		F	E	G	G Grounded
8	C_6		UST	Blue	Red		F	E	G	E Grounded
9	S_3		GST			Red & Blue	F	E	G	E & G Guarded
10										
11										
12										

Diagram



Note: To reduce the effects of severe electrostatic interference, disconnect one side of L_1 and L_2 links to break circuit between modules. All terminals and bus work not in measurement circuit must be solidly grounded.

A, C, E & G Low lead test connections
B, D, F Module live tanks
C_1 thru C_6 Module entrance bushing and grading capacitors
L_1, L_2 Connection links joining modules
S_1, S_2, S_3 Module support columns

Bushings

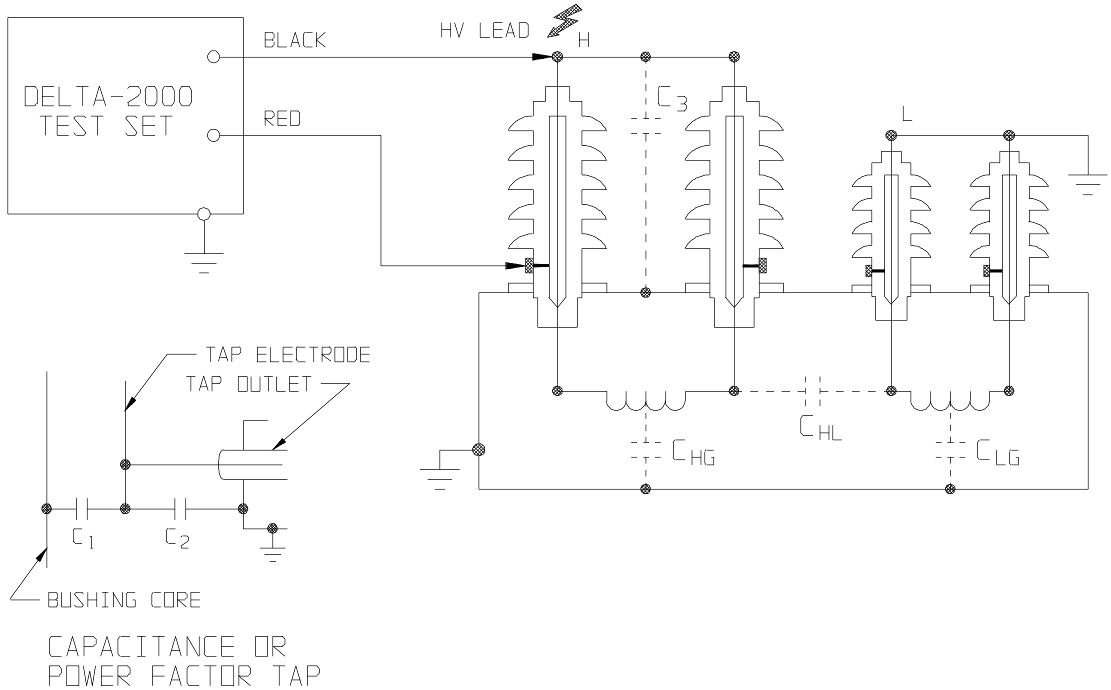
All modern bushings rated 23 kV and higher have a power factor or a capacitance tap which permits dissipation factor testing of the bushing while it is in place on the apparatus without disconnecting any leads to the bushing. The dissipation factor is measured by the ungrounded specimen test (UST) which eliminates the influence of transformer winding insulation, breaker arc-interrupters, or support structures which are connected to the bushing terminal. The effects of stray capacitance between the bushing terminal and ground as well as surface leakage over the porcelain are also eliminated from the measurement. The UST method measures only the bushing and is not appreciably affected by conditions external to the bushing.

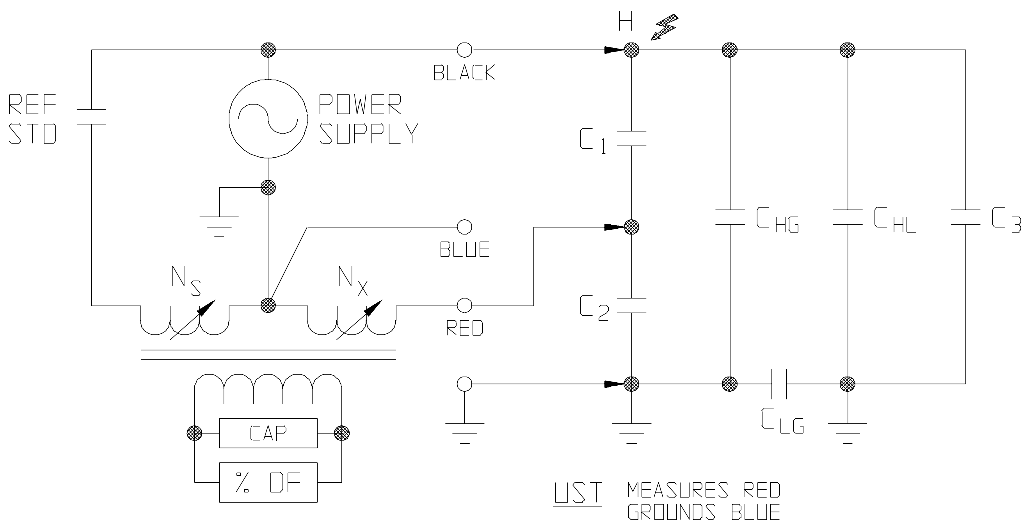
Figure 15 shows the test connections between the test set and bushing when using the UST test mode. Connect the high-voltage lead (black boot) to the terminal at the top of the bushing and the low-voltage lead (red boot) to the power factor tap. Ground the apparatus tank. The tap is normally grounded through a spring and it is necessary, when making measurements, to remove the plug which seals and grounds the tap. Use the UST measure red, ground blue test mode setting.

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

Hot Collar Test

The dielectric losses through the various sections of any bushing or pothead can be investigated by means of a hot collar test which generates localized high-voltage stresses. This is accomplished by using a conductive hot collar band designed to fit closely to the porcelain surface, usually directly under the top petticoat, and applying a high voltage to the band. The center conductor of the bushing is grounded. This test provides a measurement of the losses in the section directly beneath the collar and is especially effective in detecting conditions such as voids in compound filled bushings or moisture penetration since the insulation can be subjected to a higher voltage gradient than can be obtained with the normal bushing tests.





Measures main bushing insulation C_1

C_{HG}, C_{HL}, and C_3 shunt power supply, therefore no influence on measurement

C_2 shunts bridge winding, therefore negligible influence if less than 5000 pF

Figure 15: UST Test on Transformer Bushing

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

Power Factor or Capacitance Tap Test

Insulation tests on a power factor or capacitance tap of a bushing are performed by the GST with low lead guarded test method. For this test the high-voltage lead is connected to the tap, the low-voltage red lead to the bushing center conductor, and the bushing flange grounded. This method measures only the insulation between the tap and ground and is not appreciably affected by connections to the bushing center conductor.

CAUTION

The power factor tap is normally designed to withstand only about 500 V while a capacitance tap may have a normal rating of 2.5 to 5 kV. Before applying a test voltage to the tap, the maximum safe test voltage must be known and observed. An excessive voltage may puncture the insulation and render the tap useless.

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

Evaluation of Test Results

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

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

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

Rotating Machines

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

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

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

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

Table 11 shows the specific connections between the test set and a typical generator three-phase stator winding as well as the routine series of measurements performed on the windings. It is assumed that the connection between the winding phases and also neutral are opened. The phase-to-ground insulation tests are made by the GST test method, whereas, the phase-to-phase tests are made by the UST test method.

When testing large generator windings which have a very high value of capacitance per phase, the maximum specimen capacitance measurable at a particular test voltage may be limited due to the thermal rating of the power supply transformer (refer to Section 3, Specifications). For this case tests will have to be made at a reduced voltage level or with the use of Resonating Inductor (Cat. No. 670600).

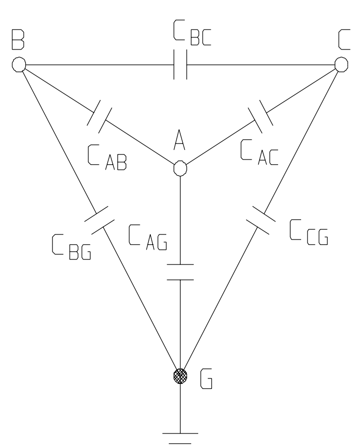
The temperature of the windings should be above and never below the ambient temperature to avoid the effects of moisture condensation on the exposed insulating surface. Temperature measurements when using temperature correction curves should be based on that at the winding surface.

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

Table 11: Three-Phase Rotating Machinery Stator Test Connections (Motors and Generators)

Test No.	Insulation Tested	Low Voltage Lead Configuration				Test Connections To Windings			Remarks
		Test Mode	Measures	Grounds	Guards	Black	Red	Blue	
1	A to ⏚	GST			Red & Blue	A	B	C	B & C Guarded
2	A to B	UST	Red	Blue		A	B	C	C Grounded
3	B to ⏚	GST			Red & Blue	B	C	A	C & A Guarded
4	B to C	UST	Red	Blue		B	C	A	A Grounded
5	C to ⏚	GST			Red & Blue	C	A	B	A & B Guarded
6	C to A	UST	Red	Blue		C	A	B	B Grounded
7	A + B + C to ⏚	GST GND				A,B,C	—	—	May require Resonating Inductor

<u>Equivalent Circuit</u>



<u>Remarks</u>

A = Phase A winding
B = Phase B winding
C = Phase C winding
G = Ground

Note: Short each winding on itself if possible.

Cables

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

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

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

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

Surge (Lightning) Arresters

A complete test on a surge arrester involves impulse and overvoltage testing as well as a test for power loss at a specified test voltage using normal 50/60 Hz operating frequency. Impulse and overvoltage testing is not generally performed in the field since it involves a large amount of test equipment that is not easily transportable. Experience has demonstrated that the measurement of power loss is an effective method of evaluating the integrity of an arrester and isolating potential failure hazards. This test reveals conditions which could affect the protective functions of the arrester, such as: the presence of moisture, salt deposits, corrosion, cracked porcelain, open shunt resistors, defective pre-ionizing elements, and defective gaps.

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

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

WARNING

Exercise extreme care when handling arresters suspected of being damaged, since dangerously high gas pressures can build up within a sealed unit.

It is recommended that tests be made on individual arrester units rather than on a complete multi-unit arrester stack. A single arrester unit can be tested by the normal ungrounded specimen test (UST) in the shop; however, it can only be tested by the grounded specimen test (GST) when mounted on a support structure in the field. Table 11 shows the recommended test procedure for testing installed multi-unit arrester stacks. When testing in the field, disconnect the related high-voltage bus from the arrester.

Surge arresters are often rated on the basis of watts loss. To obtain the equivalent 10 kV watts loss from a measurement of capacitance and dissipation factor, perform the following calculations:

Watts loss = C_{pF} x %DF x 377 x 10^{-6} (for 60 Hz)
Watts loss = C_{pF} x %DF x 314 x 10^{-6} (for 50 Hz)

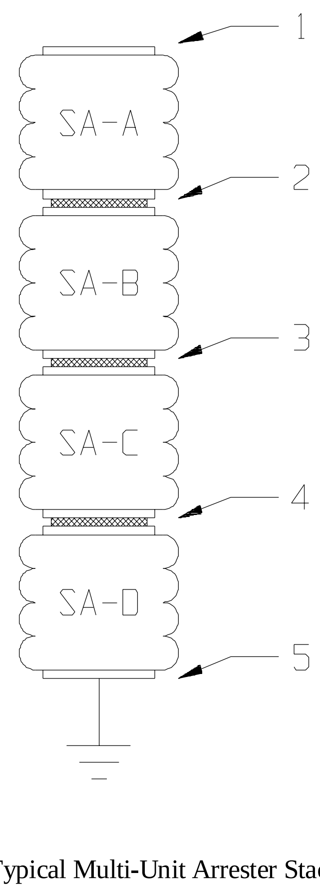
where: C_{pF} = capacitance in picofarads
%DF = percent dissipation factor

Note: Capacitance, dissipation factor, power factor, watts at 10 kV, current, and current at 10 kV can all be read directly from the DELTA-2000 test set. These formulas are provided for informational purposes only.

Table 12: Surge Arrester Test Connections

Test No.	Surge Arrester Symbol Insulation Tested	Low Voltage Lead Configuration				Test Connections To Surge Arrester			Remarks
		Test Mode	Measures	Grounds	Guards	Black	Red	Blue	
1	SA -A	UST	Blue	Red		2	3	1	Terminal 3 Grounded
2	SA - B	UST	Red	Blue		2	3	1	Terminal 1 Grounded
3	SA - C	UST	Red	Blue		4	3	—	
4	SA - D	GST			Red	4	3	—	Terminal 3 Guarded

Note: All tests normally made at 10 kV.



Typical Multi-Unit Arrester Stack

In some cases, where limited test data are recorded, it may be desirable to convert equivalent 10 kV watts loss to equivalent 2.5 kV watts loss and vice versa. The conversion can be made using the following formula. Keep in mind that the relationship is true only when testing arresters which have a linear response below a 10 kV test voltage.

$$Watts\ loss\ @\ 2.5\ kV = \frac{Watts\ loss\ @\ 10\ kV}{16}$$

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

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

A decrease in dissipation factor or watts loss values may indicate:

- Open shunt resistors
- Defective pre-ionizing elements.

Liquids

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

When samples of insulating liquid are tested, the specimen capacitance is used for determining the dielectric constant (permittivity) of the insulating liquid. The ratio of the test cell capacitance measured when empty (air dielectric) to the test cell capacitance measured when filled (liquid dielectric) is the value of dielectric constant of the liquid. Instructions for the use of the Oil Test Cell are contained in Instruction Manual AVTM670511.

Miscellaneous Assemblies and Components

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

It may sometimes be necessary to separate volume losses from surface losses by providing a third (guard) terminal on or within the specimen insulation system. For example, an insulating tube formed over a metal rod may be tested for internal damage in the insulation. A conductive band (or foil) is applied near the center of the insulating tube with additional conductive (guard) bands on each side, separated from the center band by enough clean insulation to withstand the intended test voltage. With the metal rod grounded, the test set will measure the capacitance and dissipation factor of the volume of insulation between the center conductive band (high-voltage) and the metal rod. Figure 16 shows a typical test setup.

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

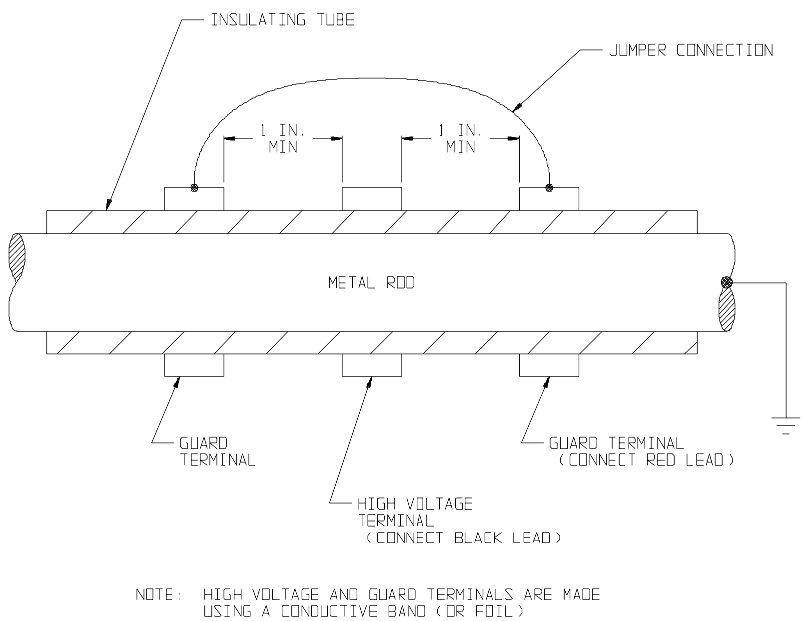


Figure 16: GST Test with Guarding on Insulated Tube Covering Metal Rod

Appendix C
Test Data Forms

Test Data Forms

- Two-Winding Transformers Capacitance and Power Factor Tests
- Three-Winding Transformers Capacitance and Power Factor Tests
- Transformer Excitation Current Tests
- Oil Circuit Breakers Capacitance and Power Factor Tests
- SF6 Dead Tank Circuit Breakers Capacitance and Power Factor Tests
- Vacuum Circuit Breakers Capacitance and Power Factor Tests
- Air-Magnetic Circuit Breakers Capacitance and Power Factor Tests
- Rotating Machinery (Motors and Generators) Capacitance and Power Factor Tests
- Miscellaneous Equipment Capacitance and Power Factor Tests

AVO International
Valley Forge, PA U.S.A.

Two-Winding Transformers
Capacitance and Power Factor Tests

COMPANY	DATE
TEST LOCATION	TESTED BY
XFMR IDENT.	TEST SET NO.
XFMR SERIAL NO.	AIR TEMPERATURE
XFMR MFR TYPE KVA	OIL TEMPERATURE
HIGH KV SGL ☐ Y☐ Δ ☐	% RH
HIGH KV BUSH	WEATHER
LOW KV SGL ☐ Y☐ Δ ☐	TERTIARY KV SGL ☐ Y☐ Δ ☐
LOW KV BUSH	TERTIARY BUSH

TRANSFORMER OVERALL TESTS

TEST NO.	INSULATION TESTED	TEST MODE	TEST CONNECTIONS (WINDINGS) ENG	GND	GAR	UST	TEST KV	CAPACITANCE C (PF)	% POWER FACTOR MEASURED	20°C %PF	CORR FCTR	☐ EQUIV 10 KV ☐ EQUIV 2.5 KV mA	WATTS	INSUL-ATION RATING
1	$C_{HG} + C_{HL}$	GST GND	H	L										
2	C_{HG}	GST	H		L									
3	C_{HL}	UST	H			L								
4	C_{HL}	—	TEST 1 MINUS TEST 2				—							
5	$C_{LG} + C_{HL}$	GST GND	L	H										
6	C_{LG}	GST	L		H									
7	C_{HL}	UST	L			H								
8	C_{HL}	—	TEST 5 MINUS TEST 6				—							
9	C_{HG}'	—	C_{HG} MINUS HIGH BUSH.				—							
10	C_{LG}'	—	C_{LG} MINUS LOW BUSH.				—							

BUSHING TESTS

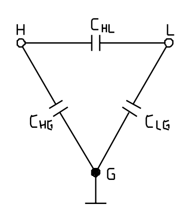
TEST NO.		BUSHING NO.	SER. NO.	φ														
HI kV	11				UST													
	12				UST													
	13				UST													
	14	N			UST													
LO kV	15				UST													
	16				UST													
	17				UST													
	18	N			UST													
	19	OIL TEST			UST													

INSULATION RATING KEY

G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

H = HIGH -VOLTAGE WINDING
L = LOW-VOLTAGE WINDING
G = GROUND
N = NEUTRAL BUSHING
NOTE: SHORT EACH WINDING ON ITSELF.

EQUIVALENT CIRCUIT



REMARKS
Test No. 4, 8, 9, 10 are calculated intercheck values.

AVO International
Valley Forge, PA U.S.A.

Three-Winding Transformers
Capacitance and Power Factor Tests

COMPANY			DATE		
TEST LOCATION			TESTED BY		
XFMR IDENT.			TEST SET NO.		
XFMR SERIAL NO.			AIR TEMPERATURE		
XFMR MFR	TYPE	KVA	OIL TEMPERATURE		
HIGH KV	SGL ☐ Y☐ Δ ☐		% RH		
HIGH KV BUSH			WEATHER		
LOW KV	SGL ☐ Y☐ Δ ☐		TERTIARY KV	SGL ☐ Y☐ Δ ☐	
LOW KV BUSH			TERTIARY BUSH		

TRANSFORMER OVERALL TESTS

TEST NO.	INSULATION TESTED	TEST MODE	TEST CONNECTIONS (WINDINGS) ENG	GND	GAR	UST	TEST KV	CAPACITANCE C (PF)	% POWER FACTOR MEASURED	20°C %PF	CORR FCTR	☐ EQUIV 10 KV ☐ EQUIV 2.5 KV mA	WATTS	INSUL-LATION RATING
1	$C_{HG} + C_{HL}$	GST	H	L	T									
2	C_{HG}	GST	H		L&T									
3	C_{HL}	UST	H	T		L								
4	C_{HL}	—	TEST 1 minus TEST 2											
5	$C_{LG} + C_{LT}$	GST	L	T	H									
6	C_{LG}	GST	L		T&H									
7	C_{LT}	UST	L	H		T								
8	C_{LT}	—	TEST 5 minus TEST 6											
9	$C_{TG} + C_{HT}$	GST	T	H	L									
10	C_{TG}	GST	T		H&L									
11	C_{HT}	UST	T	L		H								
12	C_{HT}	—	TEST 9 minus TEST 10											
13	C_{HG}'	—	C_{HG} minus high bushings											
14	C_{LG}'	—	C_{LG} minus low bushings											
15	C_{TG}'	—	C_{TG} minus tertiary bushings.											

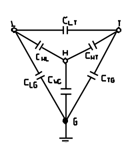
BUSHING TESTS

	TEST NO.	BUSHING NO.	SER. NO.	ϕ													
HI kV	16				UST												
	17				UST												
	18				UST												
	19	N			UST												
LO kV	20				UST												
	21				UST												
	22				UST												
	23	N			UST												
T kV	24				UST												
	25				UST												
	26				UST												
	27	N			UST												
	28	OIL TEST			UST												

INSULATION RATING KEY
G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

H = HIGH -VOLTAGE WINDING
L = LOW-VOLTAGE WINDING
T = TERTIARY WINDING
G = GROUND
N = NEUTRAL BUSHING

EQUIVALENT CIRCUIT



NOTE: SHORT EACH WINDING ON ITSELF.

REMARKS
Test No. 4, 8, 12, 13, 14, 15 are calculated intercheck values

AVO International
Valley Forge, PA U.S.A.

Transformer
Excitation Current Tests

COMPANY	DATE
TEST LOCATION	TESTED BY
XFMR INDENT.	TEST SET NO.
XFMR SERIAL NO.	AIR TEMPERATURE
XFMR MFR TYPE KVA	OIL TEMPERATURE
HIGH KV SGL ☐ Y☐ Δ ☐	%RH
LOW KV SGL ☐ Y☐ Δ ☐	WEATHER
TERTIARY KV SGL ☐ Y☐ Δ ☐	

TEST NO.	Δ LOAD TAP CHANGER POSITION	TEST KV	PHASE A TERMINAL SYMBOL	PHASE A MILLI-AMPERES	PHASE B TERMINAL SYMBOL	PHASE B MILLI-AMPERES	PHASE C TERMINAL SYMBOL	PHASE C MILLI-AMPERES	REMARKS
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

Δ TAP POSITION
R = RAISED
L = LOWERED
N = NEUTRAL
NOTE: Periodic tests should be performed at same test voltage.

REMARKS

AVO International
Valley Forge, PA U.S.A.

Oil Circuit Breakers
Capacitance and Power Factor Tests

COMPANY	DATE
TEST LOCATION	TESTED BY
BREAKER IDENT.	TEST SET NO.
BREAKER MFR TYPE	AIR TEMPERATURE
BREAKER KV AMPS	OIL TEMPERATURE
BREAKER SERIAL NO.	%RH
BUSHING MFR TYPE KV	WEATHER

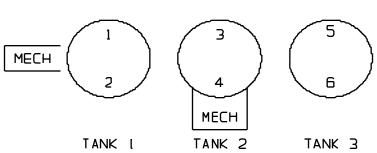
CIRCUIT BREAKER OVERALL TESTS

TEST NO.	CB	INSULATION TESTED	φ	TEST MODE	TEST CONNECTIONS BUSHING ENG	GND	GAR	UST	TEST KV	CAPACITANCE C(PF)	% POWER FACTOR MEASURED	20°C %PF	CORR FCTR	☐ EQUIV 10 KV ☐ EQUIV 2.5 KV mA	WATTS	INSUL-ATION RATING
1		C_{1G}		GST GND	1											
2	O	C_{2G}		GST GND	2											
3	P	C_{3G}		GST GND	3											
4	E	C_{4G}		GST GND	4											
5	N	C_{5G}		GST GND	5											
6		C_{6G}		GST GND	6											
7	C L	$C_{1G} + C_{2G}$		GST GND	1&2											
8	O S	$C_{3G} + C_{4G}$		GST GND	3&4											
9	E D	$C_{5G} + C_{6G}$		GST GND	5&6											

BUSHING & OIL TESTS

TEST NO.	BUSHING NO.	BUSHING SER. NO.	φ													
10	1			UST	1			TAP								
11	2			UST	2			TAP								
12	3			UST	3			TAP								
13	4			UST	4			TAP								
14	5			UST	5			TAP								
15	6			UST	6			TAP								
16		TANK 1 OIL		UST												
17		TANK 2 OIL		UST												
18		TANK 3 OIL		UST												

DIAGRAM



Note: Circuit breaker open: bushing tests (Test No. 1, 2, 3, 4, 5, 6).
Circuit breaker closed: tank tests (Test No. 7, 8, and 9).

INSULATION RATING KEY
G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

INSULATION TESTED
1 TO 6 = BUSHING TERMINALS
G = GROUND

Note: No. in ENG column is bushing energized, all other bushings must be floating.

TANK LOSS INDEX
TANK 1 = W_7 -(W_1 + W_2) =
TANK 2 = W_8 - (W_3 + W_4) =
TANK 3 = W_9 - (W_5 + W_6) =

Note: Subscripts are test no.s. Index may be positive or negative.

AVO International
Valley Forge, PA U.S.A.

SF6 Dead Tank Circuit Breakers
Capacitance and Power Factor Tests

COMPANY		DATE	
TEST LOCATION		TESTED BY	
BREAKER IDENT.		TEST SET NO.	
BREAKER MFR	TYPE	AIR TEMPERATURE	
BREAKER KV	AMPS	%RH	
BREAKER SERIAL NO.		WEATHER	
BUSHING MFR	TYPE KV		

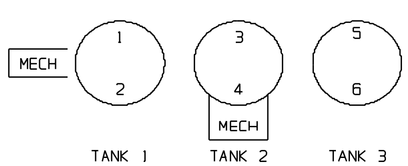
CIRCUIT BREAKER OVERALL TESTS

TEST NO.	CB	INSULATION TESTED	ϕ	TEST MODE	TEST CONNECTIONS BUSHING ENG	GND	GAR	UST	TEST KV	CAPACITANCE C(PF)	% POWER FACTOR MEASURED	20°C %PF	CORR FCTR	☐ EQUIV 10 KV ☐ EQUIV 2.5 KV mA	WATTS	INSUL-ATION RATING
1		C_{1G}		GST GND	1											
2	O	C_{2G}		GST GND	2											
3	P	C_{3G}		GST GND	3											
4	E	C_{4G}		GST GND	4											
5	N	C_{5G}		GST GND	5											
6		C_{6G}		GST GND	6											
7	O	C_{12}		UST	1			2								
8	P E	C_{34}		UST	3			4								
9	N	C_{56}		UST	5			6								
10	C L	$C_{1G} + C_{2G}$		GST GND	1&2											
11	O S	$C_{3G} + C_{4G}$		GST GND	3&4											
12	E D	$C_{5G} + C_{6G}$		GST GND	5&6											

BUSHING TESTS

TEST NO.	BUSHING NO.	SER. NO.	ϕ													
13	1			UST	1			TAP								
14	2			UST	2			TAP								
15	3			UST	3			TAP								
16	4			UST	4			TAP								
17	5			UST	5			TAP								
18	6			UST	6			TAP								

DIAGRAM



INSULATION RATING KEY
G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

INSULATION TESTED
1 TO 6 = BUSHING TERMINALS
G = GROUND

Note: No. in ENG column is bushing energized in Tests 1 through 6, 10, 11, and 12 all other bushings must be floating.

REMARKS

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AVO International
Valley Forge, PA U.S.A.

Vacuum Circuit Breakers
Capacitance and Power Factor Tests

COMPANY	DATE
TEST LOCATION	TESTED BY
BREAKER IDENT.	TEST SET NO.
BREAKER MFR TYPE	AIR TEMPERATURE
BREAKER KV AMPS	%RH
BREAKER SERIAL NO.	WEATHER
BUSHING MFR TYPE KV	

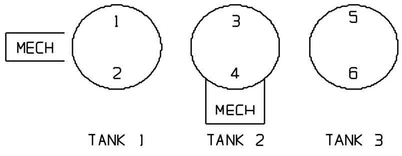
CIRCUIT BREAKER OVERALL TESTS

TEST NO.	CB	INSULATION TESTED	ϕ	TEST MODE	TEST CONNECTIONS BUSHING				TEST KV	CAPACITANCE C(PF)	% POWER FACTOR			☐ EQUIV 10 KV ☐ EQUIV 2.5 KV		INSUL-ATION RATING
					ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1	OPEN	C_{1G}		GST GND	1											
2		C_{2G}		GST GND	2											
3		C_{3G}		GST GND	3											
4		C_{4G}		GST GND	4											
5		C_{5G}		GST GND	5											
6		C_{6G}		GST GND	6											
7	OPEN	C_{12}		UST	1			2								
8		C_{34}		UST	3			4								
9		C_{56}		UST	5			6								

BUSHING TESTS

TEST NO.	BUSHING NO.	BUSHING SER. NO.	ϕ													
10	1			UST	1											
11	2			UST	2											
12	3			UST	3											
13	4			UST	4											
14	5			UST	5											
15	6			UST	6											

DIAGRAM



INSULATION RATING KEY
G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

INSULATION TESTED
1 TO 6 = BUSHING TERMINALS
G = GROUND

Note: No. in ENG column is bushing energized in Tests 1 through 6, all other bushings must be floating

REMARKS

AVO International
Valley Forge, PA U.S.A.

Air-Magnetic Circuit Breakers
Capacitance and Power Factor Tests

COMPANY			DATE
TEST LOCATION			TESTED BY
BREAKER IDENT.			TEST SET NO.
BREAKER MFR	TYPE		AIR TEMPERATURE
BREAKER KV	AMPS		%RH
BREAKER SERIAL NO.			WEATHER
BUSHING MFR	TYPE	KV	

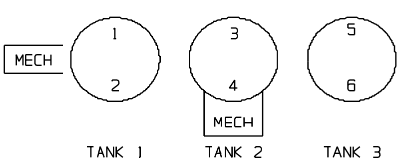
CIRCUIT BREAKER OVERALL TESTS

					TEST CONNECTIONS BUSHING						% POWER FACTOR			☐ EQUIV 10 KV ☐ EQUIV 2.5 KV		
TEST NO.	CB	INSULATION TESTED	ϕ	TEST MODE	ENG	GND	GAR	UST	TEST KV	CAPACITANCE C(PF)	MEASURED	20°C %PF	CORR FCTR	mA	WATTS	INSUL-ATION RATING
1		C_{1G}		GST	1		2									
2	O	C_{2G}		GST	2		1									
3	P	C_{3G}		GST	3		4									
4	E	C_{4G}		GST	4		3									
5	N	C_{5G}		GST	5		6									
6		C_{6G}		GST	6		5									
7	O	C_{12}		UST	1			2								
8	P E	C_{34}		UST	3			4								
9	N	C_{56}		UST	5			6								

BUSHING TESTS

TEST NO.	BUSHING NO.	BUSHING SER. NO.	ϕ													
10	1			UST	1											
11	2			UST	2											
12	3			UST	3											
13	4			UST	4											
14	5			UST	5											
15	6			UST	6											

DIAGRAM



NSULATION RATING KEY
G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

INSULATION TESTED
1 TO 6 = BUSHING TERMINALS
G = GROUND

Note: No. in ENG column is bushing energized.
Note: UST test checks grading capacitors across open contacts.

REMARKS

AVO International
Valley Forge, PA U.S.A.

Rotating Machinery
(Motors and Generators)
Capacitance and Power Factor Tests

COMPANY		DATE
TEST LOCATION		TESTED BY
EQUIPMENT TESTED		TEST SET NO.
SERIAL NO.	STATOR KV	AIR TEMPERATURE
KVA/MVA	HP	STATOR TEMPERATURE
RPM	ROTOR IN ☐ OUT ☐	% RH
MFR	TYPE	WEATHER
STATOR INSUL	AGE	

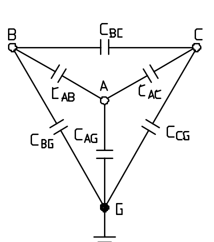
			TEST CONNECTIONS						% POWER FACTOR			☐ EQUIV 10 KV ☐ EQUIV 2.5 KV		
TEST NO.	PHASE TESTED	TEST MODE	ENG	GND	GAR	UST	TEST KV	CAPACITANCE C (PF)	MEASURED	%TIP UP	REAC-TOR	mA	WATTS	INSUL-ATION RATING
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														

INSULATION RATING KEY

G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

A = PHASE A WINDING
B = PHASE B WINDING
C = PHASE C WINDING
G = GROUND
NOTE: Short each phase winding on itself, if possible

EQUIVALENT CIRCUIT



REMARKS

AVO International
Valley Forge, PA U.S.A.

Miscellaneous Equipment
Capacitance and Power Factor Tests

COMPANY	DATE
TEST LOCATION	TESTED BY
EQUIPMENT TESTED	TEST SET NO.
EQUIPMENT IDENT.	AIR TEMPERATURE
	OIL TEMPERATURE
	% RH
	WEATHER

TEST NO.	INSULATION TESTED	TEST MODE	TEST CONNECTIONS				TEST KV	CAPACITANCE C (PF)	% POWER FACTOR			☐ EQUIV 10 KV ☐ EQUIV 2.5 KV		INSUL-ATION RATING
			ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														

INSULATION RATING KEY

G = GOOD
D = DETERIORATED
I = INVESTIGATE
B = BAD (REMOVE OR RECONDITION)

REMARKS

Appendix D
Temperature Correction Tables

Table 1: Temperature Correction Factors for Liquids, Transformers, and Regulators

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

Table 2: Bushing Temperature Correction Factors

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

Table 3: Bushing Temperature Correction Factors

TEST TEMPERATURE		LAPP INSULATOR COMPANY		MICANITE AND INSULATORS COMPANY	
°C	°F	CLASS P O C 15 TO 69 KV	P R C	25 TO 69 KV	ABOVE 69 KV
0	32.0	1.00	0.80	1.55	1.13
1	33.8	1.00			
2	35.6	1.00			
3	37.4	1.00			
4	39.2	1.00			
5	41.0	1.00	0.86	1.40	1.09
6	42.8	1.00			
7	44.6	1.00			
8	46.4	1.00			
9	48.2	1.00			
10	50.0	1.00	0.91	1.25	1.06
11	51.8	1.00			
12	53.6	1.00			
13	55.4	1.00			
14	57.2	1.00			
15	59.0	1.00	0.95	1.12	1.03
16	60.8	1.00			
17	62.6	1.00			
18	64.4	1.00			
19	66.2	1.00			
20	68.0	1.00	1.00	1.00	1.00
21	69.8	1.00			
22	71.6	1.00			
23	73.4	1.00			
24	75.2	1.00			
25	77.0	1.00	1.04	0.89	0.97
26	78.8	1.00			
27	80.6	1.00			
28	82.4	1.00			
29	84.2	1.00			
30	86.0	1.00	1.08	0.80	0.94
31	87.8	1.00			
32	89.6	1.00			
33	91.4	1.00			
34	93.2	1.00			
35	95.0	1.00	1.11	0.72	0.91
36	96.8	1.00			
37	98.6	1.00			
38	100.4	1.00			
39	102.2	1.00			
40	104.0	1.00	1.13	0.64	0.88
41	105.8	1.00			
42	107.6	1.00			
43	109.4	1.00			
44	111.2	1.00			
45	113.0	1.00	1.13	0.56	0.86
46	114.8	1.00			
47	116.6	1.00			
48	118.4	1.00			
49	120.2	1.00			
50	122.0	1.00	1.11	0.50	0.83
52	125.6	1.00			
54	129.2	1.00			
56	132.8	1.00			
58	136.4	1.00			
60	140.0	1.00	1.01		

Table 4: Bushing Temperature Correction Factors

TEST TEMPERATURE		OHIO BRASS				WESTINGHOUSE		
°C	°F	CLASS G & I 46 TO 138 KV	CLASS L 7.5 TO 34.5 KV	CLAS S GK 69 TO 196 KV	CLASS LK 23 TO 69 KV	TYPE D	CONDE N-SER TYPE O	TYPE O
0	32.0	1.54	1.29	0.90	0.85	1.26	1.61	1.11
1	33.8	1.50	1.27	0.90	0.86	1.24	1.56	1.10
2	35.6	1.47	1.26	0.91	0.86	1.23	1.52	1.10
3	37.4	1.43	1.25	0.91	0.86	1.22	1.48	1.09
4	39.2	1.40	1.24	0.91	0.87	1.20	1.44	1.09
5	41.0	1.37	1023	0.91	0.88	1.19	1.40	1.08
6	42.8	1.34	1.21	0.92	0.89	1.18	1.36	1.08
7	44.6	1.32	1.20	0.92	0.89	1.16	1.33	1.07
8	46.4	1.29	1.19	0.92	0.90	1.15	1.30	1.07
9	48.2	1.26	1.17	0.93	0.91	1.14	1.26	1.06
10	50.0	1.24	1.16	0.93	0.92	1.12	1.23	1.05
11	51.8	1.21	1.14	0.94	0.92	1.10	1.21	1.05
12	53.6	1.18	1.12	0.94	0.93	1.09	1.18	1.04
13	55.4	1.16	1.11	0.95	0.94	1.07	1.16	1.04
14	57.2	1.14	1.09	0.95	0.95	1.06	1.13	1.03
15	59.0	1.11	1.07	0.96	0.95	1.05	1.11	1.03
16	60.8	1.09	1.06	0.97	0.96	1.04	1.09	1.02
17	62.6	1.07	1.04	0.97	0.97	1.03	1.06	1.02
18	64.4	1.04	1.03	0.98	0.98	1.02	1.04	1.01
19	66.2	1.02	1.02	0.99	0.99	1.01	1.02	1.01
20	68.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
21	69.8	0.98	0.99	1.01	1.01	0.99	0.98	0.99
22	71.6	0.95	0.97	1.02	1.02	0.97	0.96	0.99
23	73.4	1.93	0.96	1.03	1.03	0.96	0.94	0.98
24	75.2	0.91	0.94	1.04	1.04	0.95	0.92	0.98
25	77.0	0.89	0.93	1.05	1.05	0.94	0.90	0.97
26	78.8	0.88	0.91	1.06	1.06	0.92	0.88	0.96
27	80.6	0.86	0.90	1.08	1.07	0.91	0.86	0.96
28	82.4	0.84	0.88	1.09	1.08	0.90	0.84	0.95
29	84.2	0.82	0.87	1.10	1.09	0.89	0.83	0.94
30	86.0	0.80	0.86	1.11	1.10	0.87	0.81	0.94
31	87.8	0.79	0.84	1.12	1.11	0.86	0.79	0.93
32	89.6	0.77	0.83	1.13	1.12	0.85	0.77	0.93
33	91.4	0.75	0.82	1.14	1.13	0.83	0.75	0.92
34	93.2	0.74	0.80	1.15	1.14	0.82	0.74	0.92
35	95.0	0.72	0.79	1.16	1.15	0.81	0.72	0.91
36	96.8	0.71	0.78	1.17	1.15	0.79	0.70	0.91
37	98.6	0.69	0.76	1.18	1.16	0.78	0.69	0.90
38	100.4	0.68	0.75	1.19	1.17	0.77	0.67	0.89
39	102.2	0.66	0.74	1.20	1.18	0.75	0.66	0.88
40	104.0	0.65	0.72	1.21	1.18	0.74	0.64	0.88
42	107.6			1.22	1.19	0.71	0.62	0.87
44	111.2			1.24	1.20	0.69	0.59	0.86
46	114.8			1.26	1.21	0.65	0.56	0.85
48	118.4			1.27	1.21	0.62	0.53	0.83
50	122.0			1.29	1.22	0.59	0.51	0.82
52	125.6			1.30	1.22	0.58	0.50	0.81
54	129.2			1.31	1.22	0.57	0.48	0.80
50	132.8			1.33	1.22	0.56	0.47	0.79
58	136.4			1.34	1.21	0.55	0.46	0.78
60	140.0			1.35	1.21	0.54	0.45	0.77
62	143.6					0.53	0.44	0.76
66	150.8					0.51	0.42	0.74
70	158.0					0.49	0.40	0.73