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## Instruction Manual

# **DELTA-3000**

### **10-kV Automated Insulation Test Set**

Catalog No. 673001

Read this entire manual before operating.

**Megger**®

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**DELTA-3000**  
**10-kV Automated Insulation Test Set**

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The information presented in this manual is believed to be adequate for the intended use of the product. If the product or its individual instruments are used for purposes other than those specified herein, confirmation of their validity and suitability must be obtained from Megger. Refer to the warranty information below. Specifications are subject to change without notice.

## WARRANTY

Products supplied by Megger 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. Contact your MEGGER representative for instructions and a return authorization (RA) number. Please indicate all pertinent information, including problem symptoms. Also specify the serial number and the catalog number of the unit. This warranty does not include batteries, lamps or other expendable 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.

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# 1

## Introduction

### ***Receiving Instructions***

Check the equipment received against the packing list to ensure that all materials are present. Notify Megger 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 Megger, 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-3000 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 full VGA color display
- 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 in the preferences screen (toggle with space bar). 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.
- USB memory device and internal memory can store over 1000 test results (depending on size) for retrieval and analysis. Stored data can also be transferred to a PC via PowerDB software.
- 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.

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# 2

## Safety

### *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. 673001      120 V  $\pm 10\%$ , 60  $\pm 2$  Hz

For Cat. No. 673001-44   120 V  $\pm 10\%$ , 50  $\pm 2$  Hz

For Cat. No. 673001-45   230 V  $\pm 10\%$ , 60  $\pm 2$  Hz

For Cat. No. 673001-47   230 V  $\pm 10\%$ , 50  $\pm 2$  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.

It is not possible to eliminate all potential hazards from, and in using, 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. Megger 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.**

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# 3

## Specifications

### ***Electrical***

#### **Input Power**

Cat. No. 673001	120 V ac, 60 Hz, 12 A continuous, IEC 1010-1 installation category II
Cat. No. 673001-44	120 V ac, 50 Hz, 12A continuous, IEC 1010-1 installation category II
Cat. No. 673001-45	230 V ac, 60 Hz, 6 A continuous, IEC 1010-1 installation category II
Cat. No. 673001-47	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, continuously adjustable, 200 mA continuous
Maximum continuous current:	310 mA for up to 5 minutes.

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, 1 $\mu$ A maximum resolution on low range The measurement can be corrected to 2.5 kV and 10 kV equivalents.
Capacitance:	1 pF to 1.1 $\mu$ F, 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):	$\pm(1\% \text{ of reading} + 1 \text{ digit})$
Current (rms):	$\pm(1\% \text{ of reading} + 1 \text{ digit})$
Capacitance:	$\pm(0.5\% \text{ of reading} + 2 \text{ pF})$ in UST mode $\pm(0.5\% \text{ of reading} + 6 \text{ pF})$ in GST mode
Dissipation factor:	$\pm(2\% \text{ of reading} + 0.05\% \text{ DF})$
Power factor:	$\pm(2\% \text{ of reading} + 0.05\% \text{ PF})$
Watts loss at 10 kV:	$\pm(2\% \text{ of reading} + 1 \text{ mW})$

## **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  $\mu$ T 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  $\mu$ F 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 ( $\mu$ F) (200 mA at continuous service)	
	60 Hz	50 Hz
2.5 & less	0.11	0.11
4.0	0.11	0.11
5.0	0.11	0.11
6.0	0.088	0.106

Table 1: Maximum Measurable Specimen Capacitance at 50/60 Hz		
Test Volts (kV)	Maximum Capacitance (μF) (200 mA at continuous service)	
	60 Hz	50 Hz
8.0	0.066	0.080
10.0	0.052	0.062
12.0	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: 16 x 22 x 16 in. (406 x 559 x 406 mm) (H x W x D)  
74 lb (33 kg)

High-voltage unit: 16 x 22 x 16 in. (406 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  $\pm 0.5\%$ , 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**

Full VGA color display, 8.4 inches

**Printer**

A battery/line-powered 8.5"x11" (A4) thermal paper USB Pentax printer (or as updated by factory via factory installed driver).

**USB Memory Device**

USB Memory device is supplied with the Delta-3000.

**Terminals**

High-voltage  
Low-voltage (2) marked RED and BLUE  
Interconnection (2)  
Resonating Inductor Return  
Supply power  
External interlock (2)  
Ground  
Bar code wand  
USB (host), qty=2  
Ethernet

## ***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.
- Over-voltage 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***

- USB portable thermal printer (120 V)
- USB portable thermal printer (240 V)
- PowerDB software, 1st machine license, soft key
- High voltage lead: 70 ft (21.4 m), double shielded, interchangeable hook or clip termination
- Low voltage leads: 70 ft (21.4 m), shielded (color-coded red and blue)
- Ground lead: 15 ft (4.6 m)
- 120 volt Power cord: [1] 8 ft (2.5 m)
- 240 volt Power cord: [1] 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)
- Interconnect cables: For connecting the control and high voltage units, two 5 ft (1.5 m)
- Foam transit case: two, foam padded, heavy-duty cases for control and high voltage unit
- Instruction and application manual

---

**Optional Accessories**

▪ PowerDB, 1st machine license, USB dongle	DB1001S
▪ HV TTR capacitor (10 nF, 10 kV)	36610
▪ HV reference capacitor (100 pF, 10 kV)	36610-1
▪ HV reference capacitor (1000 pF, 10 kV)	36610-2
▪ Carry case for capacitors	36610-CC
▪ Capacitor kit (TTR cap, 2 ref caps, carry case)	36610-KIT
▪ Resonating inductor	670600
▪ Calibration standard	670500-1
▪ Oil test cell	670511
▪ Hot collar belts [3]	670505
▪ Bushing tap connectors [2]	670506
▪ Transit cases for cables (heavy-duty, foam-padded)	218744
▪ Transit cases for calibration standard (heavy-duty, foam-padded)	670635
▪ Bar code scanner	36528
▪ High voltage lead, 25 ft (7.6 m)	30012-8
▪ Thermal paper (8.5" x 11") for printer	36809-1
▪ Thermal paper (A4) for printer	36809-2
▪ Replacement/spare battery pack for printer	37077
▪ Accessory kit: mini bushing tap connectors [2], hot collar straps [3], temperature/humidity meter [1], .75" bushing tap connector [1], 1" bushing tap connector [1], "J" probe bushing tap connector [1], 3-ft non-insulating shorting lead [3], 6-ft non-insulating shorting lead [3]	670501

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# 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. | USER<br>INTERFACE<br>PANEL | Via the small rubber keypad, the user selects main menu icons, moves cursor up or down, selects setup for operating mode, etc. The large QWERTY keypad is used for entering alphanumeric information.               |
| 4. | DISPLAY                    | Display guides the operator through setup and test procedures; displays test results and indicates status of setup and operating procedures.  |
| 5. | POWER                      | This white lamp when lit indicates that the main circuit breaker is set to ON and the test set is energized.  |
| 6. | ON/OFF                     | This two-pole, magnetic main circuit breaker controls power to the test set and provides short-circuit and overload protection.   |
| 7. | HIGH VOLTAGE<br>ON         | This red lamp when lit indicates that the high-voltage output circuit is enabled.   |
| 8. | HIGH VOLTAGE<br>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. |



*Figure 1: Top Panel Controls – Control Unit*

- |     |                      |   |
|-----|----------------------|---|
| 9.  | 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. |
| 10. | 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.                         |
| 11. | OPERATION            | Red lamp <input type="checkbox"/> 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.

---

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

12,13,14	NOT USED	
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.

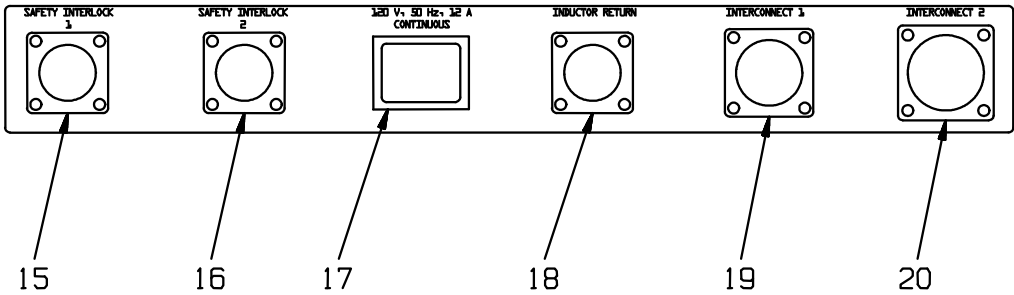


Figure 2: Control Unit Connector Panel (Right)

- 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.

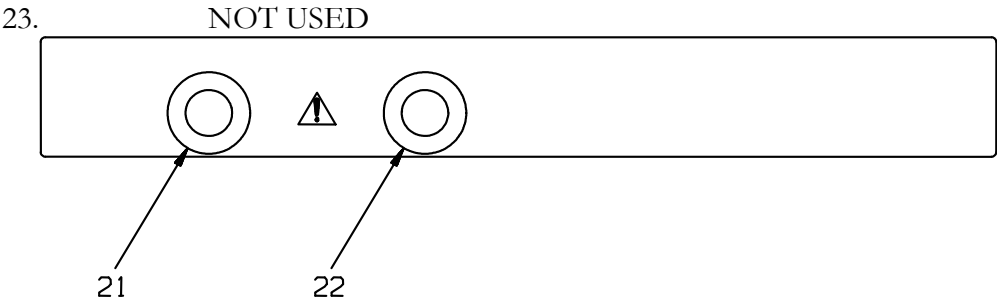


Figure 3: Control Unit Connector Panel (Left)

Figure 4: Not used

## High-Voltage Unit Connector Panel (Fig. 5)

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

- |         |                      |  |
|---------|----------------------|--|
| 24      | NOT USED             |  |
| 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. |

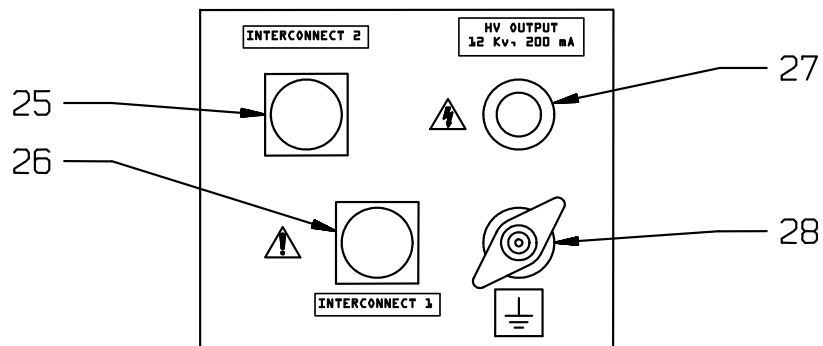


Figure 5: Connector Panel, High-Voltage Unit

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# 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-3000, 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-3000 in the shade whenever possible. Although the DELTA-3000 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-3000 off when not in use.



## CAUTION

Do NOT operate the Delta 3000 without the High Voltage cable connected to the High Voltage output terminal.

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 on the specimen if possible, 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.



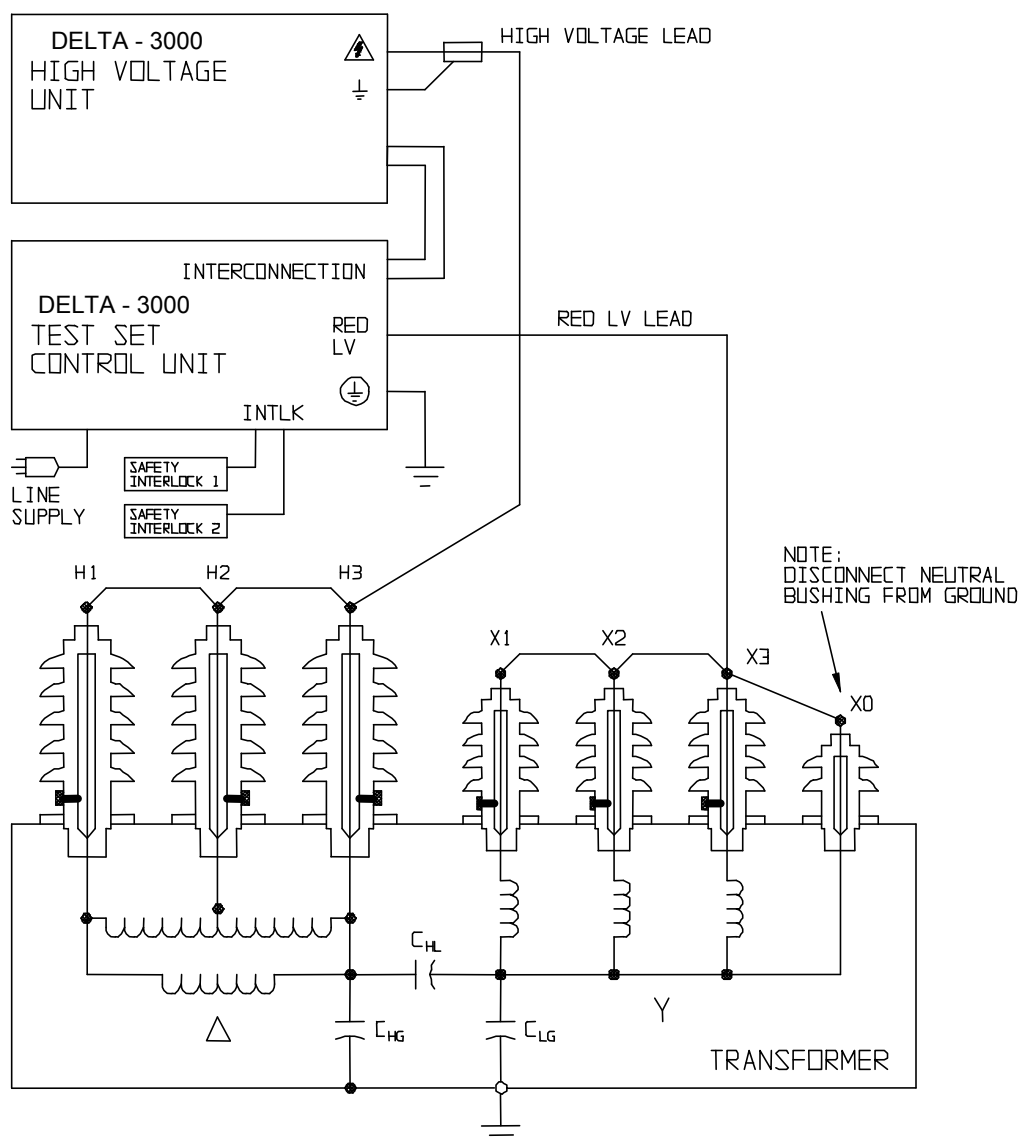
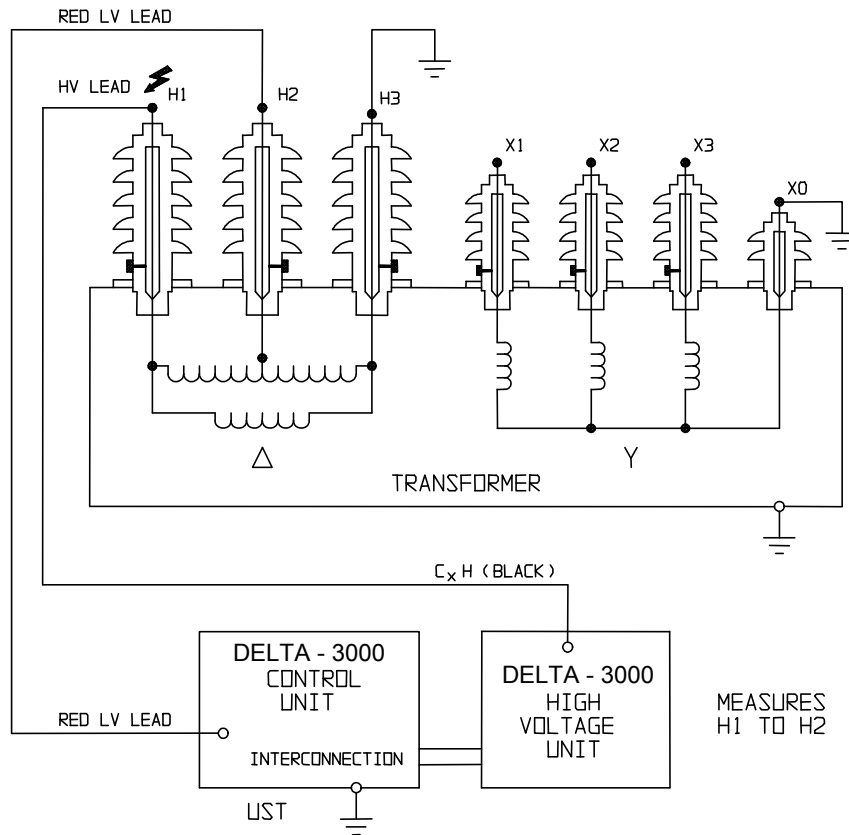


Figure 6: Typical Test Setup for Ac Insulation Testing of a Three-Phase Power Transformer



**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 one of the USB port of the test set if desired.
7. Connect the bar code wand (optional) to its USB receptacle, 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: No other connections should be made to terminal (28).*

---

<i>Note:</i>	<i>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.</i>
--------------	--

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-3000, 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-3000 will be disabled.
  - The voltage supplied to the DELTA-3000 should be 120 V  $\pm 10\%$  (108 to 132 V). For the -47 model, the voltage should be 230 V  $\pm 10\%$  (207 to 253 V). Frequency stability should be higher than  $\pm 2$  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.

## User Interface Panel

**Test Button:**



Initiates and Terminates Testing

**Navigation Keys:**



Use Arrow keys to highlight a desired Selection. Use Enter button (in center) to Activate the Selection.

**Home Key:**



Toggles HOME Action Icons

**Zone Key:**



Allows User to select Active area of the screen.



**Keypad:**

Key board for entering notes and data.

**Power Suspend:**



Prepares the Instrument for Shutdown. A message will indicate when Input Power can be safely removed (not used on some models)

**Help Function:**



Provides on screen Help to assist operator.

**Information Key:**



Provides on screen information to assist operator

**Function Key:**



Displays the options available for any highlighted Selection (when applicable)

*Figure 8. User Interface Panel*

## Communications ports



Figure 9. Communications ports

## HOME Action Icons

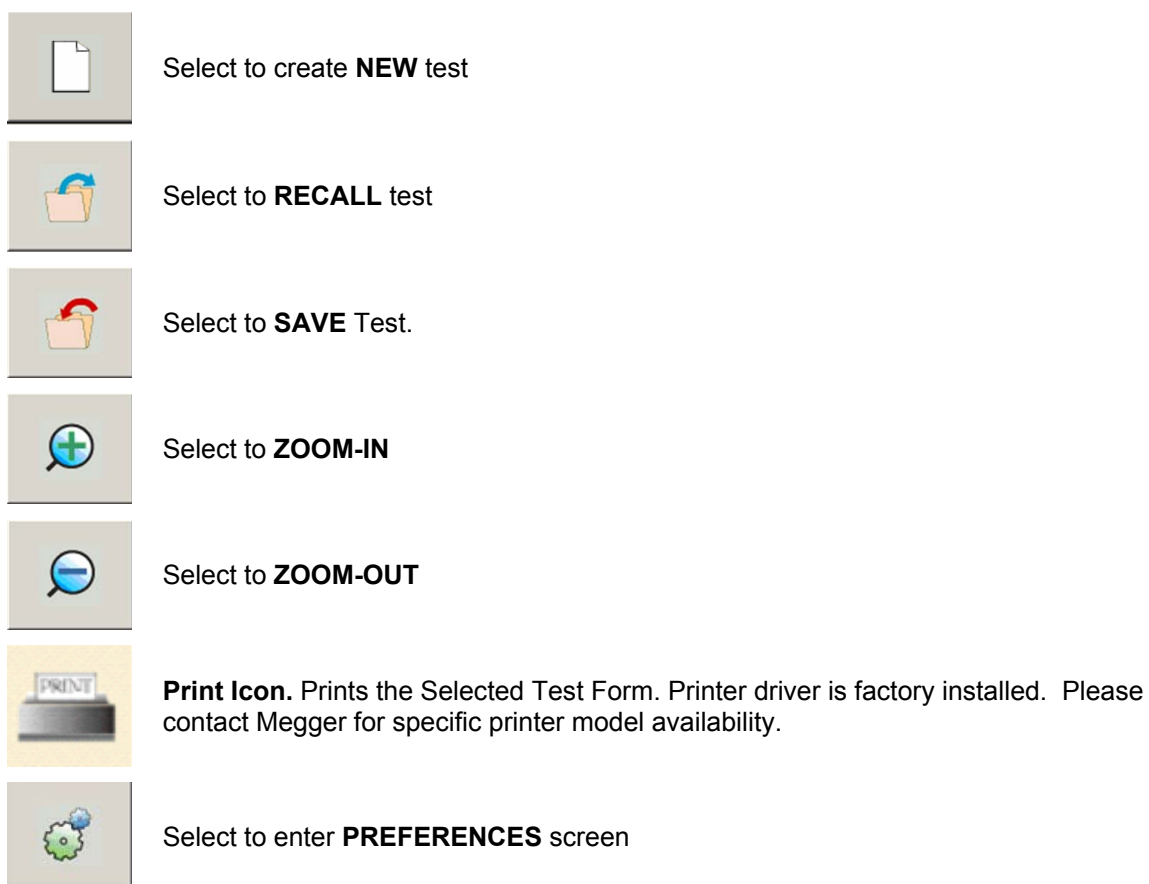


Figure 10. HOME Action Icons

## Utility Icons



**Cancel Icon.** Select to Cancel without Saving.



**Delete Icon.** Deletes the Selected File or Report.



**Print Icon.** Prints the Selected Report. Printer must be standard USB supporting HP PCL protocol.



**USB Out Icon.** Select to Transfer Files or Reports from external USB Memory Stick to the TTR.



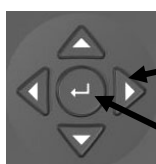
**USB In Icon.** Select to Transfer Files or Reports from the TTR to the external USB Memory Stick.



**Back Icon.** Select to return back to the previous screen.

*Figure 11. Utility Icons*

## Navigating the screen



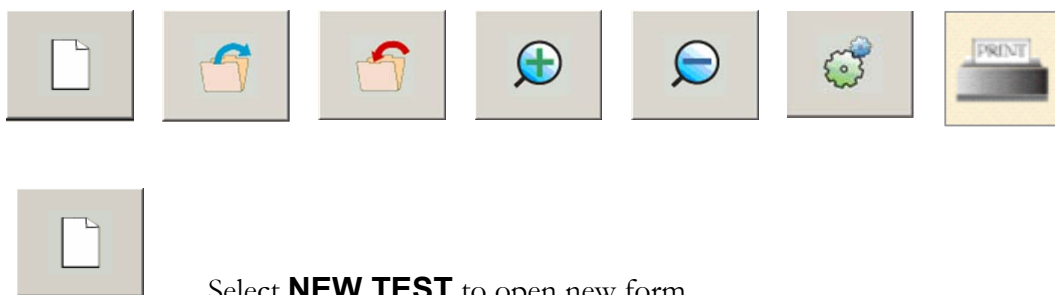
Use **Arrows** keys to **highlight** desired action

Use **ENTER** key (in center) to **select** highlighted action

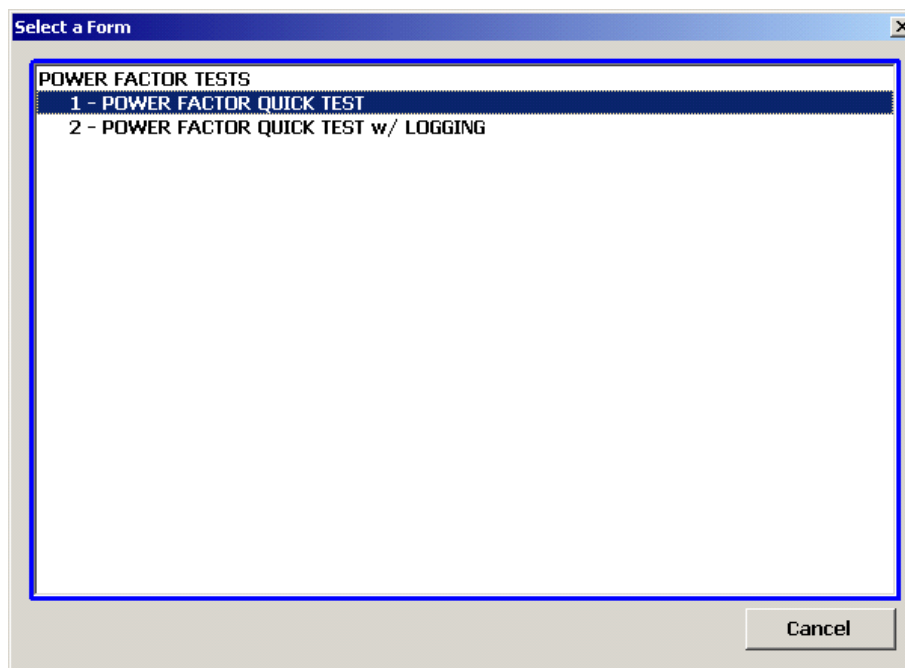
## HOME Screen Action Icons



Select HOME key to display Action Icons

**Action Icons:**

Select **NEW TEST** to open new form



*Figure 12 New Test Form screen*

**Quick test:**

This setup provides a quick path for single phase transformer testing. It requires minimum transformer nameplate information to be entered before testing. The test results displayed do not include either the calculated ratio (per nameplate) or ratio deviation values.

**Quick test with logging:**

This setup requires entering main transformer nameplate information. The “WITH LOGGING” test is used for obtaining full test information of a transformer. This setup may be saved and recalled later for future testing of the same or similar type transformers.

## QUICK test, example

*F1 for HELP* ASSET ID: a1234

DESCRIPTION: Test 1

MODE: 2 UST:MEAS RED, GND BLUE

TEST VOLTAGE	% POWER FACTOR	10 KV EQ.	
		MILLIAMPS	WATTS
3	0	0.373	0

CAPACITANCE: 99.98 pF

Press  TEST to initiate testing

Figure 13 QUICK test Screen

*F1 for HELP* ASSET ID: a1234 TCF 1.00

#	MODE/ DESCRIPTION	TEST VOLT.	CAP.	PWR FACTOR		10 KV EQ.	
				MEAS.	20 C	mA	WATTS
1	2 UST:MEAS RED, GND BLUE	3.11	99.99	0	0	0.376	0
2	2 UST:MEAS RED, GND BLUE	3.1	99.99	0	0	0.374	0
3	2 UST:MEAS RED, GND BLUE	2.25	99.99	0	0	0.373	0
4	2 UST:MEAS RED, GND BLUE	1.59	99.99	0.01	0.01	0.376	0.0003
5	1 UST:MEAS BLUE, GND RED				0		

Press  TEST to initiate testing

Figure 14 QUICK TEST WITH LOGGING screen



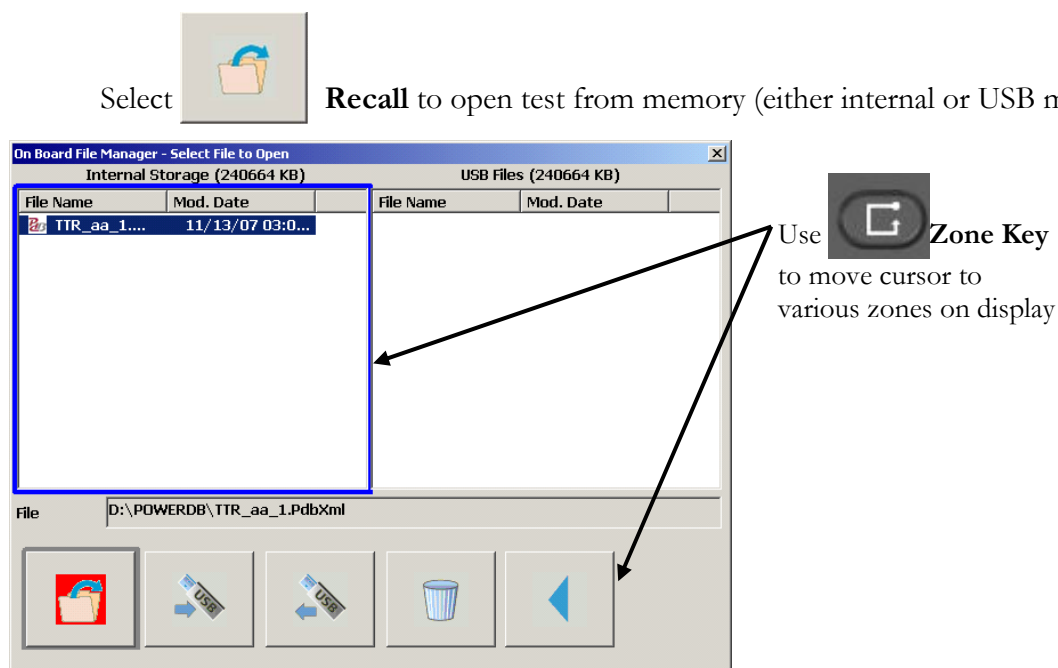


Figure 15. File Manager -Recall Test

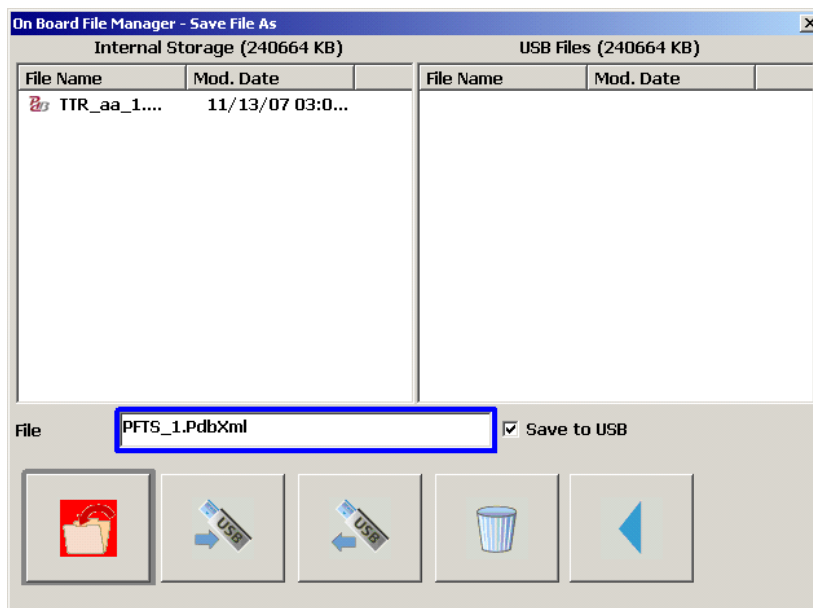
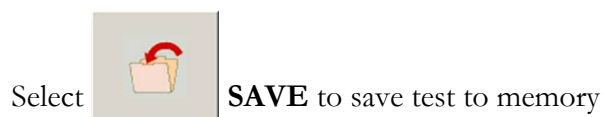


Figure 16 File Manager –SAVE Test screen

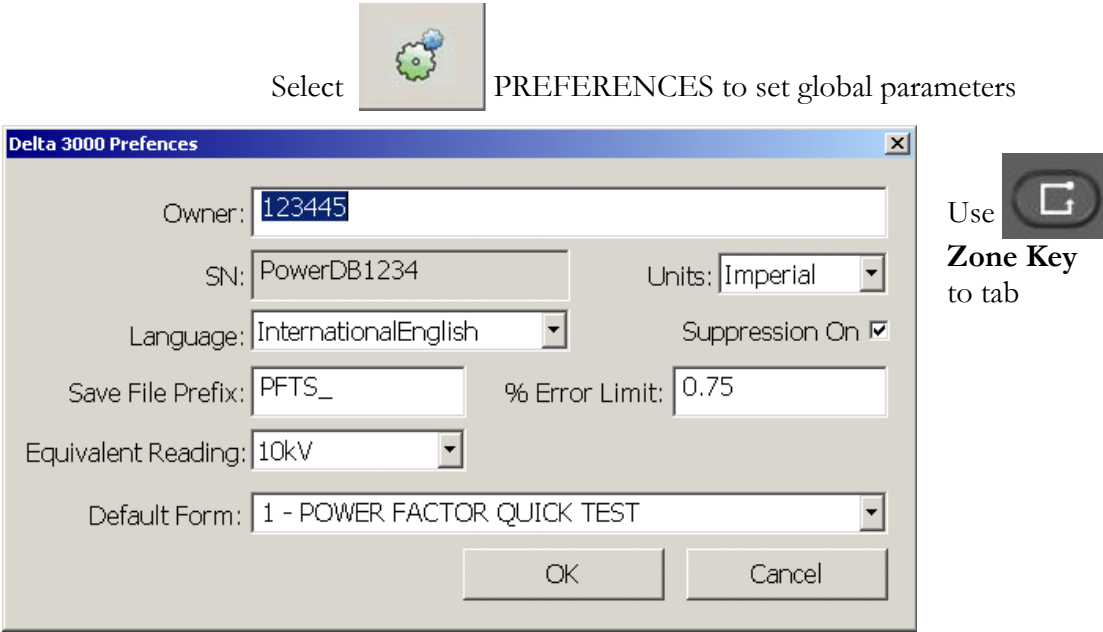
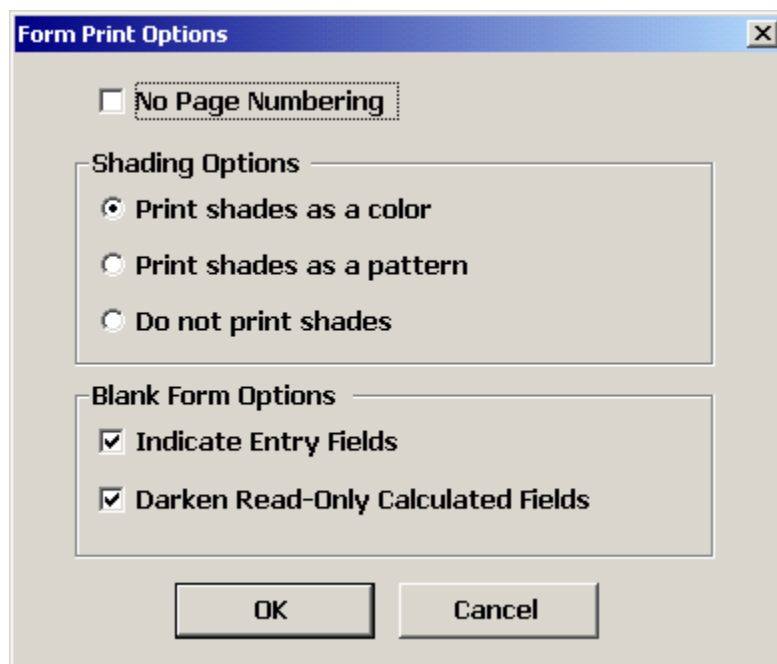


Figure 17 Global Settings – Preferences screen

<b>Owner:</b>	User specified field
<b>SN:</b>	Serial Number of Test Instrument
<b>Units:</b>	Units of Measure setting
<b>Language:</b>	Indicates displayed language
<b>Suppression On:</b>	Toggles Noise suppression circuit (use space bar to select)
<b>Save File Prefix:</b>	All Saved files will begin with this prefix
<b>% Error limit:</b>	Sets error limit
<b>Equivalent reading:</b>	Sets voltage level to display “equivalent reading” level
<b>Default form:</b>	Indicates default form, upon power-up





Use **SPACE** bar to  
select **OPTIONS**

Use **Z**one key to tab

Figure 18      *PRINT*

## ***Ac Insulation Test Procedure***

Proceed only after fully understanding Section 2, Safety, and setting up the test set as described in Section 5. 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 USB memory device into the instrument or the internal memory may be used.
3. Close the main breaker. The white POWER lamp should light. The opening display screen appears, and after diagnostic self-check, the test screen is displayed.
4. Enter temperature
5. Select the desired LOW VOLTAGE LEAD CONFIGURATION by selecting the appropriate UST/GST parameter.
6. Close the external interlock switches.
7. Set the HIGH VOLTAGE CONTROL to ZERO START.

- 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.**



- 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 300 mA is exceeded, the high voltage will shut down.*

- Once the set-up is completed in the Preferences screen, and the desired form is selected, then the TEST may be initiated. This will light the red operation lamp (MEASURE). When the test is completed, test voltage is removed from the specimen and test results are displayed on the 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.

- The operator may now choose to conduct another test.

## WARNING

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



- 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. 7). 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 Xo) 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.

1. Remove all safety grounds from the specimen to be tested.
2. Close the main breaker. The white POWER lamp should light. After a diagnostic self-check, the default test screen is displayed.
3. Not used.
4. Enter the TEMPERATURE, if desired.
5. Select the desired LOW VOLTAGE LEAD CONFIGURATION by selecting the appropriate UST/GST parameter (UST: Measure Red, Ground Blue, when making initial test in accordance with Fig. 7). The lead configuration selected will appear on the test screen (UST: MEAS RED, GND BLUE).
6. Close the external interlock switches.
7. Set the HIGH VOLTAGE CONTROL to ZERO START.

8. 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.**

9. Adjust the HIGH VOLTAGE CONTROL to obtain the desired test voltage. The test voltage and measurement current values are shown on the test screen.
10. Once the Set-up is performed in the Preferences section, and the desired Test form is selected, then Press the TEST button when ready to make a measurement. This will light the red operation lamp (MEASURE) and initiate a measurement test (either single or continuous, depending on which OPERATION MODE was selected). When the test is completed, remove test voltage from the specimen and test results are displayed on the screen. After removing test voltage from the specimen, the red HIGH VOLTAGE ON lamp extinguish and the red operation lamp will be extinguished.

*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.*

11. For additional testing, press the TEST button to start the next test. When completed, the new test results will be shown on the display.
12. Repeat steps 7 through 11 as many times as desired to repeat a measurement.
13. 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.

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# 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.

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

## ***Troubleshooting***

### **General Guidelines**

This section provides general guidelines for basic troubleshooting of the DELTA-3000. The DELTA-3000 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-3000 using Megger’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-3000, 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).



**CAUTION**  
**Do NOT operate the Delta 3000 without the High Voltage cable connected to the High Voltage output terminal.**

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

Megger 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-3000 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.

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# 7

## Spare Parts List

Description	Part Number
Cable, ground (hook lug)	4702-7
Cable, high-voltage	30012-5
Cable, interconnect	27978
Cable, interconnect	27979
Knob (HIGH VOLTAGE CONTROL)	4690-28
Lead, low-voltage (red)	25572-1
Lead, low-voltage (blue)	25572-2
Line cord (for Cat. No. 673001)	17032-4
Line cord (for Cat. No. 673001-47)	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
Safety interlock hand switch 8 ft (2.4 m)	34460-020
Safety interlock hand switch 70 ft (21 m)	34460-021

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# 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



# **Appendix A**

## ***PowerDB Lite***

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## Delta 2000/3000 PowerDB Lite User Manual

### ***Introduction***

PowerDB Lite is a free, but limited capability, version of the PowerDB software tool that is designed specifically to control and/or extract data from Megger instruments. The primary difference between PowerDB Lite and PowerDB is that PowerDB is designed to work with all manufacturers' equipment and has field and office synchronization capabilities. PowerDB Lite will present your test data into a professional looking data form that can be sent to a printer or .pdf file distiller such as PDF995.

PowerDB Lite allows you to use a sub-set of the standard PowerDB forms that are appropriate for specific Megger instruments. PowerDB Lite detects the instrument and enables the appropriate form(s). Data can be entered on-screen or captured directly while using the test instrument. Completed data forms can be saved as files to your computer.

### **Minimum Recommended System**

Operating System:	Windows 2000 or later
RAM:	64 MB RAM minimum, 512+ MB RAM recommended
Processor:	300 MHz Pentium Class processor minimum, 1 GHZ or better recommended

For information about the features of the full version of PowerDB please visit our website at [www.powerdb.com](http://www.powerdb.com). Get acquainted with the following features by scheduling a live demonstration at [info@powerdb.com](mailto:info@powerdb.com).

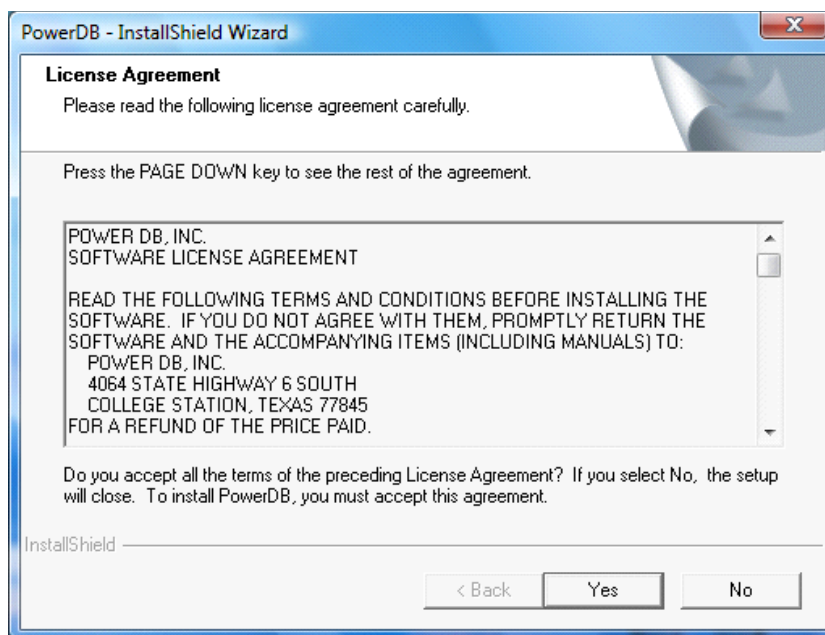
- Synchronize All of Your Test Records Into a Single Corporate Database
- Reduce Test Time
- Improve Data Integrity
- Standardize Test Procedures
- Easily Use Historical Trending for Evaluation of Test Results
- Eliminates the Need to Install and Maintain a Software Application per Instrument
- Eliminates All Hand Written Test Sheets

- Create Your Own Test Forms
- Use or Modify One of Our 200 Built-in Test Forms
- One Step Procedure To Generate Test Reports With Table of Contents and Deficiency Summaries
- Allows All Of Your Field Test Data To Be Integrated With CMMS Systems Such As Maximo or SAP
- Imports >From Many Other Industry Standard Software Applications
- Controls and Imports Data From Many non-Megger Instruments

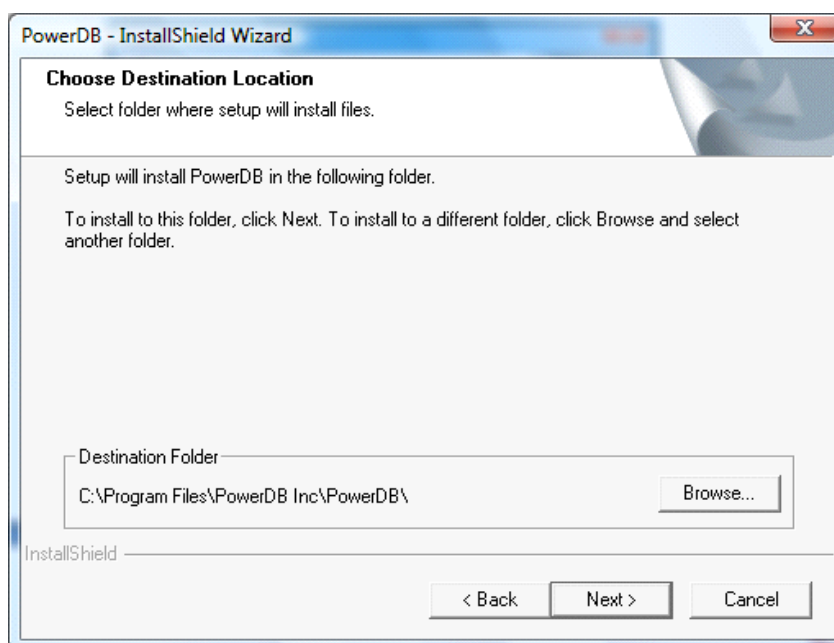
## Software Installation

To install **PowerDB Lite**, load the PowerDB Lite CD into your CD-ROM drive and follow the on-screen instructions.

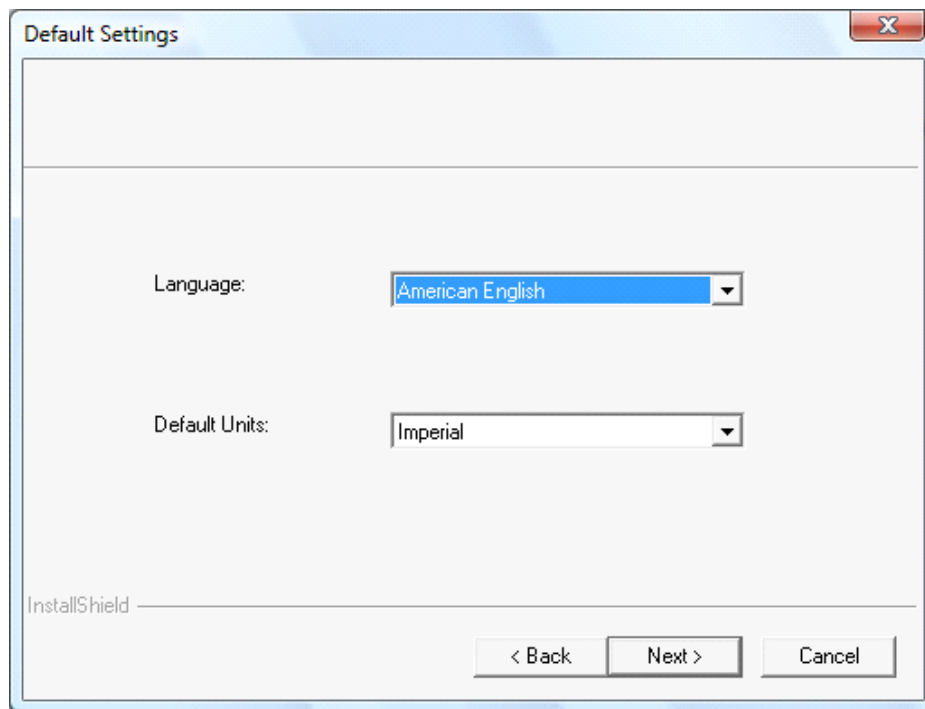
1. Accept the terms of the License agreement.



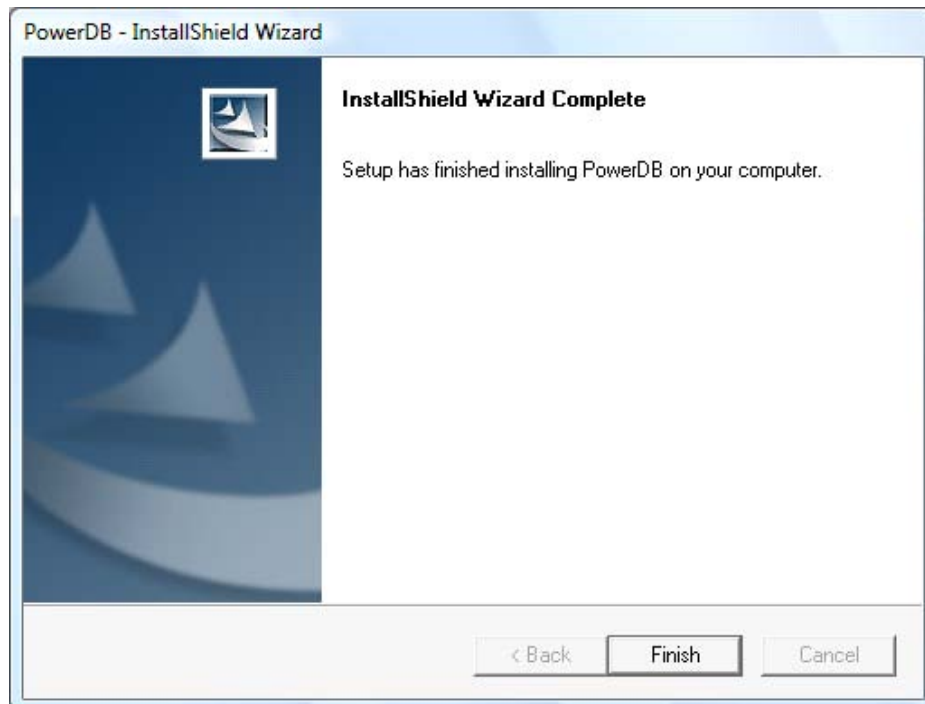
2. Choose the destination location for the PowerDB Lite files.



3. Select Default Settings.

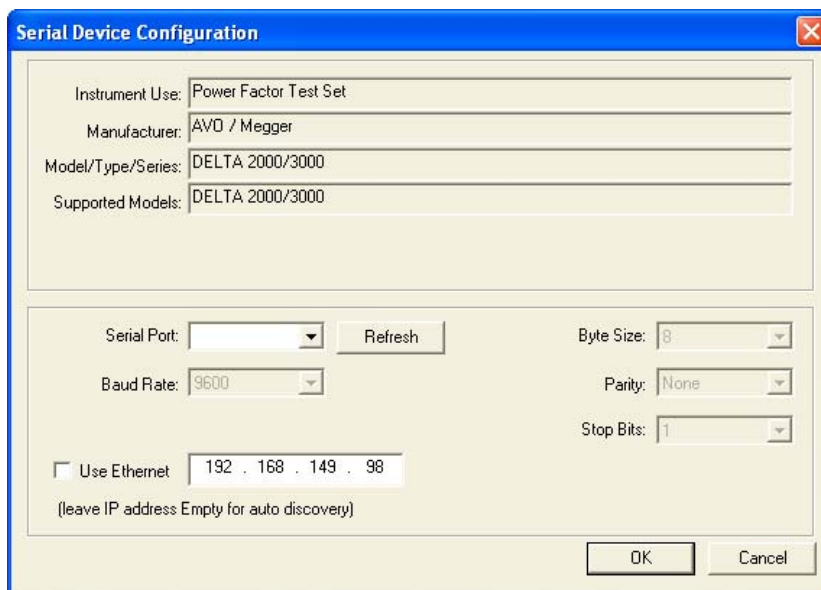
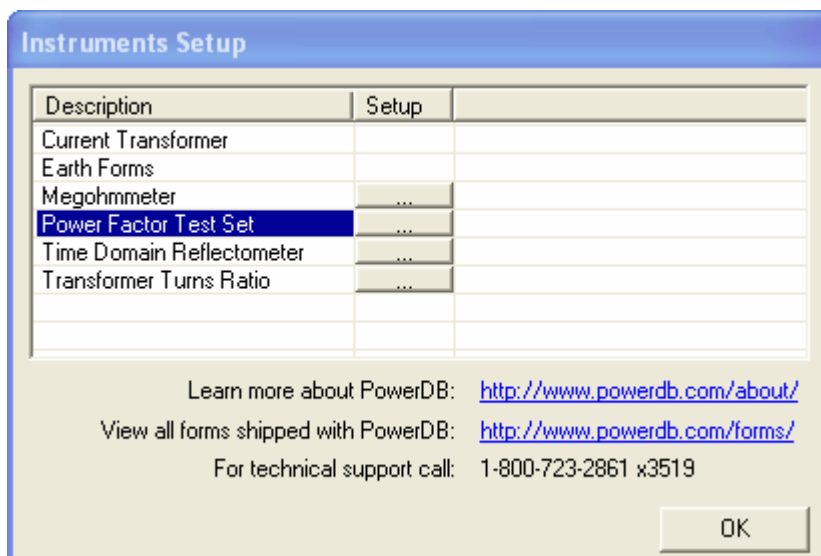


4. InstallShield Wizard will complete the installation of PowerDB Lite. Click Finish to close the installation program.



## Using PowerDB Lite

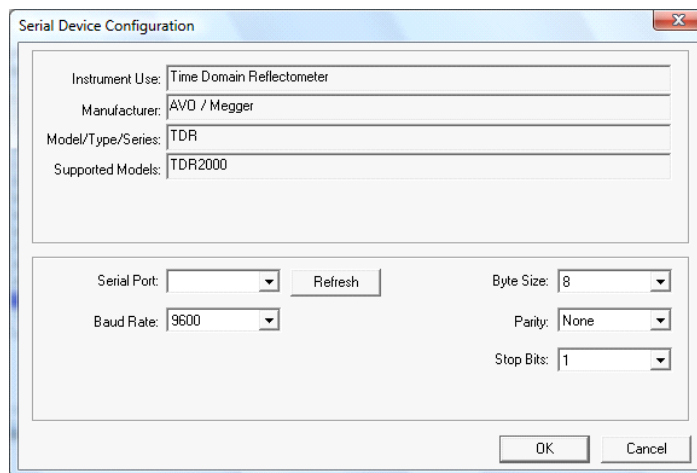
1. Select your Instrument from the Instrument Setup screen.
  - a. You can always view the Instrument Setup screen from the Tools menu or F3.
  - b. Select the appropriate row in the Description column. Then click the “...” button in the Setup column.



- c. The Delta 2000 only uses serial communicate, so never check ‘Use Ethernet’ if you are using a Delta 2000. Select the appropriate communication settings on the Serial Device Configuration screen. Use the Refresh button to find any ports that may have not been connected at the startup of PowerDB Lite. If you are

using a USB serial port and do not know the port assigned to it please perform the following.


- a. Remove the USB serial adapter
- b. Press Refresh
- c. Click on the port drop down and record the options
- d. Plug the adapter back in
- e. Press Refresh
- f. Select the port that was not in the original list



Verify that the baud rate is set to 9600, Parity is set to none, Byte Size is set to 8, and Stop Bits is set to 1.

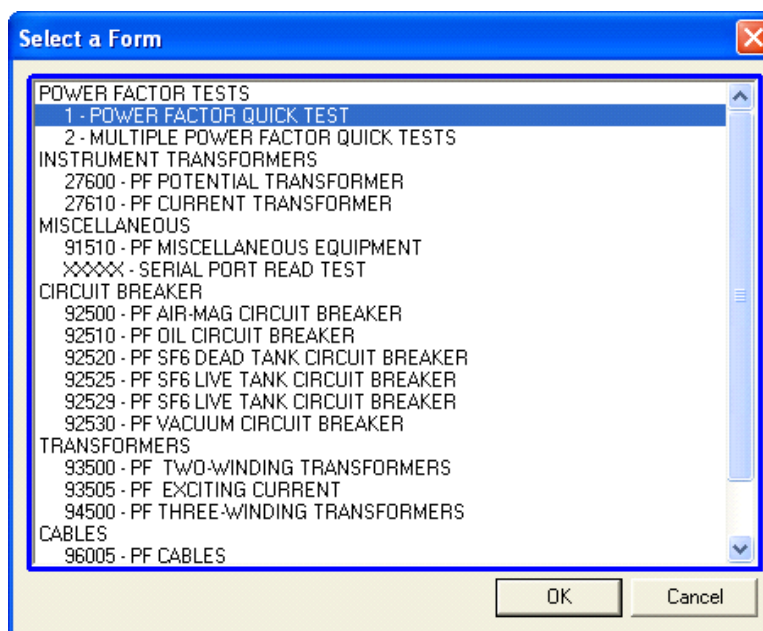
- d. The Delta 3000 only uses Ethernet, so make sure 'Use Ethernet' is always checked if you are using a Delta 3000. Enter the IP address of the Delta 3000 if it is known. Leave the IP address empty if it is unknown, and PowerDB Lite will automatically detect it. To connect to a Delta 3000 use a network cable to connect to the Delta 3000 to the LAN, or use a crossover network cable to connect directly to the PC running PowerDB Lite.
- e. Then Click OK on the Instrument Setup Screen to finish

## 2. Open a New Form


- a. Select the File>New menu item, or type CTRL+N, or press the New toolbar button. 
- b. The forms associated with the detected instrument will be shown in the Select a Form screen.



- c. Choose a form by double-clicking or by navigating with the arrow keys and pressing the OK button.
- d. Press the F1 key to see Form Help for further instruction on test steps.



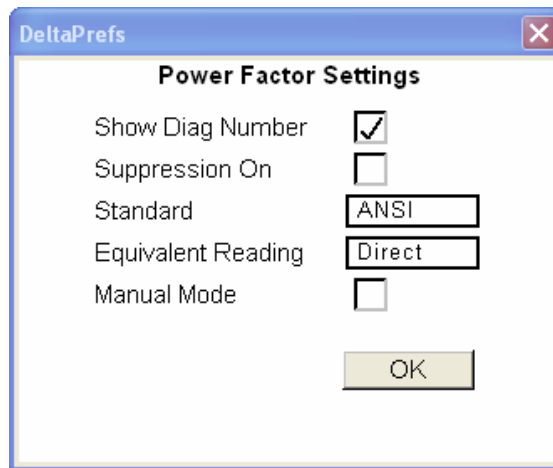
### 3. Enter Test Data

- a. Header and nameplate information can be manually typed into a form.
- b. Click the Initialize Instrument button  to initialize the test set.
- c. Form fields with automation will now be colored cyan.
- d. Right-clicking these fields will start the test.

TEST VOLTAGE	% POWER FACTOR	EQUIV.	
		MILLIAMPS	WATTS


CAPACITANCE: 0.00 pF

- e. To change the settings of the Power Factor test instrument, place the mouse on the form and right-click. Then select “Power Factor Settings”.



- f. This dialog box allows you to change the Power Factor settings. The settings that can be changed are as follows:
1. **Show Diagram Number:** When enabled this will display a numeric field below the winding configuration diagram on the form. The diagram can then be changed by entering a number in this field.
  2. **Suppression On:** Allows you to enable suppression while running a test.
  3. **Standard:** This enables you to choose between the ANSI, Australian, or IEC Standard.
  4. **Equivalent Reading:** Allows you to change the equivalent reading from Direct, 2.5kV, or 10kV.
  5. **Manual Mode:** Checks to see if you are using a Delta 2000 with a firmware version 5 or less.


#### 4. Running an Automated Test

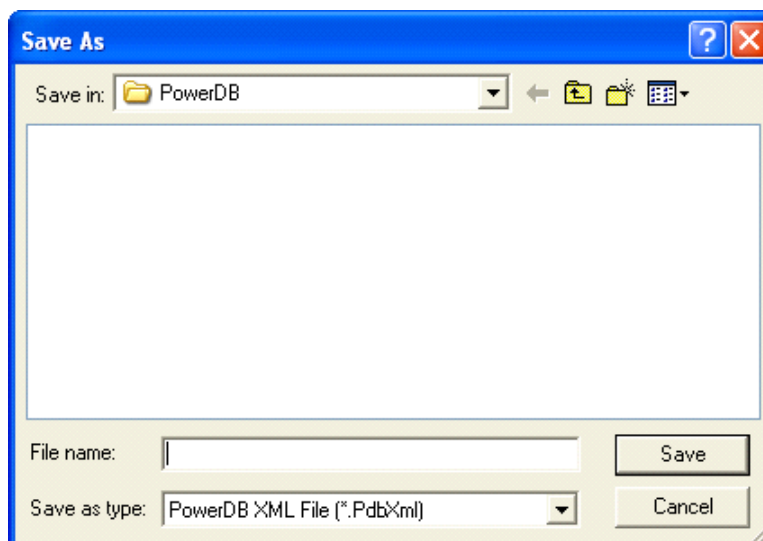
- a. Select the Initialize Instrument button. 
- b. Automated fields should now turn cyan colored.
- c. Right-click on the cyan colored fields.
- d. Follow the on screen instructions specific to the test.

#### 5. Comments and Deficiencies

When imported into the full version of PowerDB, the comments and deficiencies on each form are used to generate summary reports. These summary reports repeat the notations and lists the page number where reported. This allows the user to scroll to a particular page to view a reported anomaly. For more information on features of PowerDB visit us at our website at [www.PowerDB.com](http://www.PowerDB.com).

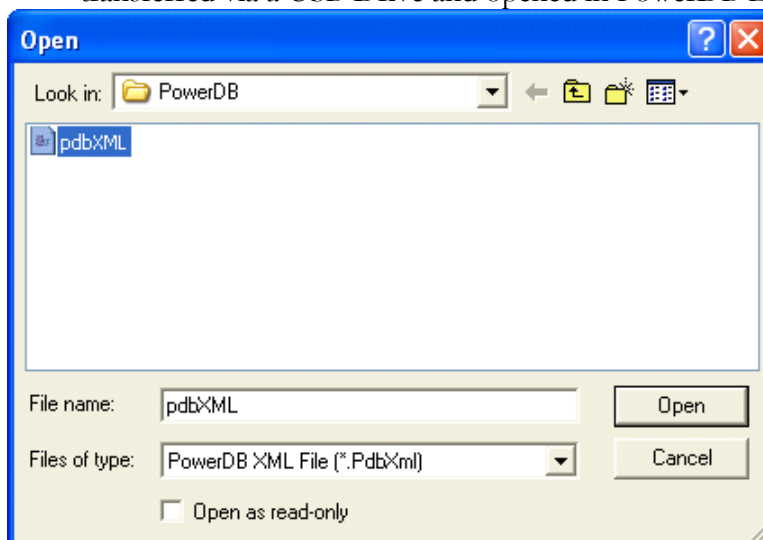
## 6. Save the Data

- a. Select the File>Save menu item, or press CTRL+S, or press the Save toolbar button. 
- b. The Save As screen will allow you to specify a location and file name for your PowerDB Lite XML file.



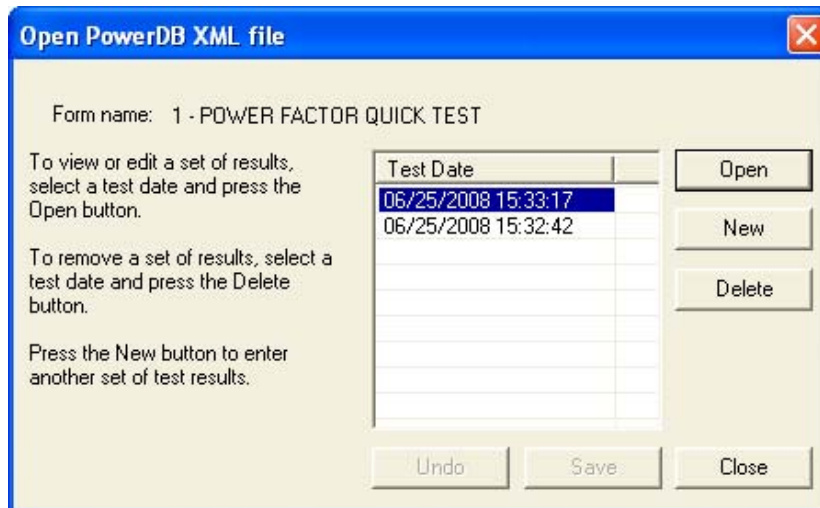
## 7. Opening an Existing File

- a. Select the File> Open menu item.
- b. Browse to the file you would like to open. Note: Delta 3000 files can be transferred via a USB Drive and opened in PowerDB Lite.



- c. Press the Open dialog button.

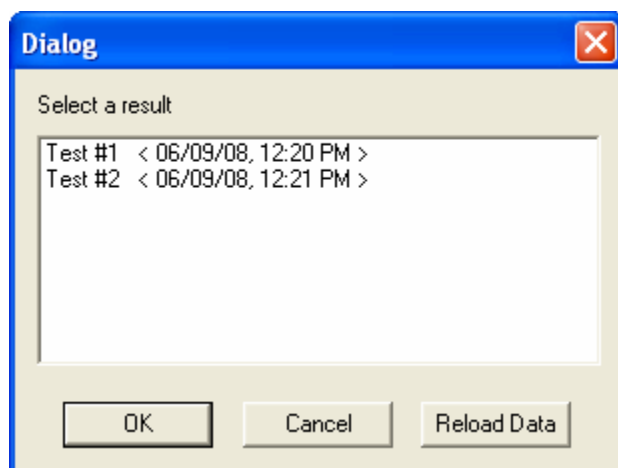
- d. If the file contains multiple test dates, select the date that you would like to open for editing or select New to append a new set of results to the file. To remove a set of results, click on the selected file and press the Delete button.



## 8. Loading Data Files

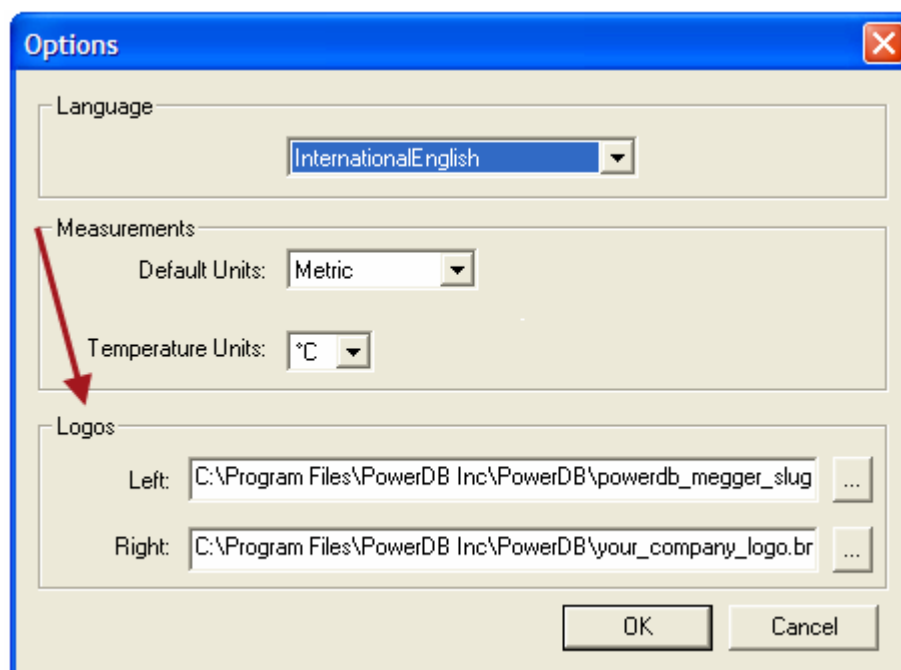
When testing with the Delta 2000 (not Delta 3000) you may import data using a datakey. To load these files use the following steps:

- a. Connect the "Datakey Electronics" Datakey reader to the com port that is specified on the Delta 2000 Instrument Setup Screen.
- b. Remove Datakey from Delta 2000, and insert it into the Datakey reader and turn it to lock it in.
- c. Right-click on a form and select "Import From Datakey". PowerDB Lite will load the data and present the results for the user to select.



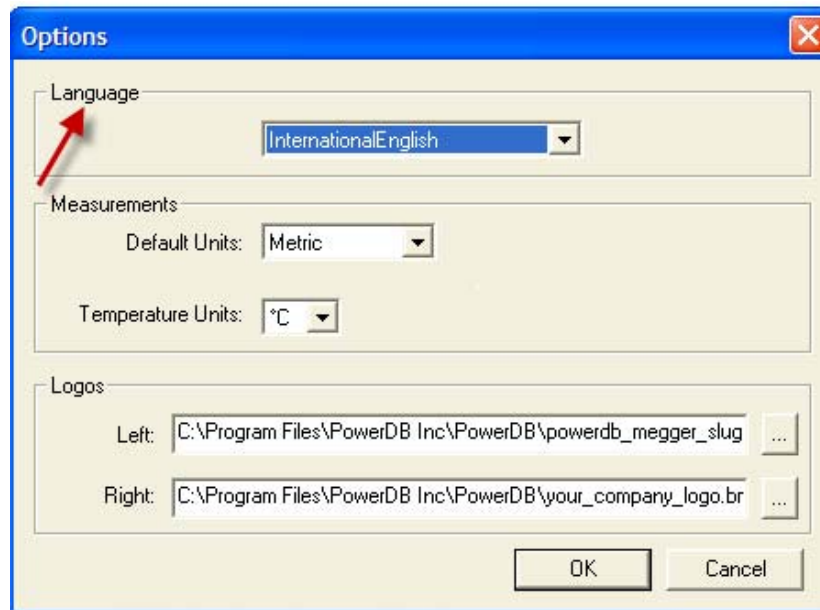
## 9. Setting the Logos

- a. Select the Tools>Options menu item.
- b. The Logos section specifies paths to the left and right logos files to use.
- c. To change the left logo press the “...” button by the left logo path.
- d. The Open screen allows you to browse to a file location, select a .JPG or .BMP file, and press the Open button.
- e. Repeat steps (c) and (d) for the right logo path.
- f. Note that a logo will not be shown if the logo file path is blank or the file does not exist.
- g. Note after specifying the logo files the image will not be shown until the next time a form is opened (File>Open, or the File>New menu items).
- h. Note that the logos will look the best if the resolution of the file is 400 pixels wide by 240 pixels high. DPI is not important.



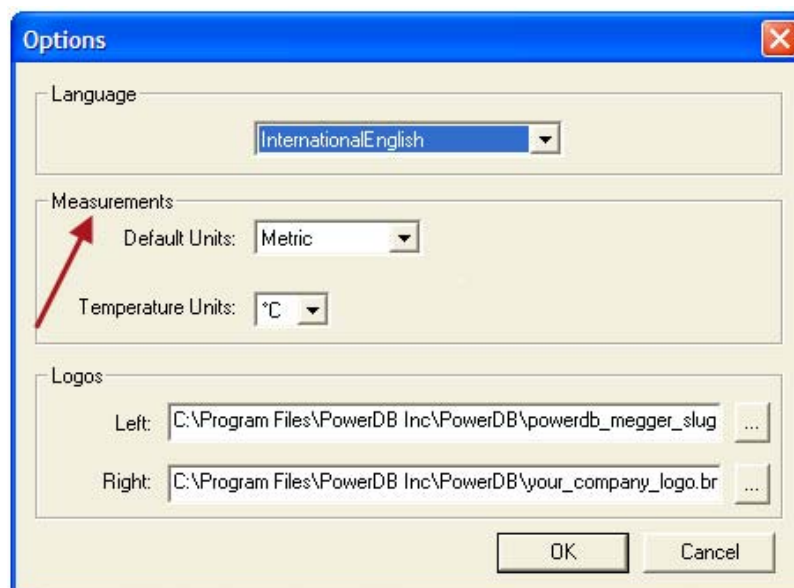
## 10. How to change Languages

- a. Select the Tools>Options menu item.
- b. Select the appropriate language in the dropdown menu.




## 11. How to change units of measurement

- a. Select the Tools> Options menu item.
- b. Select the units in the drop down Default Units under Measurements.



## 12. Additional Notes

- a. Additional forms can be filled out by repeating steps 2 through 6.
- b. Forms can be printed with the File>Print menu item, or type CTRL+P, or press the Print toolbar button. 
- c. A help guide may be found in the Help>PowerDB Lite Help menu item

## ***Frequently Asked Questions (FAQ's)***

### 1. **Can I change the forms?**

No. You must have the full version of PowerDB to change forms.

### 2. **Can I synchronize forms to a database?**

No. You must have the full version of PowerDB for database support and to synchronize multiple field databases to a single master database.

### 3. **Can I import PowerDB Lite files into PowerDB?**

Yes. You can use the File>Import menu item in PowerDB to import files from PowerDB Lite.

## Specific Form Help Instructions

### Operating Instructions for the Power Factor Quick Test Form

1. Enter the Asset ID
2. Press the Enter key.
3. Enter the optional description.
4. Press the Enter key.
5. Use the up and down arrow keys to select the type of test.
6. Press the Enter key.
7. Use the up and down arrows to turn Suppress on or off.
8. Hit the Test key (F2).

PowerBIT Lite (Power Factor Test Set)

File Edit View Tools Help

Press F2 to execute a test; Press F1 for HELP

ASSET ID: [text box]

DESCRIPTION: [text box]

MODE: UST:MEAS RED, GND BLUE

Suppress: Off

TEST VOLTAGE	% POWER FACTOR	EQUIV.	
		MILLIAMPS	WATTS

CAPACITANCE: 0.00 pF



## Operating Instructions for the Multiple Power Factor Quick Test Form

1. Enter the Asset ID.
2. Press the Enter key.
3. Use the up and down arrows to turn Suppress on or off.
4. Press the Enter key.
5. Enter the description under Insulation Tested.
6. Hit the Enter key.
7. Select the type of test under Test Lead Configuration.
8. Hit the Test key (F2).
9. Repeat steps 5 through 8 for subsequent tests.

PowerDB Lite (Power Factor Test Set)

File Edit View Tools Help

Press F2 to execute a test; Press F1 for HELP

ASSET ID:

Suppress: Off

TEST NO	INSULATION TESTED	TEST LEAD CONFIGURATION	TEST KV	CAP (pF)	% POWER FACTOR			EQUIV		INSULATION RATING
					MEAS	20° C	CORR	mA	WATTS	
1		SELECT TEST MODE								

**Megger.**

## **Appendix B**

### **Applications Guide**

**Megger.**

# 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.

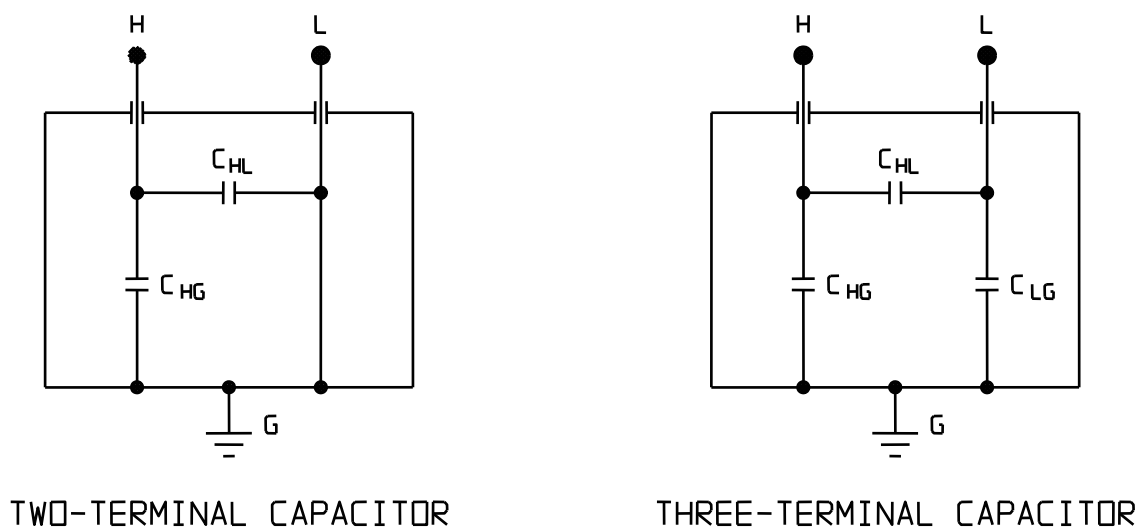
It is possible to have a complex insulation system that has four or more terminals. A direct measurement of any capacitance component in a complex system can be made with this test set since it has the capability for measuring both ungrounded and grounded specimens.

Figure 2 shows a simplified measuring circuit diagram of the DELTA-3000 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 ( $C_S$ ).

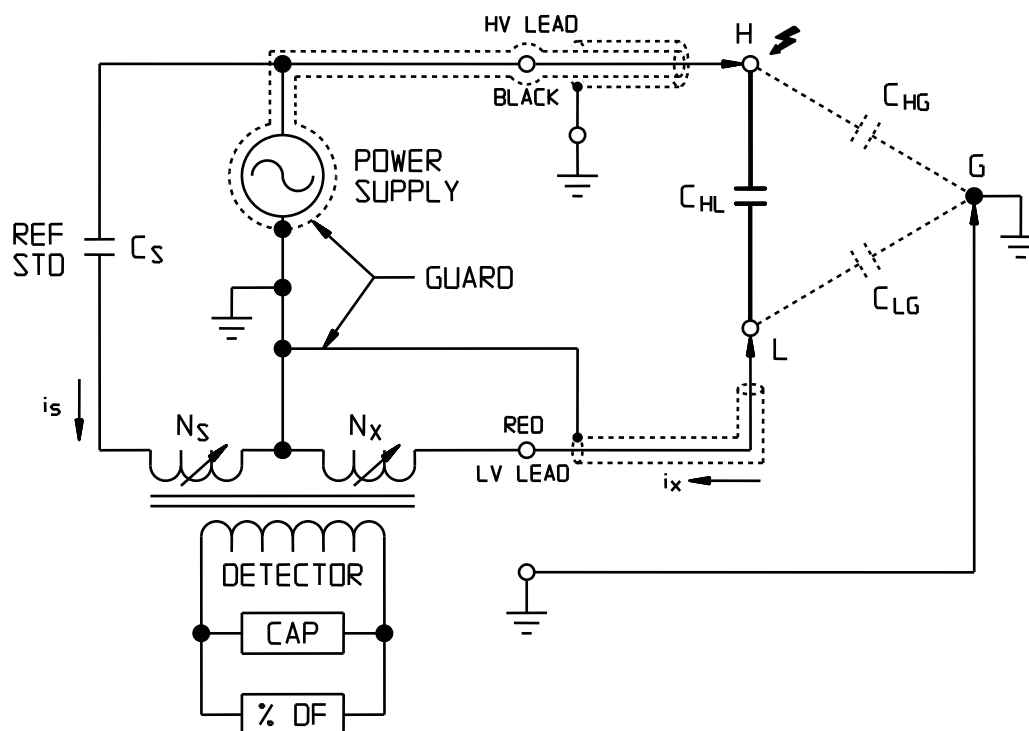
The same voltage is applied to the two capacitors by the power supply. An ampere-turn balance is obtained for the quadrature (capacitance) component of current by automatic adjustment of the  $N_x$  and  $N_s$  turns. The value of the capacitance is then displayed on the LCD.

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 power factor is defined as:

and the dissipation factor is defined as:

The DELTA-3000 test set is calibrated for direct reading in terms of capacitance and dissipation factor ( $\tan \delta$ ).





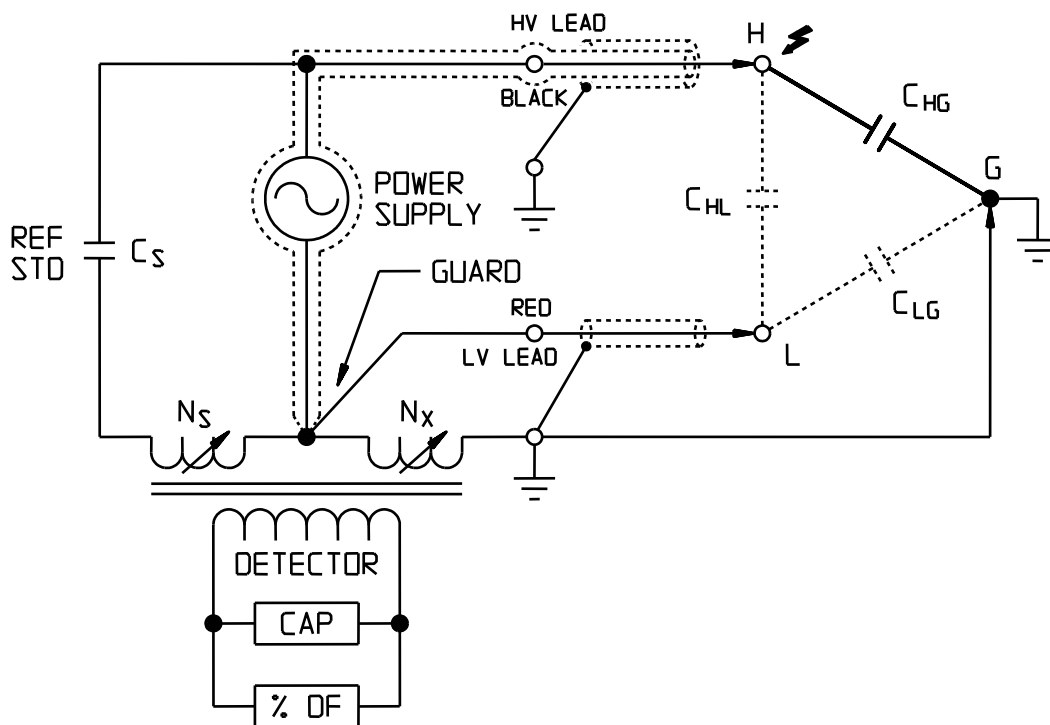


Figure 4: Simplified Measuring Circuit Diagram, GST GUARD RED Test Mode

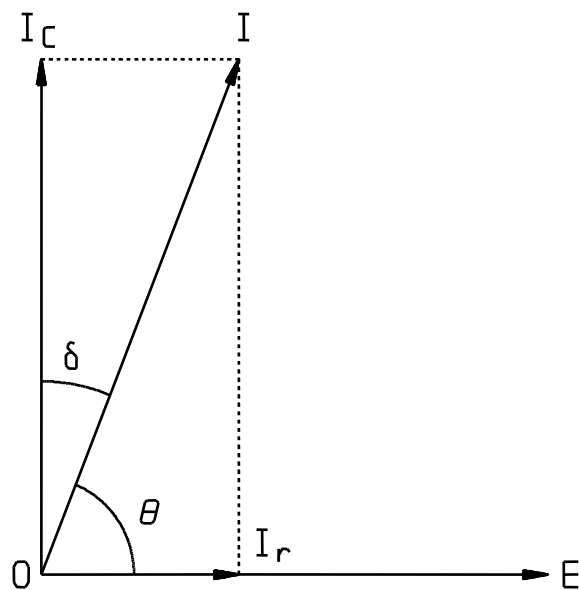
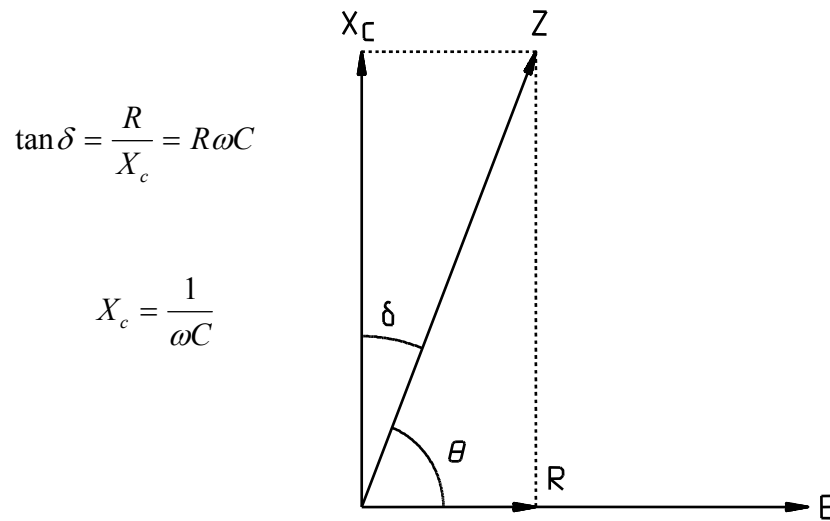


Figure 5: Vector Diagram Insulation System



**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  $\delta$  is very small,  $\sin \delta$  practically equals  $\tan \delta$ . 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 ( $\sin \delta$ ) 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 ( $\tan \delta$ ) 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.

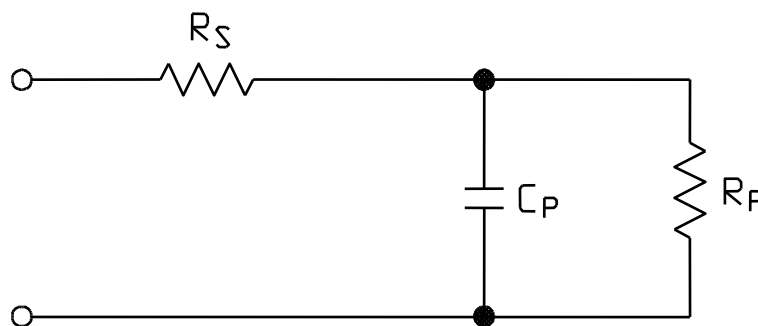


Figure 7: Equivalent Circuit for Capacitor Losses

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

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

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

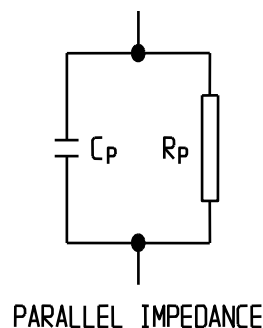
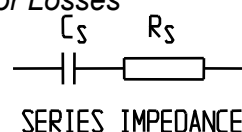


Figure 8: Series - Parallel Equivalent Circuit

## 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-3000 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-3000 test set against the milliampere reading as well as the DELTA-3000 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)

$$\begin{array}{l} C_{pF} = mA \times 1061 \\ mA = C_{pF} \times 94.3 \times 10^{-5} \\ \%DF = \frac{W_{loss} \times 40}{mA} \end{array} \left. \begin{array}{l} \\ \\ \end{array} \right\} \begin{array}{l} \text{Applicable when DF (PF)} \\ \text{is less than 20 percent} \end{array}$$
$$W_{loss} = C_{pF} \times \%DF \times 23.6 \times 10^{-6} \quad \text{No limitation}$$

## Conversion Formulas for test at 10 kV, 60 Hz

(based on equivalent 10 kV values)

$$\begin{array}{l} C_{pF} = mA \times 265 \\ mA = C_{pF} \times 377 \times 10^{-5} \\ \%DF = \frac{W_{loss} \times 10}{mA} \end{array} \left. \begin{array}{l} \\ \\ \end{array} \right\} \begin{array}{l} \text{Applicable when DF (PF)} \\ \text{is less than 20 percent} \end{array}$$
$$W_{loss} = C_{pF} \times \%DF \times 377 \times 10^{-6} \quad \text{No limitation}$$

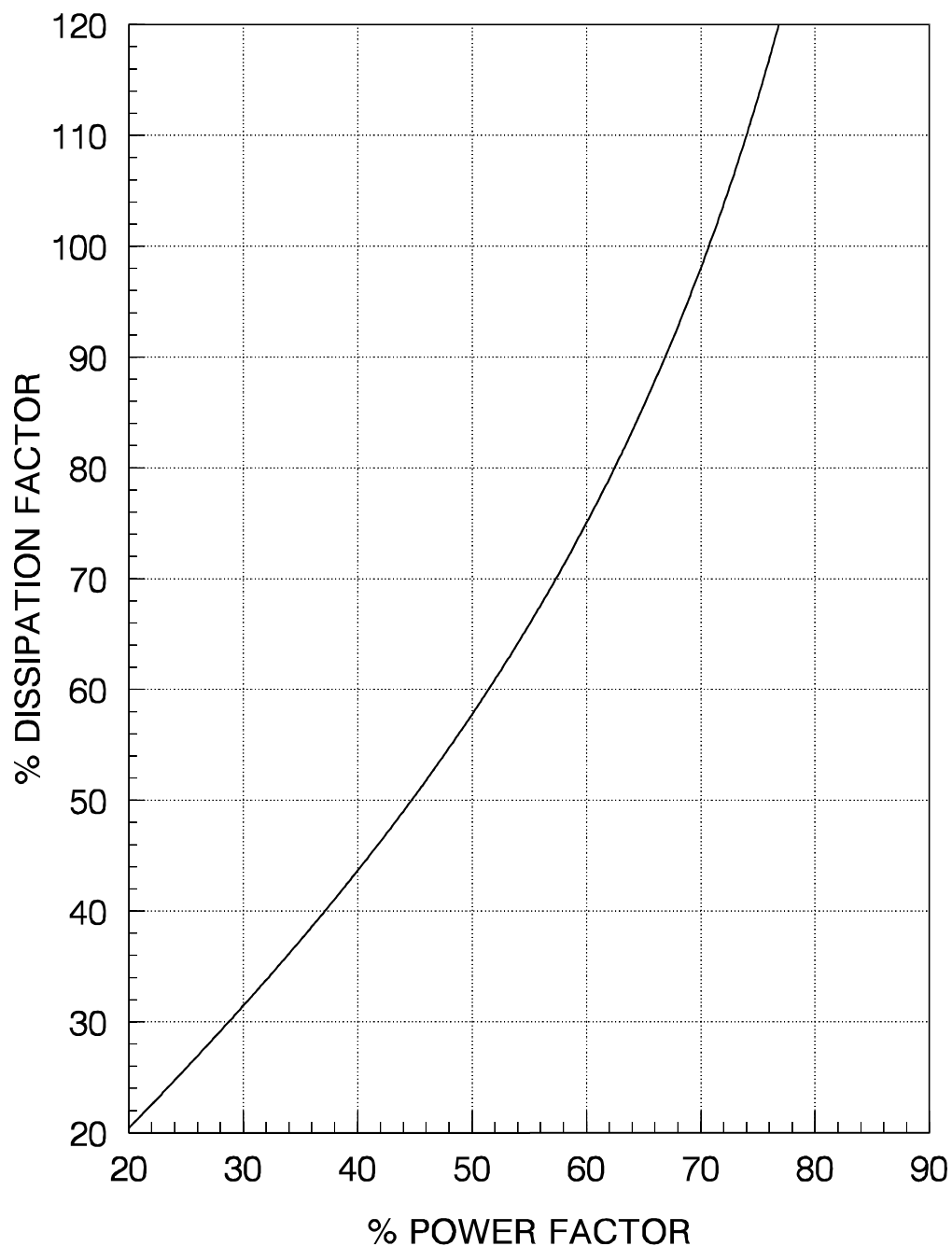


Figure 9: Graph for Converting Power Factor vs. Dissipation Factor Above 20%

## Conversion Formulas for test at 2.5 kV, 50 Hz

(based on equivalent 2.5 kV values)

$$\begin{array}{l} C_{pF} = mA \times 1273 \\ mA = C_{pF} \times 78.6 \times 10^{-5} \\ \%DF = \frac{W_{loss} \times 40}{mA} \end{array} \left. \vphantom{\begin{array}{l} C_{pF} = mA \times 1273 \\ mA = C_{pF} \times 78.6 \times 10^{-5} \\ \%DF = \frac{W_{loss} \times 40}{mA} \end{array}} \right\} \begin{array}{l} \text{Applicable when DF (PF)} \\ \text{is less than 20 percent} \end{array}$$
$$W_{loss} = C_{pF} \times \%DF \times 19.6 \times 10^{-6} \quad \text{No limitation}$$

## Conversion Formulas for test at 10 kV, 50 Hz

(based on equivalent 10 kV values)

$$\begin{array}{l} C_{pF} = mA \times 318 \\ mA = C_{pF} \times 314 \times 10^{-5} \\ \%DF = \frac{W_{loss} \times 10}{mA} \end{array} \left. \vphantom{\begin{array}{l} C_{pF} = mA \times 318 \\ mA = C_{pF} \times 314 \times 10^{-5} \\ \%DF = \frac{W_{loss} \times 10}{mA} \end{array}} \right\} \begin{array}{l} \text{Applicable when DF (PF)} \\ \text{is less than 20 percent} \end{array}$$
$$W_{loss} = C_{pF} \times \%DF \times 314 \times 10^{-6} \quad \text{No limitation}$$

## General Conversion Formulas

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

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

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

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

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

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

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

Applicable when DF (PF) is less than 20 percent

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

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

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
$\omega$	=	$2\pi f$
$W_{loss}$	=	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 MEGGER 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-3000 Test Set (Cat. No. 673001)		TEST MODE POSITION (Cat. No. 670025, 670065, 670070)
UST		
GROUPS	MEASURES	
—	RED & BLUE	1
BLUE	RED	3
RED	BLUE	2
GST GROUND		
	GROUPS RED & BLUE	4
GST		
GUARDS RED & BLUE	GROUPS —	5
RED	BLUE	7
BLUE	RED	6



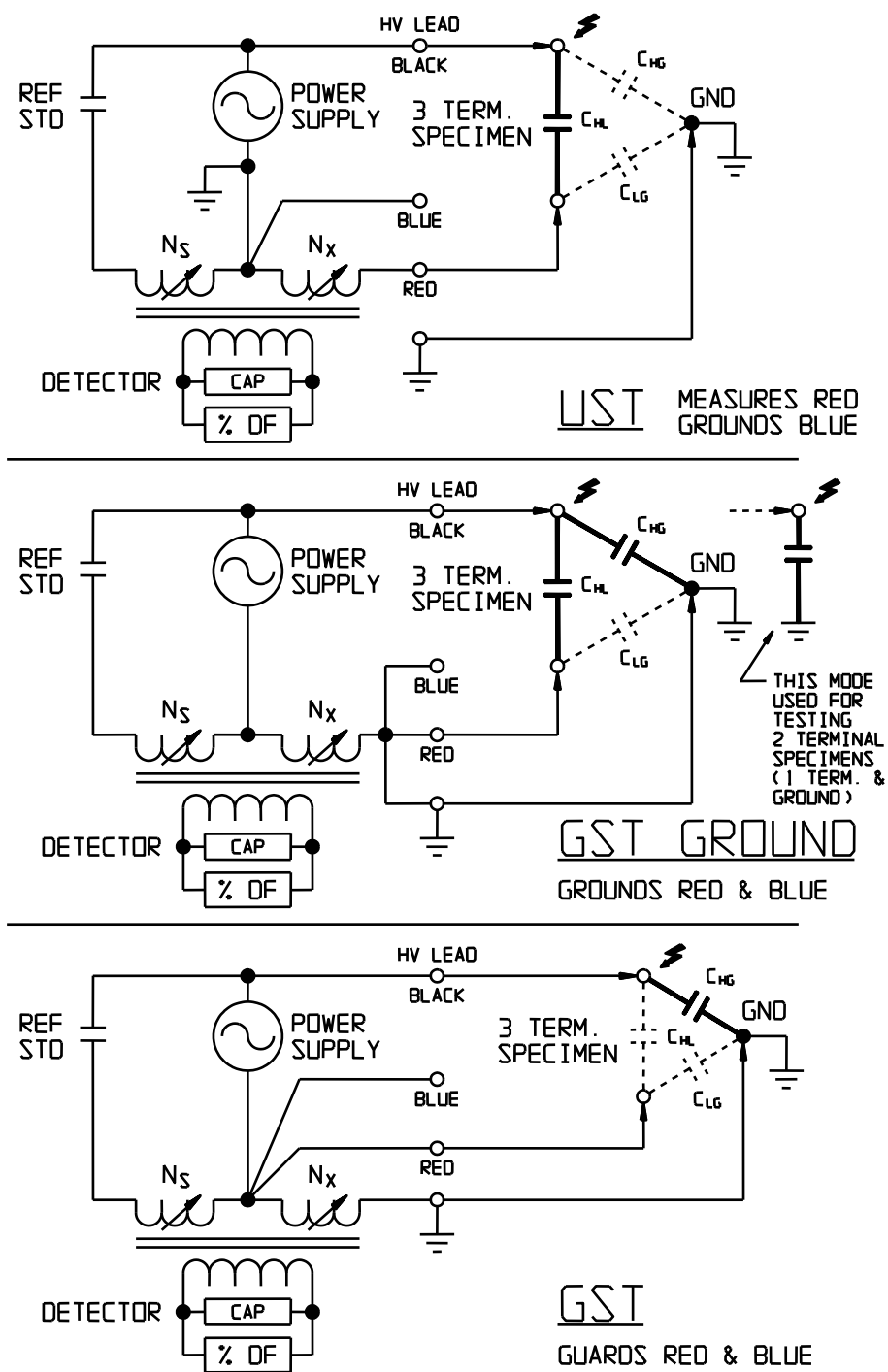


Figure 10: Connection for Three-Phase Specimens

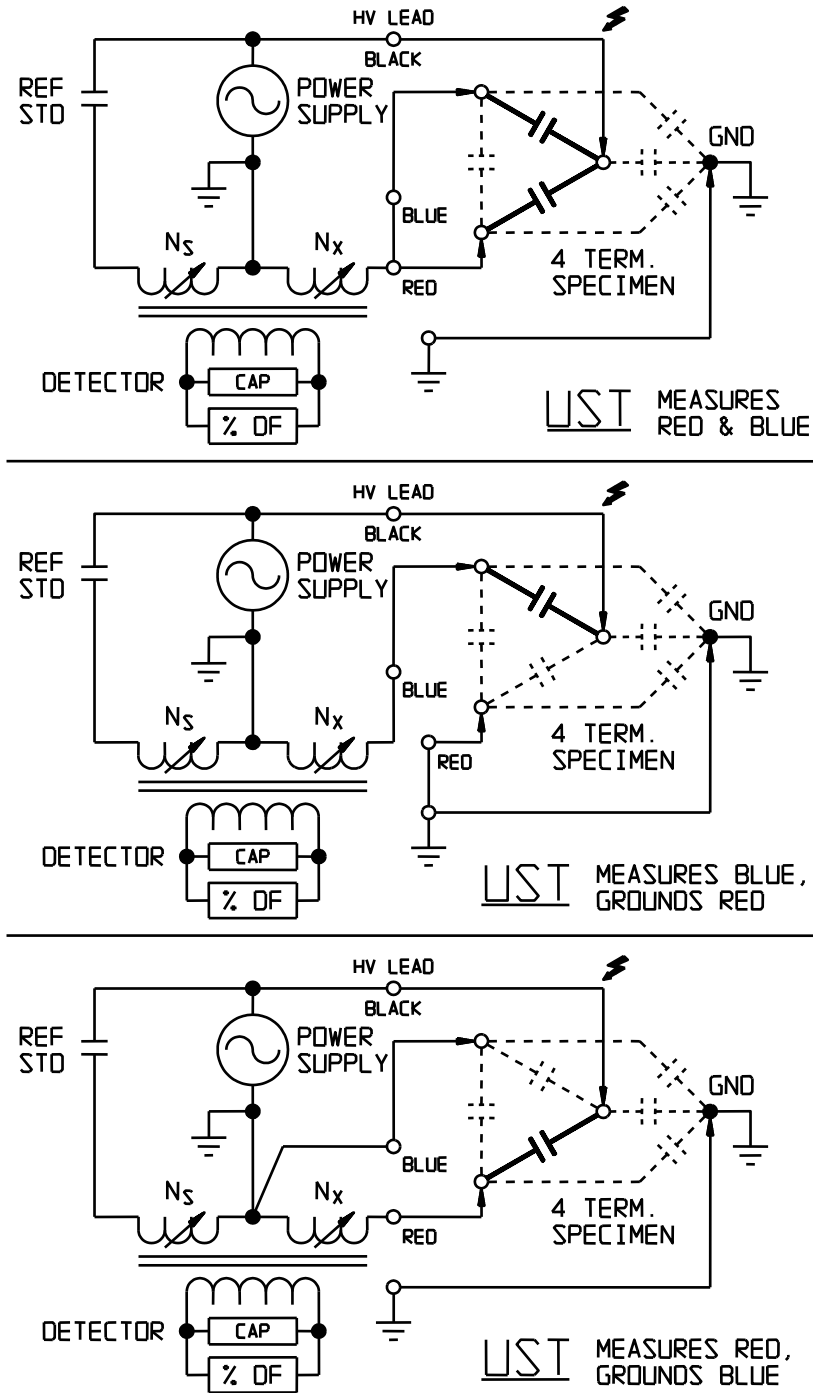


Figure 11: Connection for Four-Terminal Specimens, UST Test Modes

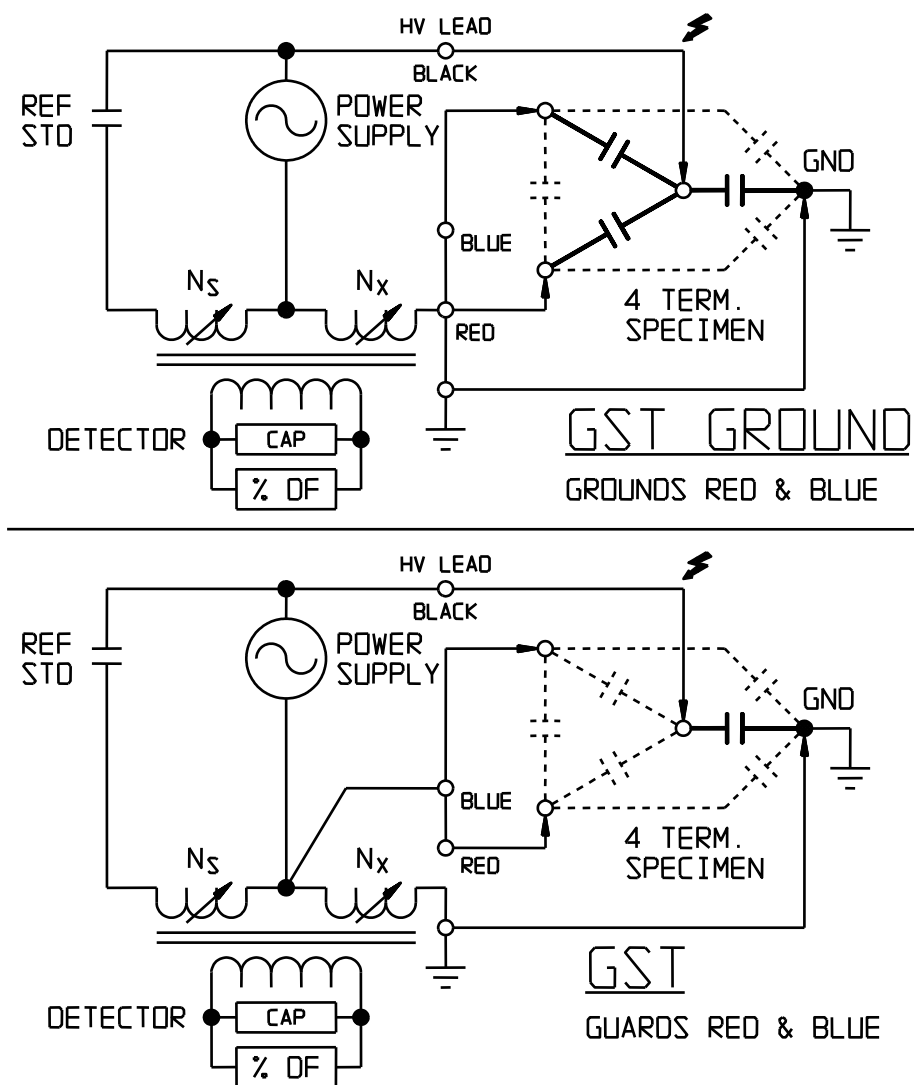


Figure 12: Connection for Four-Terminal Specimens, GST Test Modes

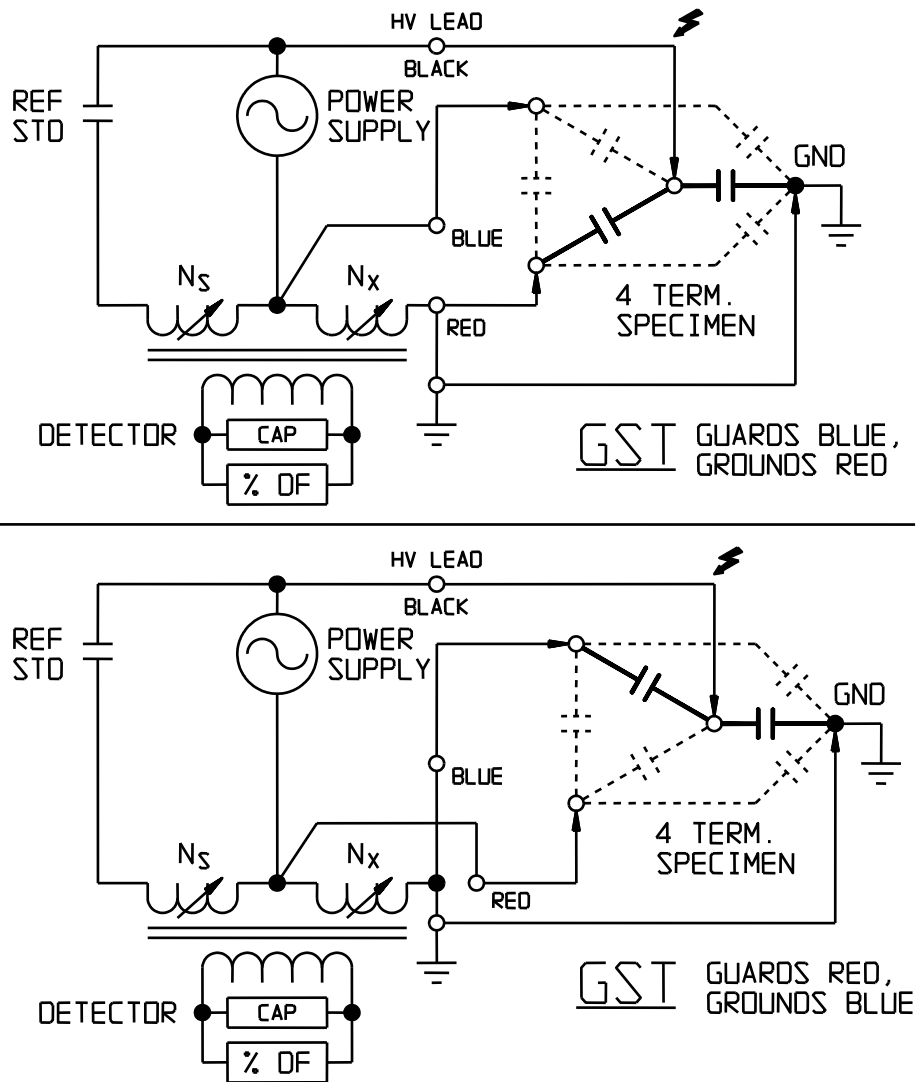


Figure 13: Connection for Four-Terminal Specimen, GST Guard Modes

# 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)	0.25 to 1.0
15 years old, high-voltage	0.75 to 1.5
Low-voltage, distribution type	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	3.0 to 10.0
Compound-filled, up to 15 kV	5.0 to 10.0
Compound-filled, 15 to 46 kV	2.0 to 5.0
Oil-filled, below 110 kV	1.5 to 4.0
Oil-filled, above 110 kV and condenser type	0.3 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.

# 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.

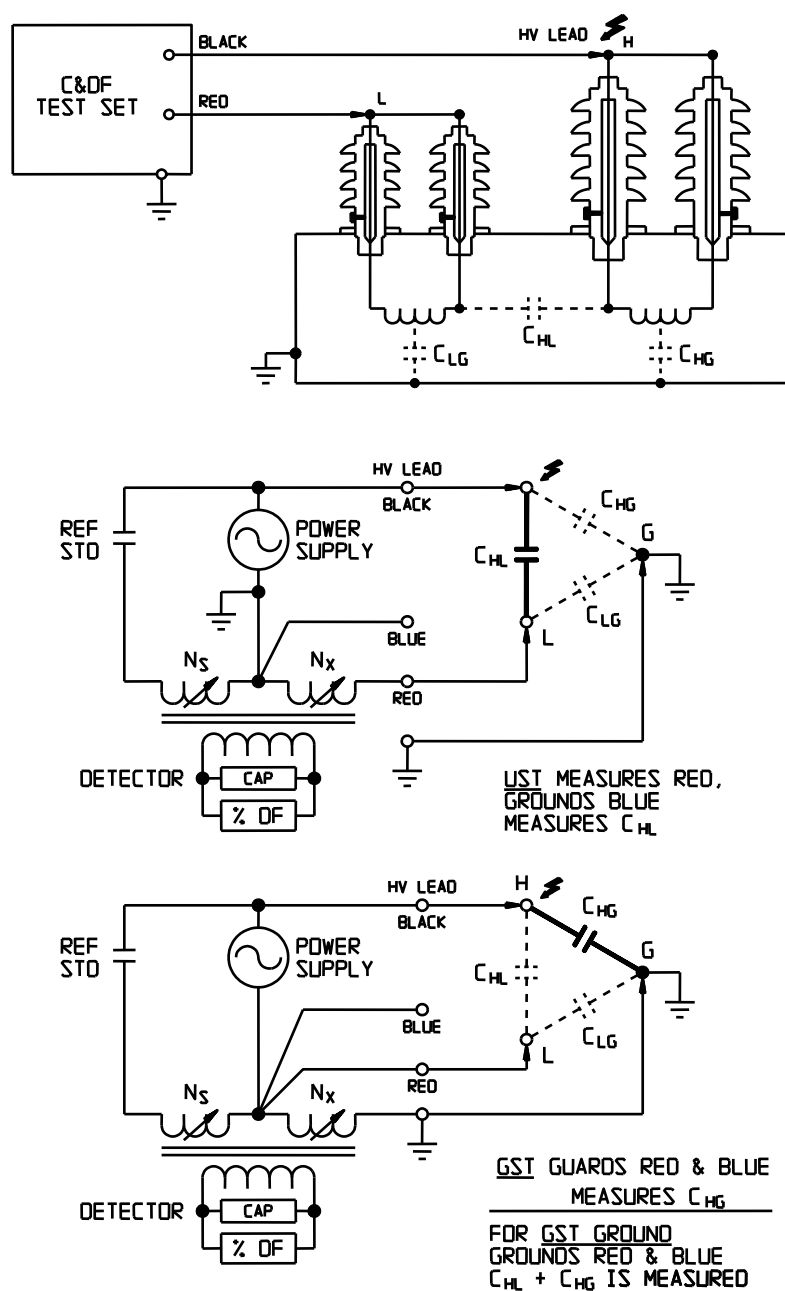

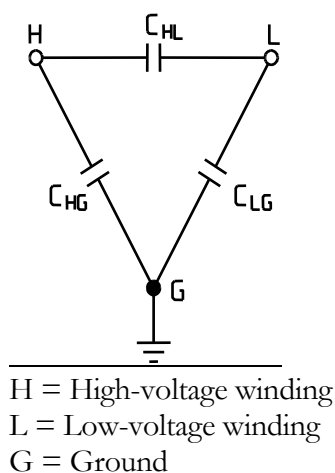


Figure 14: Two-Winding Transformer Tests

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



Note: Short each winding on itself.

### Measurement Interchecks (Calculated)

#### Capacitance

$$C_4 = C_1 - C_2$$

$$C_8 = C_5 - C_6$$

#### Watts


$$W_4 = W_1 - W_2$$

$$W_8 = W_5 - W_6$$

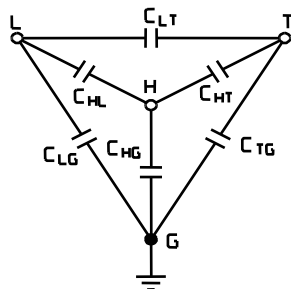
Note: Subscripts are test numbers



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

$$W_4 = W_1 - W_2$$

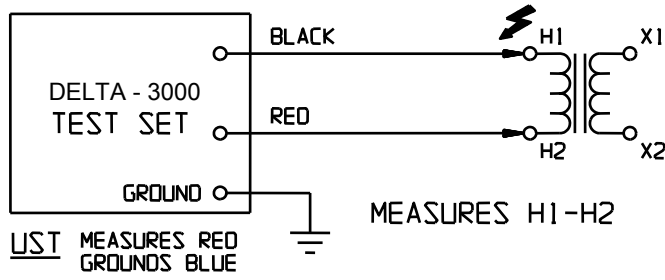
$$W_8 = W_5 - W_6$$

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

Note: Subscripts are test numbers.

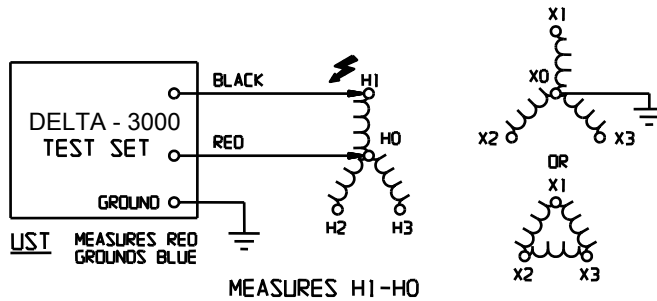
Table 5: Transformer Excitation Current Test Connections

### Single Phase



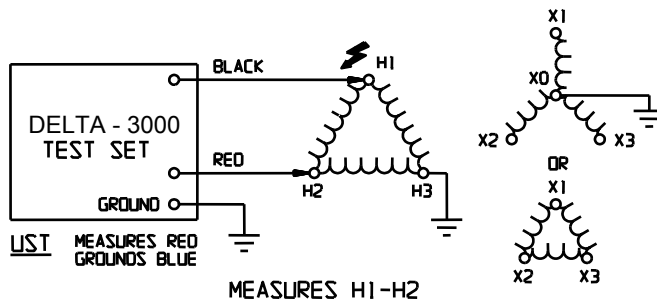
Measures	Test Lead Connections		
Terminal Symbol	Black	Red	Ground
H1-H2	H1	H2	—
H2-H1	H2	H1	—

### 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

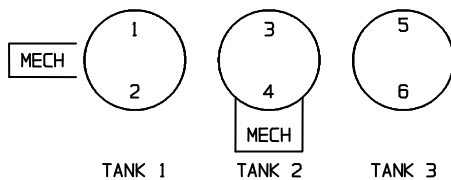
for a standard temperature. On this basis, an attempt should be made to conduct tests at approximately the same time of the year to minimize temperature variations. The measurements on the bushings, however, may readily be corrected to the base temperature, usually 20°C. Separate tests for measuring 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 Connections To Bushings			Remarks
			Test Mode	Measures	Grounds	Guards	 Black	Red	Blue	
1	O P E N	C <sub>1G</sub>	GST GND		Red & Blue		1			Bushing 2 floating
2		C <sub>2G</sub>	GST GND		Red & Blue		2			Bushing 1 floating
3		C <sub>3G</sub>	GST GND		Red & Blue		3			Bushing 4 floating
4		C <sub>4G</sub>	GST GND		Red & Blue		4			Bushing 3 floating
5		C <sub>5G</sub>	GST GND		Red & Blue		5			Bushing 6 floating
6		C <sub>6G</sub>	GST GND		Red & Blue		6			Bushing 5 floating
7	O P E N	C <sub>12</sub>	UST	Red	Blue		1	2		
8		C <sub>34</sub>	UST	Red	Blue		3	4		
9		C <sub>56</sub>	UST	Red	Blue		5	6		
10	C L O S E D	C <sub>1G</sub> + C <sub>2G</sub>	GST GND		Red & Blue		1 or 2			
11		C <sub>3G</sub> + C <sub>4G</sub>	GST GND		Red & Blue		3 or 4			
12		C <sub>5G</sub> + C <sub>6G</sub>	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
$<\pm 0.16$ 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
$<\pm 0.16$ W	Normal results for one open CB test  Other has high losses	1. Bushing with high loss reading 2. Arc interruption assembly	Investigate
$<\pm 0.16$ 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

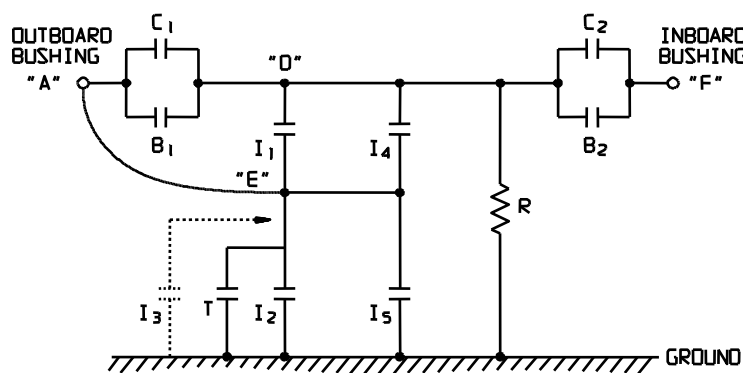
Table 8: Tank-Loss Index of Oil Circuit Breakers (Equivalent to 2.5 kV Losses)

Tank Loss Index	Test Remarks	Probable Problem	Insulation Rating
$<\pm 10$ 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
$<\pm 10$ mW	Normal results for one open CB test  Other has high losses	1. Bushing with high loss reading 2. Arc interruption assembly	Investigate
$<\pm 10$ 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 Connections To Breaker			Remarks
		Test Mode	Measures	Grounds	Guards	 Black	Red	Blue	
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.




- $B_1$  &  $B_2$  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

#### Measurement Intercheck

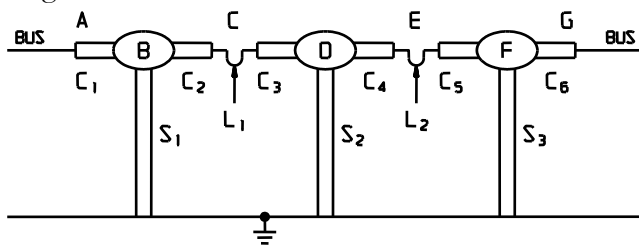
Capacitance:  $C_1 = C_3 - C_2$   
Watts:  $W_1 = W_3 - W_2$   
Note: Subscripts are test no.'s.



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

Test No.	Insulation Tested	$\phi$	Low Voltage Lead Configuration				Test Connections To Breaker			Remarks
			Test Mode	Measures	Grounds	Guards	 Black	Red	Blue	
1	C <sub>1</sub>		UST	Red	Blue		B	A	C	C Grounded
2	C <sub>2</sub>		UST	Blue	Red		B	A	C	A Grounded
3	S <sub>1</sub>		GST			Red & Blue	B	A	C	A & C Guarded
4	C <sub>3</sub>		UST	Red	Blue		D	C	E	E Grounded
5	C <sub>4</sub>		UST	Blue	Red		D	C	E	C Grounded
6	S <sub>2</sub>		GST			Red & Blue	D	C	E	C & E Guarded
7	C <sub>5</sub>		UST	Red	Blue		F	E	G	G Grounded
8	C <sub>6</sub>		UST	Blue	Red		F	E	G	E Grounded
9	S <sub>3</sub>		GST			Red & Blue	F	E	G	E & G Guarded
10										
11										
12										

Diagram



A, C, E & G      Low lead test connections  
 B, D, F      Module live tanks  
 C<sub>1</sub> thru C<sub>6</sub>      Module entrance bushing and grading capacitors  
 L<sub>1</sub>, L<sub>2</sub>      Connection links joining modules  
 S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>      Module support columns

Note: To reduce the effects of severe electrostatic interference, disconnect one side of L<sub>1</sub> and L<sub>2</sub> links to break circuit between modules. All terminals and bus work not in measurement circuit must be solidly grounded.

## ***Bushings***

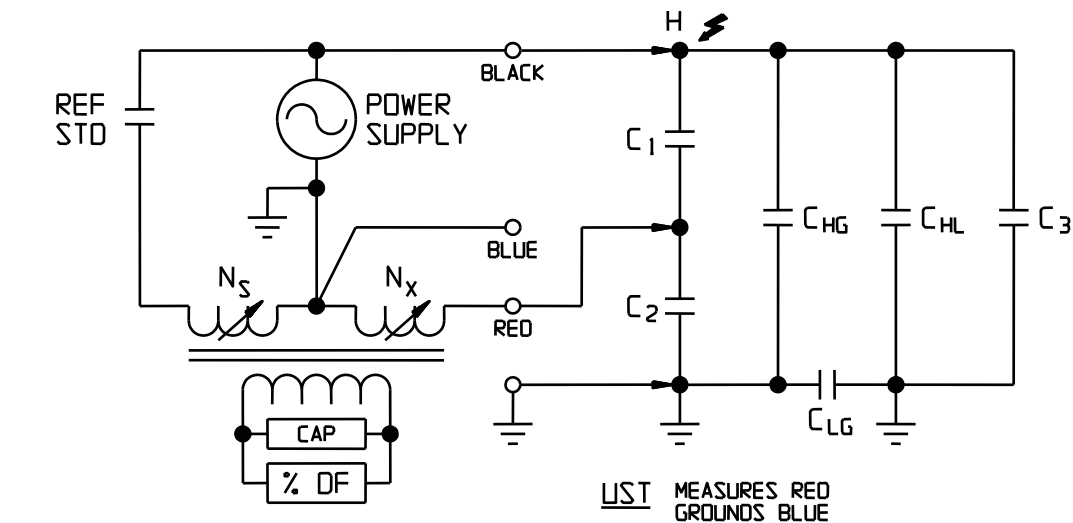
All modern bushings rated 23 kV and higher have a power factor or a capacitance tap which permits dissipation factor testing of the bushing while it is in place on the apparatus without disconnecting any leads to the bushing. The dissipation factor is measured by the ungrounded specimen test (UST) which 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.



C<sub>2</sub> 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.

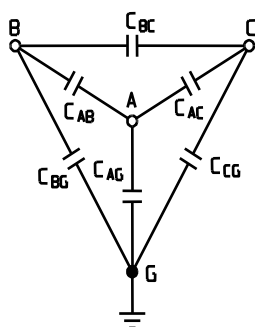
Avoid prolonged exposure to high humidity conditions before testing because such exposure may result in moisture absorption in the insulating materials. It is desirable to make tests on the winding insulation shortly after shutdown.

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 $\perp$	GST			Red & Blue	A	B	C	B & C Guarded
2	A to B	UST	Red	Blue		A	B	C	C Grounded
3	B to $\perp$	GST			Red & Blue	B	C	A	C & A Guarded
4	B to C	UST	Red	Blue		B	C	A	A Grounded
5	C to $\perp$	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 $\perp$	GST GN D				A,B, C	—	—	May require Resonating Inductor

Equivalent Circuit

Remarks



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

Note: Short each winding on itself if possible.

## **Cables**

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

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

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

Cables are inherently of relatively high capacitances per unit length (typically 0.5  $\mu\text{F}$  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:

$$\text{Watts loss} = C_{pF} \times \%DF \times 377 \times 10^{-6} \text{ (for 60 Hz)}$$


$$\text{Watts loss} = C_{pF} \times \%DF \times 314 \times 10^{-6} \text{ (for 50 Hz)}$$

where:  $C_{pF}$  = capacitance in picofarads

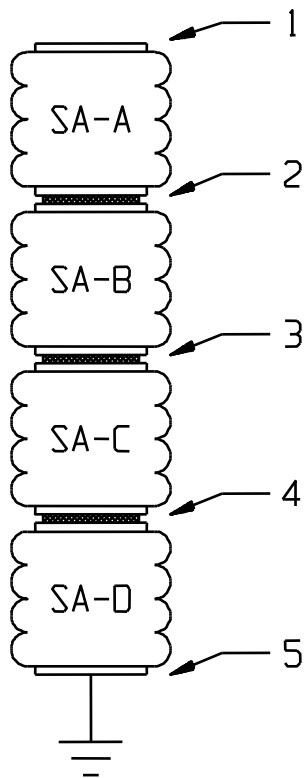
$\%DF$  = percent dissipation factor

*Note: Capacitance, dissipation factor, power factor, watts at 10 kV, current, and current at 10 kV can all be read directly from the DELTA-3000 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.

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

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.

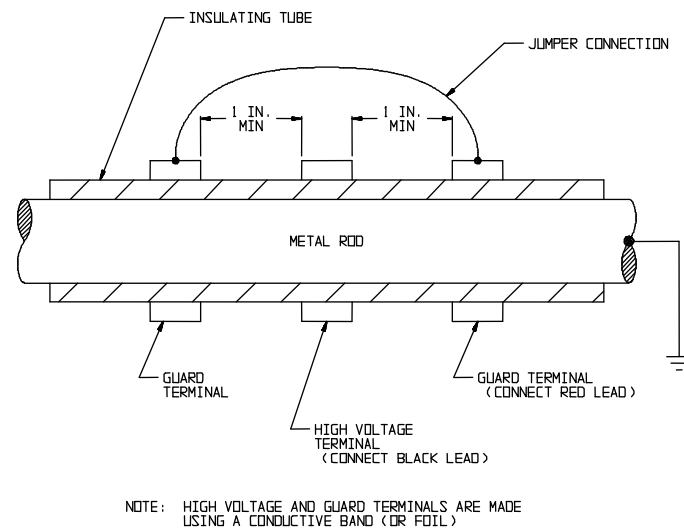
## ***Miscellaneous Assemblies and Components***

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**

**Megger.**

## ***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

**Megger.**



## 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 <input type="checkbox"/> Y <input type="checkbox"/> Δ <input type="checkbox"/>				% RH	
HIGH KV BUSH				WEATHER			
LOW KV		SGL <input type="checkbox"/> Y <input type="checkbox"/> Δ <input type="checkbox"/>				TERTIARY KV	
LOW KV BUSH						TERTIARY BUSH	

TRANSFORMER OVERALL TESTS														
TEST NO.	INSULATION TESTED	TEST MODE	TEST CONNECTIONS (WINDINGS)				TEST KV	CAPACITANCE C (PF)	% POWER FACTOR			□ EQUIV 10 KV □ EQUIV 2.5 KV		INSULATION RATING
			ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1	C <sub>HG</sub> + C <sub>HL</sub>	GST GND	H	L										
2	C <sub>HG</sub>	GST	H		L									
3	C <sub>HL</sub>	UST	H			L								
4	C <sub>HL</sub>	—	TEST 1 MINUS TEST 2				—							
5	C <sub>LG</sub> + C <sub>HL</sub>	GST GND	L	H										
6	C <sub>LG</sub>	GST	L		H									
7	C <sub>HL</sub>	UST	L			H								
8	C <sub>HL</sub>	—	TEST 5 MINUS TEST 6				—							
9	C <sub>HG</sub> '	—	C <sub>HG</sub> MINUS HIGH BUSH.				—							
10	C <sub>LG</sub> '	—	C <sub>LG</sub> MINUS LOW BUSH.				—							

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

### INSULATION RATING KEY

values.

G = GOOD

D = DETERIORATED

I = INVESTIGATE

B = BAD (REMOVE OR RECONDITION)

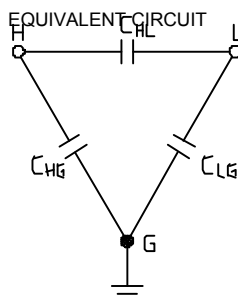
H = HIGH -VOLTAGE WINDING

L = LOW-VOLTAGE WINDING

G = GROUND

N = NEUTRAL BUSHING

NOTE: SHORT EACH WINDING ON ITSELF.



### REMARKS

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

## 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 <input type="checkbox"/> Y <input type="checkbox"/> Δ <input type="checkbox"/>				% RH	
HIGH KV BUSH				WEATHER			
LOW KV		SGL <input type="checkbox"/> Y <input type="checkbox"/> Δ <input type="checkbox"/>		TERTIARY KV		SGL <input type="checkbox"/> Y <input type="checkbox"/> Δ <input type="checkbox"/>	
LOW KV BUSH				TERTIARY BUSH			

### TRANSFORMER OVERALL TESTS

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

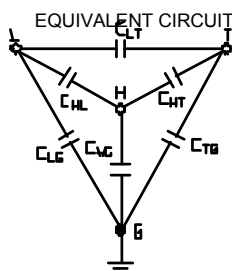
### BUSHING TESTS

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  
NOTE: SHORT EACH WINDING ON ITSELF.



#### REMARKS

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

## 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 <input type="checkbox"/>	Y <input type="checkbox"/>	Δ <input type="checkbox"/>	%RH			
LOW KV	SGL <input type="checkbox"/>	Y <input type="checkbox"/>	Δ <input type="checkbox"/>	WEATHER			
TERTIARY KV	SGL <input type="checkbox"/>	Y <input type="checkbox"/>	Δ <input type="checkbox"/>				

TEST NO.	Δ LOAD TAP CHANGER POSITION	TEST KV	PHASE A		PHASE B		PHASE C		REMARKS
			TERMINAL SYMBOL	MILLI-AMPERES	TERMINAL SYMBOL	MILLI-AMPERES	TERMINAL SYMBOL	MILLI-AMPERES	
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

## 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		

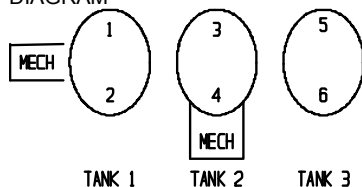
### CIRCUIT BREAKER OVERALL TESTS

TEST NO.	CB	INSULATION TESTED	$\phi$	TEST MODE	TEST CONNECTIONS BUSHING				TEST KV	CAPACITANCE C(PF)	% POWER FACTOR			<input type="checkbox"/> EQUIV 10 KV <input type="checkbox"/> EQUIV 2.5 KV		INSULATION RATING
					ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1	O P E N	C <sub>1G</sub>		GST GND	1											
2		C <sub>2G</sub>		GST GND	2											
3		C <sub>3G</sub>		GST GND	3											
4		C <sub>4G</sub>		GST GND	4											
5		C <sub>5G</sub>		GST GND	5											
6		C <sub>6G</sub>		GST GND	6											
7	C L O S E D	C <sub>1G</sub> + C <sub>2G</sub>		GST GND	1&2											
8		C <sub>3G</sub> + C <sub>4G</sub>		GST GND	3&4											
9		C <sub>5G</sub> + C <sub>6G</sub>		GST GND	5&6											

### BUSHING & OIL TESTS

TEST NO.	BUSHING		$\phi$													
	NO.	SER. NO.		UST	1			TAP								
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.

## 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			

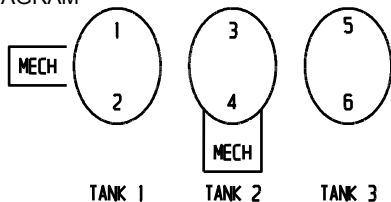
### CIRCUIT BREAKER OVERALL TESTS

TEST NO.	CB	INSULATION TESTED	$\phi$	TEST MODE	TEST CONNECTIONS BUSHING				TEST KV	CAPACITANCE C(PF)	% POWER FACTOR			<input type="checkbox"/> EQUIV 10 KV <input type="checkbox"/> EQUIV 2.5 KV		INSULATION RATING
					ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1	O P E N	C <sub>1G</sub>		GST GND	1											
2		C <sub>2G</sub>		GST GND	2											
3		C <sub>3G</sub>		GST GND	3											
4		C <sub>4G</sub>		GST GND	4											
5		C <sub>5G</sub>		GST GND	5											
6		C <sub>6G</sub>		GST GND	6											
7	O P E N	C <sub>12</sub>		UST	1			2								
8		C <sub>34</sub>		UST	3			4								
9		C <sub>56</sub>		UST	5			6								
10	C L O S E D	C <sub>1G</sub> + C <sub>2G</sub>		GST GND	1&2											
11		C <sub>3G</sub> + C <sub>4G</sub>		GST GND	3&4											
12		C <sub>5G</sub> + C <sub>6G</sub>		GST GND	5&6											

### BUSHING TESTS

TEST NO.	BUSHING		$\phi$													
	NO.	SER. NO.														
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

## 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							

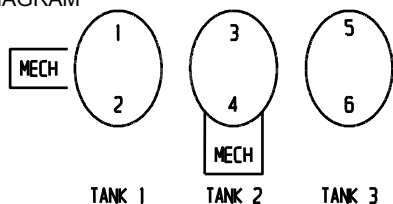
### CIRCUIT BREAKER OVERALL TESTS

TEST NO.	CB	INSULATION TESTED	$\phi$	TEST MODE	TEST CONNECTIONS BUSHING				TEST KV	CAPACITANCE C(PF)	% POWER FACTOR			<input type="checkbox"/> EQUIV 10 KV <input type="checkbox"/> EQUIV 2.5 KV		INSULATION RATING
					ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1	O P E N	C <sub>1G</sub>		GST GND	1											
2		C <sub>2G</sub>		GST GND	2											
3		C <sub>3G</sub>		GST GND	3											
4		C <sub>4G</sub>		GST GND	4											
5		C <sub>5G</sub>		GST GND	5											
6		C <sub>6G</sub>		GST GND	6											
7	O P E N	C <sub>12</sub>		UST	1			2								
8		C <sub>34</sub>		UST	3			4								
9		C <sub>56</sub>		UST	5			6								

### BUSHING TESTS

TEST NO.	BUSHING		$\phi$														
	NO.	SER. NO.															
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, 10, 11 and 12. All other bushings must be floating.

#### REMARKS

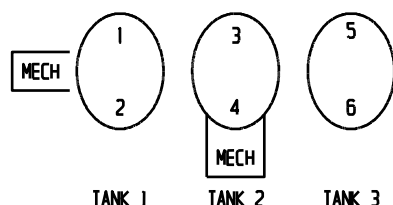
## Air-Magnetic Circuit Breakers Capacitance and Power Factor Tests

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 NO.	CB	INSULATION TESTED	$\phi$	TEST MODE	TEST CONNECTIONS BUSHING				TEST KV	CAPACITANCE C(PF)	% POWER FACTOR			<input type="checkbox"/> EQUIV 10 KV <input type="checkbox"/> EQUIV 2.5 KV		INSULATION RATING
					ENG	GND	GAR	UST			MEASURED	20°C %PF	CORR FCTR	mA	WATTS	
1	OPEN	C <sub>1G</sub>		GST	1		2									
2		C <sub>2G</sub>		GST	2		1									
3		C <sub>3G</sub>		GST	3		4									
4		C <sub>4G</sub>		GST	4		3									
5		C <sub>5G</sub>		GST	5		6									
6		C <sub>6G</sub>		GST	6		5									
7	OPEN	C <sub>12</sub>		UST	1			2								
8		C <sub>34</sub>		UST	3			4								
9		C <sub>56</sub>		UST	5			6								

BUSHING TESTS																
TEST NO.	BUSHING		$\phi$													
	NO.	SER. NO.		UST	1											
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.

Note: UST test checks grading capacitors across open contacts.

### REMARKS

## 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 <input type="checkbox"/> OUT <input type="checkbox"/>	% RH
MFR	TYPE	WEATHER
STATOR INSUL	AGE	

TEST NO.	PHASE TESTED	TEST MODE	TEST CONNECTIONS				TEST KV	CAPACITANCE C (PF)	% POWER FACTOR			<input type="checkbox"/> EQUIV 10 KV <input type="checkbox"/> EQUIV 2.5 KV		INSULATION RATING
			ENG	GND	GAR	UST			MEASURED	% TIP UP	REACTOR	mA	WATTS	
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														

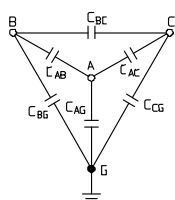
### INSULATION RATING KEY

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

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



## 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			<input type="checkbox"/> EQUIV 10 KV <input type="checkbox"/> EQUIV 2.5 KV		INSULATION 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

**Megger.**

# **APPENDIX D**

## **Temperature Correction Tables**

**Megger.**

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	CLASS 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