AVTM670065Ja
Rev A
March 2003

Instruction Manual AVTM670065Ja

for

Capacitance and Dissipation Factor Test Set
Catalog No. 670065, 670070, 670070-R

High-Voltage Equipment
Read the entire manual before operating.
Aparato de Alto Voltaje
Antes de operar este producto lea este manual enteramente.

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TABLE OF CONTENTS

SECTION 1

SECTION 2

SECTION 3

SECTION 4

SECTION 5

SECTION 6

SECTION 7

SECTION 8

LIST OF ILLUSTRATIONS

LIST OF TABLES

Section 1
Introduction

Receiving Instructions

Check the equipment received against the packing list to ensure that all materials are present. Notify AVO International of any shortage. Telephone (215) 646-9200.

Examine the equipment for possible damage received in transit. If any damage is discovered, file a claim with the carrier at once and notify AVO International or its nearest authorized sales representative, giving a detailed description of the damage.

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

General Information

The Capacitance and Dissipation Factor Test Set is used for shop and field testing of high-voltage electrical insulating systems at 50/60 Hz by applying test voltage up to 12 kV. The test set evaluates the condition and quality of electrical insulation materials and manufacturing processes, and reveals 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 canvas carrying bag. See Figure 1.

Tests are made by measuring the capacitance and dissipation factor (power factor) of a specimen at test voltages up to 12 kV. The measured values change when undesirable conditions exist such as moisture on or in the insulation; shorts or opens in windings or insulation; presence of conductive contaminants in insulating oil, gas, or solids; and the presence of internal partial discharges.

Capacitance and dielectric losses (dissipation factor) of electrical insulation on high-voltage power equipment such as cables, bushings, insulators, circuit breakers, transformers, rotating machines, capacitors, and lightning arresters are measured. The test set measures changes of capacitance and dielectric loss due to variations of voltage level and ambient conditions, e.g., 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 capacitance and dissipation factor tests on high-voltage apparatus:

  Ungrounded specimen test (UST)
  Grounded specimen test (GST L-GROUND)
  Grounded specimen test using guard connection (GST L-GUARD)

- Test mode selector switch simplifies setting up and minimizes connections.

- Dual low-voltage output cables simplify measurements on multi-winding transformers and circuit breakers containing inboard and outboard bushings.

- Suppression circuits make possible tests in switchyards under electrostatic and magnetic interference conditions.

- Low impedance transformer-ratio-arm circuit plus fully shielded and guarded circuits shield all critical internal assemblies, connections and external cables essentially eliminating the influence of stray capacitance to ground.
- Built-in safety controls protect the operator and the equipment.

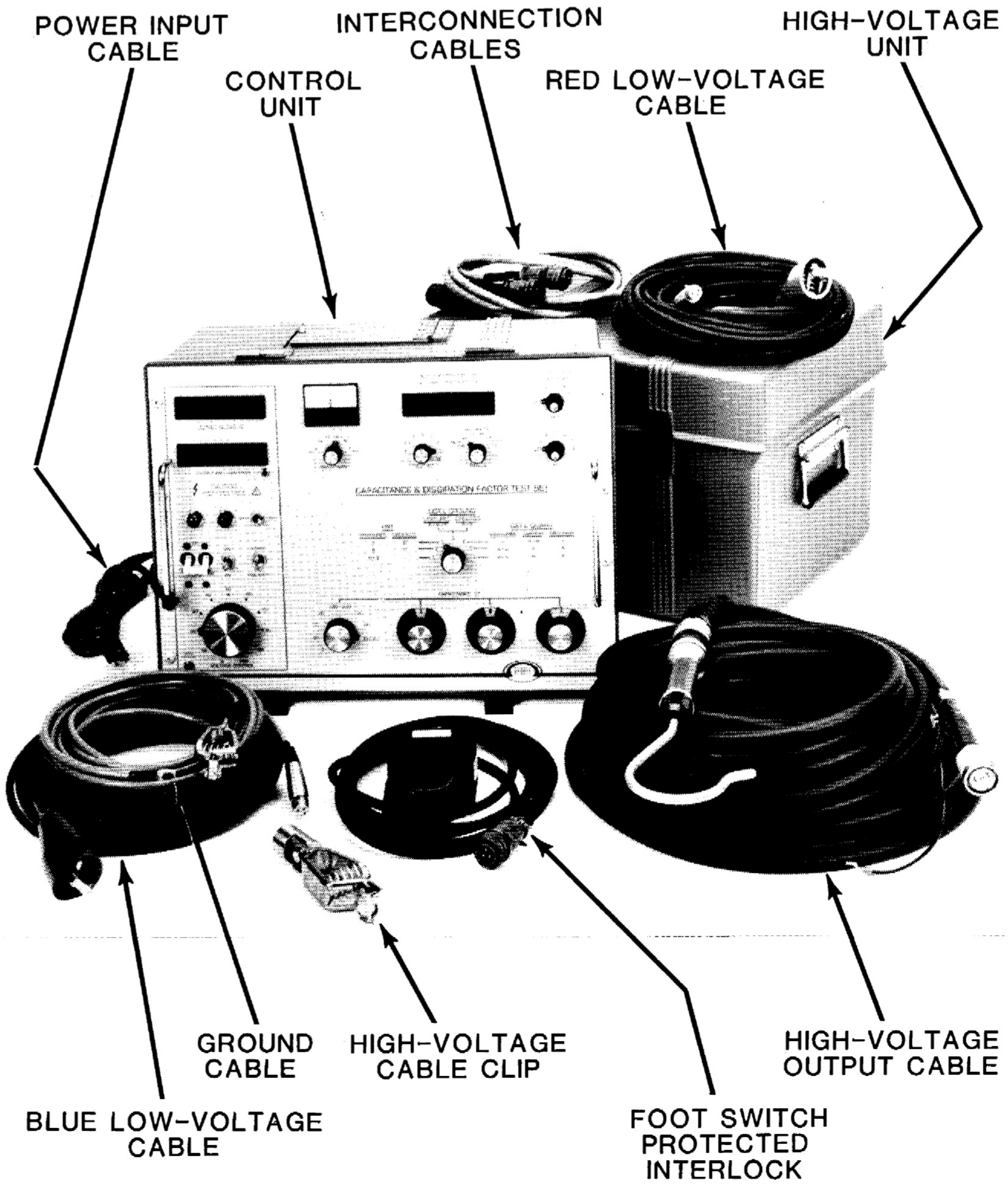


Figure 1: Capacitance and Dissipation Factor Test Set

Section 2
Safety

The test set and specimen to which it is connected are a source of high-voltage electrical energy and all persons making or assisting in the 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 unless the 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.

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 the high-voltage conductor and ground of the apparatus under test before connecting the test leads. Always disconnect test leads from the apparatus under test 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.

On termination of a test always gradually reduce the test voltage to zero before turning off the power supply. The terminals of the test specimen should be short-circuited by means of a safety ground stick to ground all live parts. Safety ground jumpers should then be applied and left in place.

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 pole of the power source must not exceed the maximum rated operating voltage:

120 V, 60 Hz for Cat. No. 670065, 670070, and 670070-R

120 V, 50 Hz for Cat. No. 670065-44, 670070-44, and 670070-R-44

250 V, 60 Hz for Cat. No. 670065-47, 670070-47, and 670070-R-47

250 V, 50 Hz for Cat. No. 670065-45, 670070-45, and 670070-R-45.

The neutral pole must be at ground potential. 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 type 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.

Test sets energized with 120 V input voltage must be operated with proper source connection of hot and neutral wires. The protective ground (earth) wire must have good continuity.

Test sets energized with 220/240 V input voltage are energized via an internal autotransformer which is used for voltage reduction. 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. These test sets must not be energized from a power source where both poles are live. These test sets are protected by a fuse. Refer fuse replacement to qualified service personnel only. To avoid electric shock and fire hazard use only the fuse specified in Section 3, Specifications, which is identical in respect to type, voltage rating and current rating.

AVO International has make formal safety reviews of the initial design and any subsequent changes. This procedure is followed for all new Biddle products and covers areas in addition to those included in applicable standards. Regardless of these efforts, it is not possible to eliminate all hazards from electrical test equipment. For this reason, every effort has been made to point out in this instruction manual the proper procedures and precautions to be followed by the user in operating this equipment and to mark the equipment itself with precautionary warnings where appropriate. It is not possible however 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 equipment to energized equipment or use in an explosive atmosphere.
- Operation is prohibited in rain or snow.
- 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 be performed only by a person who is 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.

High-voltage discharges and other sources of strong electric or magnetic field 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.

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 controls. AVO International considers this an excellent safety practice.

The following specific warning and caution notices are used throughout this manual where applicable and should be strictly observed.

WARNING

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

CAUTION

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

Section 3
Specifications

Electrical

Input Power

Cat. No. 670065, 670070, and 670070-R
120 V, 60 Hz, 10 A continuous; IEC 1010-1 installation category II

Cat. No. 670065-44, 670070-44, and 670070-R-44
120 V, 50 Hz, 10 A continuous; IEC 1010-1 installation category II

Cat. No. 670065-47, 670070-47, and 670070-R-47
240 V, 60 Hz, 5 A continuous; IEC 1010-1 installation category II

Cat. No. 670065-45, 670070-45, and 670070-R-45
240 V, 50 Hz, 5 A continuous; IEC 1010-1 installation category II

Protective Devices

Circuit breaker, all models:	10 A
Fuse, 220/240 V models only:	15 A, 250 V, time delay, IEC designation T (Buss designation MDA, ceramic)

Output Voltage and Current (two ranges)

Output voltage range:	0 to 5 kV continuously adjustable.
Maximum continuous current:	200 mA at 5 kV
Maximum current:	400 mA at 5 kV for 10 min on, 1 hr off

Output voltage range:	0 to 10 kV continuously adjustable (12 kV max output)
Maximum continuous current:	00 mA at 10 kV
Maximum current:	200 mA at 10 kV for 10 min on, 1 hr off

Test Frequency

50 or 60 Hz

Measuring Ranges

Voltage: 0 to 12 kV, 0.01 kV resolution

Current: 0 to 200 mA, 0.1 mA maximum resolution
above 200 mA, 1 mA maximum resolution

Capacitance: 0 to 220,000 pF in eight ranges
Resolution: 0.01% of range selected
Extended range of 1.1 μF on Cat. No. 670070 and 670070-R
Sensitivity: Sufficient to resolve 0.01% of range selected, at test voltages of 1 kV rms or higher.

Dissipation factor:
0 to 20%, 0 01% DF maximum resolution
0 to 200%, 0.1% DF maximum resolution

Automatic balance except for manual selection of range. The correct reading is displayed after the capacitance dials have been adjusted to null as indicated on the capacitance null detector. The reading is digital readout with LED display.

The % DISSIPATION FACTOR/WATTS/MILLIWATTS readout is direct reading at 1, 2, 2.5, 4, 5, 6, 8, 10, and 12 kV. Indirect readings may be taken at intermediate test voltages.

Dissipation factor resolution as small as 0.001% may be obtained, by indirect methods, when making measurements at 10 kV.

Watts loss: LO/HI equivalent milliwatts at 10 kV.

LO/HI equivalent watts at 10 kV.

Test set can also measure negative values of DF, PF, and watts loss.

Note: When using the 10K multiplier on Catalog No. 670070 and 670070-R, multiply the watts reading by 10.

Accuracy

Voltage (rms):	±(1% of reading + 1 digit)
Current (rms):	±(1% of reading + 0.1 mA)
Capacitance:	±(1% of reading + 2 pF) UST; ±(1% of reading + 6 pF) GST
Dissipation factor:	20% range: ±(2% of reading + 0.05% DF)
	200% range: ±(2% of reading + 0.5% DF)

Test Modes

Seven test modes to make all UST and GST tests.

Interference Suppression

Separate CAP and DF INTERFERENCE suppressor controls allow independent suppression of the interference current which is in phase and in quadrature to the bridge current. Six ranges are provided for each control.

Bridge Circuit

Based on principle of opposing ampere-turn balance using adjustable transformer ratio arms. A third winding is used for the null detector signal.

Null Detector

Two channel, phase sensitive null detector. The balance display for the capacitance channel is a zero center meter. Readout for the dissipation factor channel is a digital panel meter. The sensitivity of the capacitance channel is regulated by a six-position switch. Sensitivity adjustment provided is: full, 1/3, 1/10, 1/30, 1/100, and 1/300. Sensitivity adjustment for the dissipation factor channel is automatic. Synchronization for both channels is automatic.

Reference Capacitor

Fixed gas, fully shielded, 100 pF ±1%.

Guarding

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

Power Transformer

Double-shielded construction.

Maximum Specimen Capacitance Measurable at 50/60 Hz

Test Volts (kV)	Maximum Capacitance (μF) (200 mA continuous service)		Maximum Capacitance (μF) (400 mA for 10 minutes)	
	60 Hz	50 Hz	60 Hz	50 Hz
2.5 & less	0.220	0.220	0.220	0.220
4.0	0.130	0.160	0.220	0.220
5.0	0.110	0.130	0.220	0.220
	Maximum Capacitance (μF) (100 mA continuous service)		Maximum Capacitance (μF) (200 mA for 10 minutes)	
6.0	0.044	0.053	0.088	0.106
8.0	0.033	0.040	0.066	0.080
10.0	0.026	0.031	0.052	0.062
12.0	0.022	0.026	0.044	0.053

Note: Maximum measurable capacitance at 10 kV can be increased to 1 μF on Cat. No. 670070 and 670070-R by using the Resonating Inductor (Cat. No. 670600).

Terminals

High voltage
Low voltage (2) marked red and blue
Interconnection (2)
Supply power
External interlock
Ground

Safety Features

Zero start for output voltage.
External interlock foot switch.
Double ground required for test set to be energized; amber lamp indicates open ground.
Green lamp indicates that the power supply is on; red lamp indicates that output voltage is available.
All controls at ground potential.
No accessible energized terminals on outside of case.
Circuit breaker for short-circuit protection.
High-voltage polarity reversing switch with center OFF position.
Overvoltage protective devices prevent damage to the test set in the event of specimen breakdown.

SHORT setting on capacitance multiplier dial for protection when raising voltage on a specimen of questionable insulation or for use as a basic safety procedure.

Environmental

Operating temperature range: -22 to 131°F (-30 to 55°C)

Storage temperature range: -40 to 149°F (-40 to 65°C)

Humidity: 0 to 95% relative humidity, noncondensing

Note: GST measurements may be adversely affected by high humidity conditions where the relative humidity exceeds 80 percent.

Physical Data

The test set consists of two separate units: control unit and high-voltage unit (not included with Cat. No. 670070-R). The cases are bronze color polycarbonate structural foam with heavy-duty carrying handles. Two black canvas bags are provided to carry test cables.

Dimensions

Control unit and high-voltage unit case: 19-1/2 x 15 x 12-1/2 in. (L x W x H) (51 x 38 x 31 cm)

Canvas carrying bag for test cables: 15 x 17 x 4 in. (W x H x thick) (38 x 43 x 10 cm)

Weight

Control unit: 48 lb (22 kg)

High-voltage unit: 56 lb (25 kg)

Cables: 34 lb (16 kg)

Cables Supplied

One 70-ft (21 m) high-voltage test cable CxH, 12 kV, double shielded (black).

Two 70-ft (21 m) low-voltage test cables, CxL, 600 V, single shielded (red and blue).

Two 5-ft (1.5 m) interconnection cables.

One 8-ft (2.5 m) power supply input cable, three conductor.

One 8-ft (2.5 m) external interlock control cable with foot switch.

One 15-ft (4.5 m) ground cable.

Optional Accessories

Calibration and Dissipation Factor Standard	Cat. No. 670500-1
Oil Test Cell	Cat. No. 670511
Hot-Collar Belts (3 belts)	Cat. No. 670505
Bushing Tap Connectors (2 connectors)	Cat. No. 670506
Hook for use with high-voltage test cable	Part No. 23641
Transit case for test set	Cat. No. 670626
Transit case for cables	Cat. No. 218744-1
Transit case for standard	Cat. No. 670635
Resonating Inductor (for use with Cat No. 670070 and 670070-R)	Cat. No. 670600

Section 4
Description

Controls, Indicators, And Connectors

Table 1 describes the controls, indicators, and connectors of the test set. Figures 2 and 3 show their panel location.

Table 1: Controls, Indicators, and Connectors

Description	Function
Main ON/OFF breaker K1	Two-pole, magnetic circuit breaker controls power to the test set and provides short-circuit and overload protection.
OPEN GROUND indicator DS3	Amber lamp indicates an open in double ground system or defective grounding of test set.
ON indicator DS1	Green lamp indicates that the circuit breaker is set to ON and the test set is energized.
HV ON/OFF switch S1	Toggle switch controls an internal relay energizing the high-voltage circuit and the high-voltage indicator lamp.
High-voltage indicator DS2	Red lamp indicates that the HV/ON/OFF switch is set to ON and voltage can be applied.
NORM/OFF/REV POLARITY switch S2	Toggle switch reverses polarity of high voltage.
5 KV/10 KV switch S7	Toggle switch selects high-voltage output range.
VOLTAGE CONTROL T1	Variable ratio autotransformer adjusts output voltage by controlling primary voltage of high-voltage power transformer, in conjunction with a zero start switch, which requires control shaft initially be set to "0" for operation.
OUTPUT KILOVOLTS meter M2	Digital kilovoltmeter measures test specimen ac test voltage.
OUTPUT MILLIAMPERES meter M1	Digital milliammeter measures test specimen current.
Output Milliamperes LO/HI switch S15	Toggle switch selects low or high current range.

Table 1: Controls, Indicators, and Connectors	
Description	**Function**
UST/GST test mode selector switch S8	Seven-position rotary switch selects the UST-GST operating mode. 1. Ungrounded specimen test measures Hi to red Lo and Hi to blue Lo leads. 2. Ungrounded specimen test measures Hi to blue Lo lead and grounds red lead. 3. Ungrounded specimen test measures Hi to red Lo lead and grounds blue lead. 4. Grounded specimen test measures Hi to red Lo and Hi to blue Lo leads plus Hi to ground. 5. Grounded specimen test measures Hi to ground and guards red and blue leads. 6. Grounded specimen test measures Hi to red Lo lead and Hi to ground and guards blue lead. 7. Grounded specimen test measures Hi to blue Lo lead and Hi to ground and guards red lead.
Capacitance multiplier dial S9	Nine-position rotary switch selects capacitance multiplier value. SHORT position provided for bridge protection. (For Cat. No. 670070 and 670070-R, a 10-position rotary switch is used to gain the added multiplier value of 10K for use with the Resonating Inductor, Cat. No. 670600).
Capacitance measuring dials S10, S11, R6	Two decade switches and slide-wire dial capacitance balancing dials indicate capacitance value of sample after applying multiplier value.
Capacitance null detector meter M4	Zero center micrometer indicates bridge capacitance balance, C interference suppressor balance indicator.
% DISSIPATION FACTOR/WATTS/MILLIWATTS at 10 kV meter M3	Indicates % dissipation factor value of specimen or equivalent watts/milliwatts dissipated at 10 kV; indicates negative values; DF interference suppressor indicator. (For Cat. No. 670070 and 670070-R, when capacitance multiplier switch is set to 10K, the watts reading must be multiplied by 10).
SENSITIVITY switch S4	Six-position rotary switch regulates sensitivity of capacitance null detector meter.
TEST KV switch S5	Nine-position rotary switch allows direct reading of %DF/watts/milliwatts when test voltage is set to value indicated by TEST KV switch.

Table 1: Controls, Indicators, and Connectors

Description	Function
RANGE switch S6	Six-position rotary switch selects %DF/watts/milliwatts measuring range.
CAP INTERFERENCE SUPPRESSOR switch R54/S12	Ten-turn control and seven-position switch cancels the effects of capacitance interference current; switch selects range, has OFF position.
DF INTERFERENCE SUPPRESSOR switch R53/R13	Ten-turn control and seven-position switch used to cancel the effects of dissipation factor/watts/milliwatts interference current; switch selects range, has OFF position.
Input power receptacle J1	Plug receptacle for connection of test set to ac power source.
INTERLOCK receptacle J2	Plug receptacle for connection of a normally open external interlock switch. A foot interlock switch is supplied; however, in the event that the foot 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. The interlock system should be wired such that connection is make to A and B sockets of the INTERLOCK receptacle. When the interlock loop is opened the test is automatically terminated.
Warning **When the external interlock circuit is open and the HV ON switch is depressed, the complete interlock circuit is energized at 120 V. The interlock circuit wiring must be insulated for 120 V.**	
Interconnection receptacles J7, J8	Two plug receptacles for connection of control unit to high-voltage unit.
CxL RED receptacle J4	Plug receptacle for connection of red low-voltage test cable, used for single low-voltage cable applications.
CxL BLUE receptacle J5	Plug receptacle for connection of blue low-voltage test cable.
Ground terminal J6	Thumb nut terminal for connection of test set to earth ground.
Inductor return J30	Found only on Cat. No. 670070 and 670070-R. Thumb nut terminal for connection of test set to inductor return terminal on the Resonating Inductor.

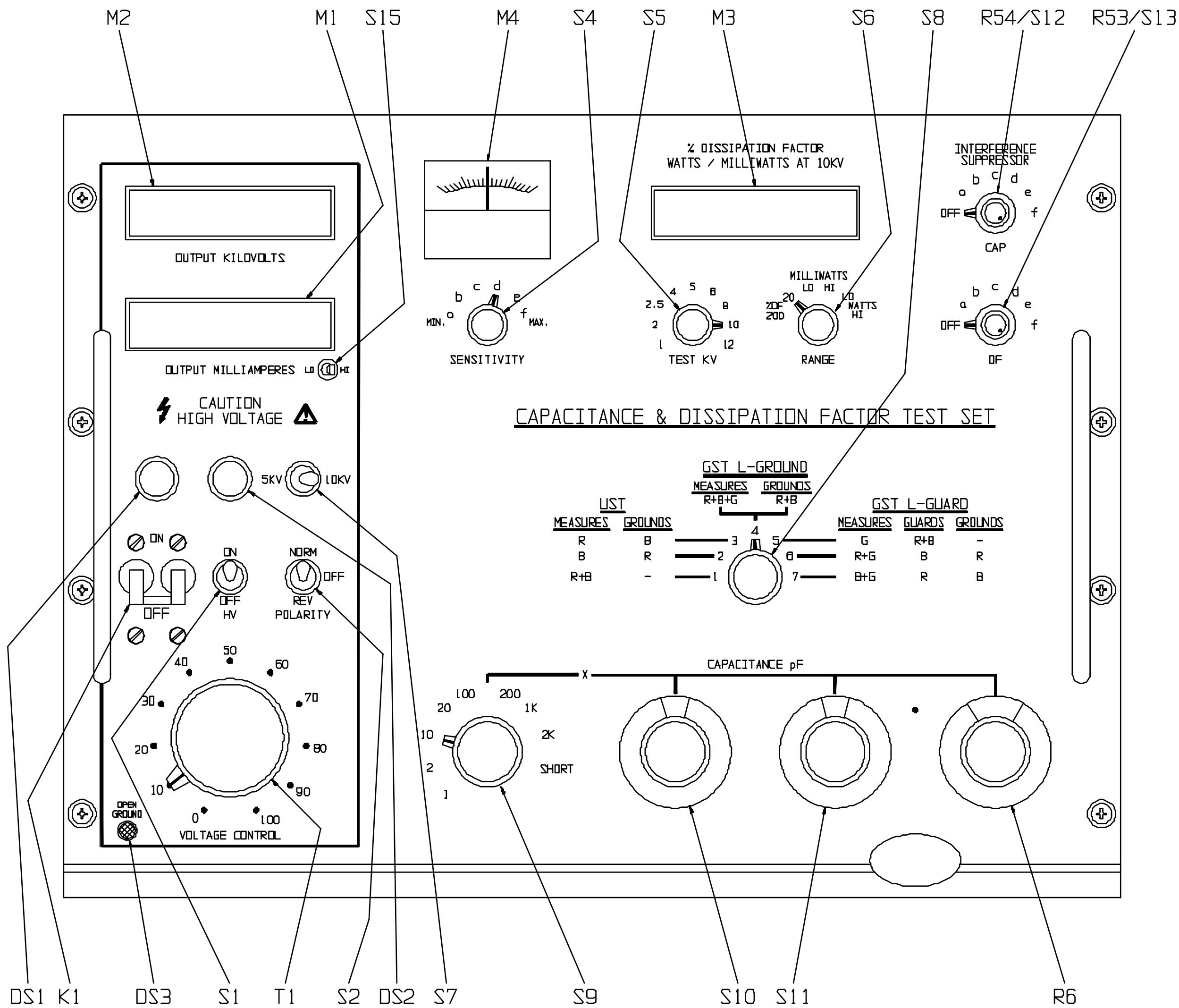
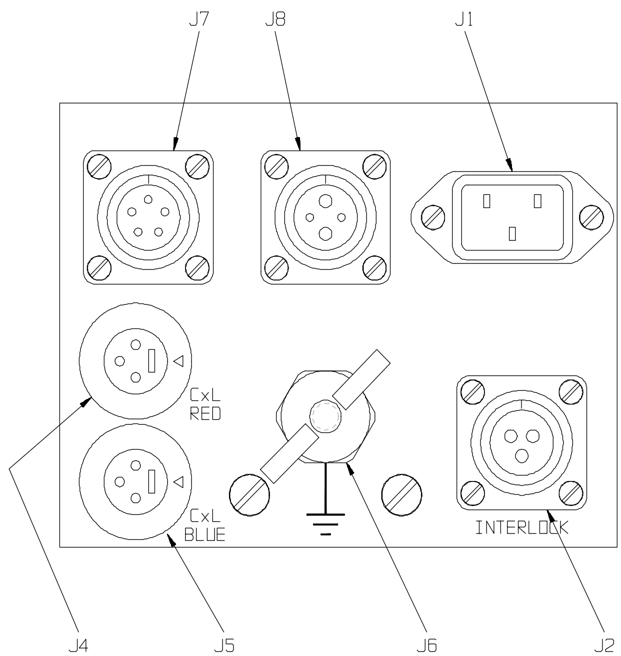
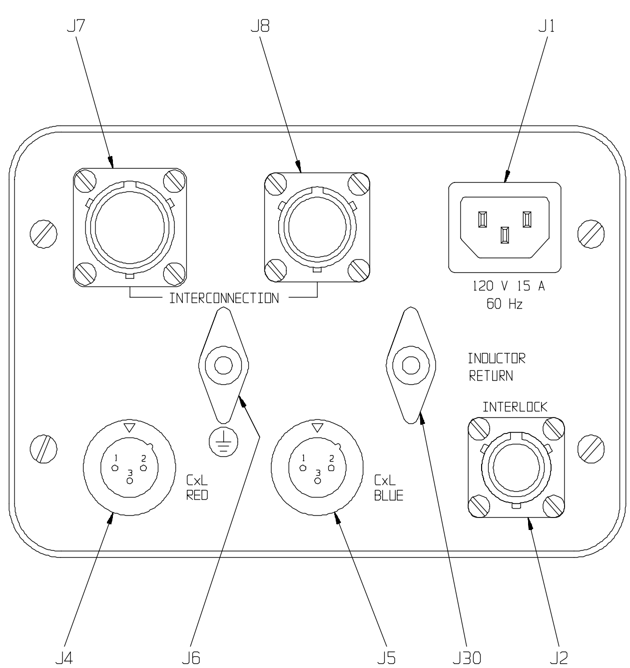


Figure 2: Control Unit Panel



Catalog No. 670065



Catalog No. 670070 and 670070-R

Figure 3: Control Unit Connector Panel

Circuit Description

The electrical operation of the test set is described in the following paragraphs and is shown in the schematic diagram, Figure 4. Power is supplied to the test set through the three-conductor input cable. The green wire of this cable conforms to electrical code requirements and provides a separate panel ground connection. The separate ground cable provided must be connected to a known earth ground to prevent shock hazard or damage to the test set.

Test sets furnished with the 220/240 V option differ from standard sets only in that a separate internal step-down autotransformer T8 is connected in series with the input. The 240 V ac input is stepped-down to 120 V ac. The test set must be connected to the line power source as described in Section 2, Safety.

Input power is brought directly to main power switch K1, a trip-free magnetic circuit breaker. This switch also serves as the test set ON/OFF switch. A second pole on this circuit breaker provides protection for autotransformer T1 so that under all overload circumstances at least one pole will have a current overload. If either circuit breaker pole is tripped, both poles will open.

The amber OPEN GROUND lamp DS3 indicates when lit that there is an open circuit in the ground wire of the power cord or that the test set case is improperly grounded. The lamp will also light in the event of a high resistance ground circuit (>50 Ω) between the ground cable and power cord ground. The high-voltage output circuit cannot be energized with an open ground. Transformer T6 and relay K5 control this operation. The control contacts of K5 are in series with the external-interlock switch circuit.

Power controlled by K1 is brought to line relay K2. Autotransformer T1 receives power under control of K2. Output voltage is controlled by variable autotransformer T1 whose output feeds the primary of the high-voltage transformer T2. The zero-start safety feature of this test set requires that VOLTAGE CONTROL T1 be initially set to 0 in order for the advancement of the voltage control to develop an output voltage. This feature is controlled by line relay K2 whose contacts initially remain open after circuit breaker K1 is closed. This prevents the application of voltage to the input of high-voltage transformer T2 until the contacts of relay K2 are closed. The contacts are closed by setting VOLTAGE CONTROL T1 to 0, which closes zero-start switch S3, by switching HV ON/OFF switch S1 to ON and by closing the external interlock switch which is connected to receptacle J2.

The contacts of relay K2 remain closed until power is removed either by switching the HV ON/OFF switch S1 to OFF, opening of the external interlock switch, or opening of main circuit breaker switch K1. To reestablish output, power must again be applied and the VOLTAGE CONTROL reset to 0.

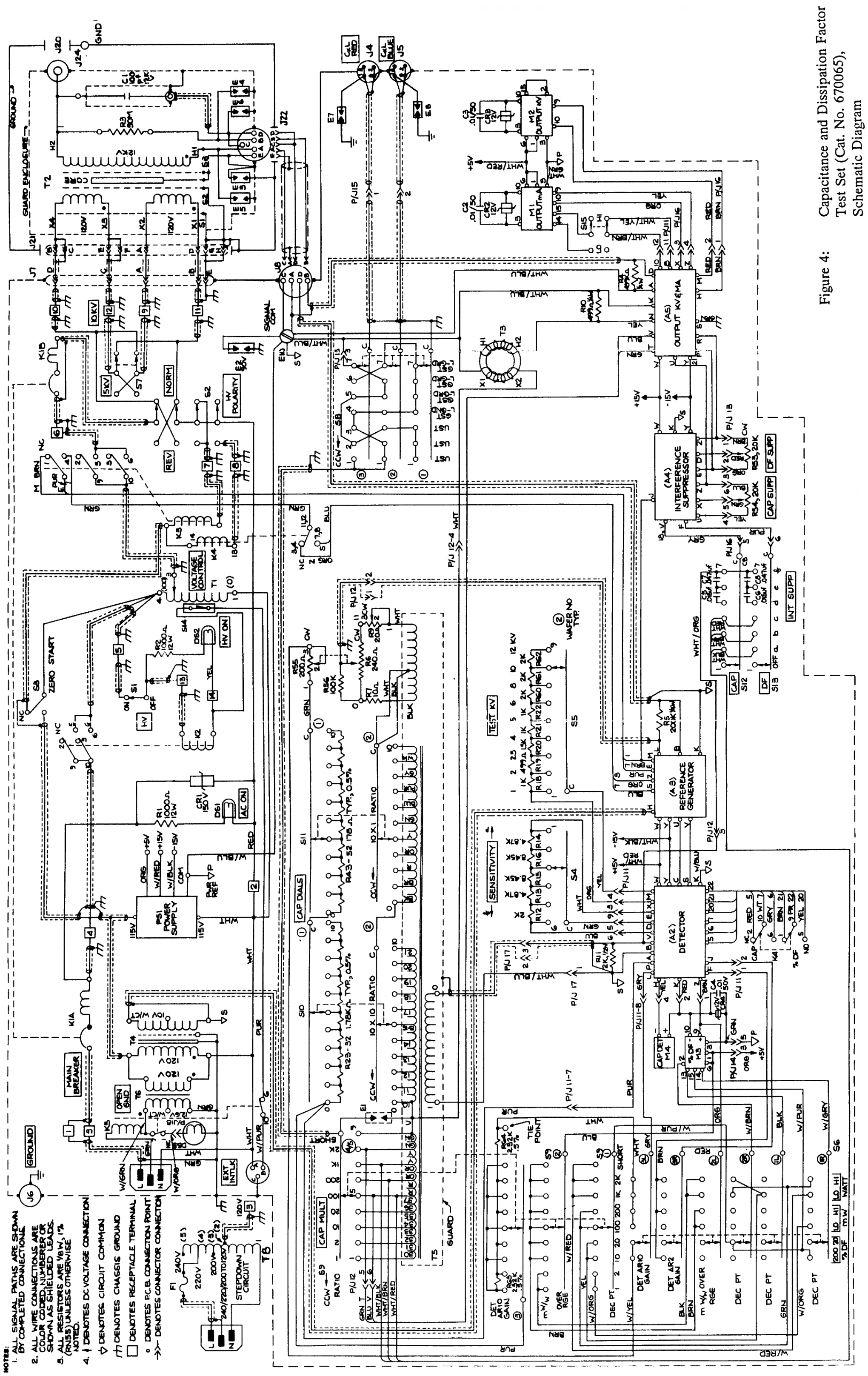


Figure 4: Capacitance and Dissipation Factor Test Set (Cat. No. 670065), Schematic Diagram

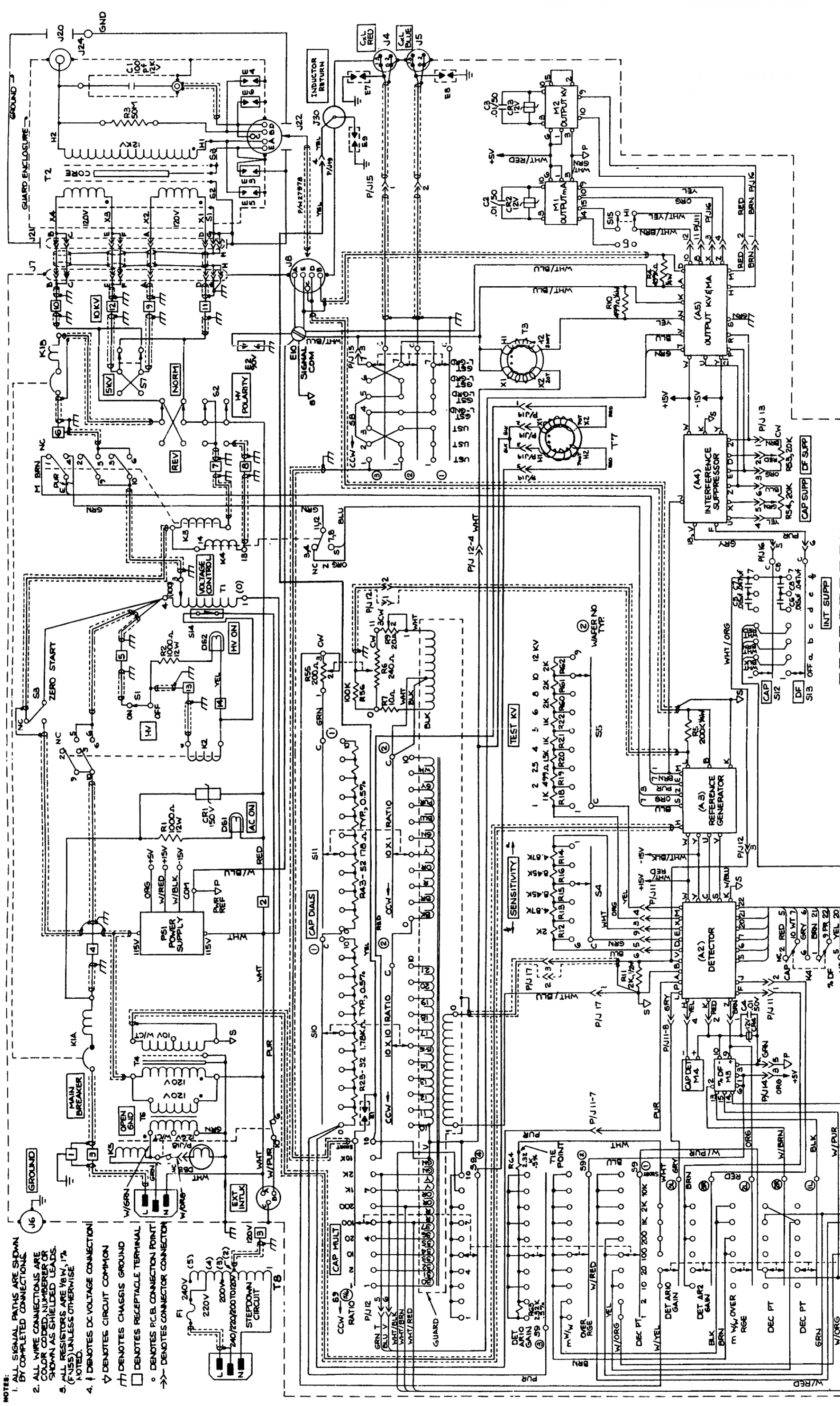


Figure 4a: Capacitance and Dissipation Factor Test Set (Cat. No. 670070), Schematic Diagram

Figure 4a: Capacitance and Dissipation Factor Test Set (Cat. No. 670070), Schematic Diagram

Indicator DS1 (green lamp) indicates when lit that the circuit breaker is set to ON and the test set is energized. High-voltage indicator DS2 (red lamp) indicates when lit that the high-voltage circuit is energized and output voltage can be applied. Transient voltage suppressor CR1 provides overvoltage protection from input power line surges.

The NORM/OFF/REV POLARITY switch S2 is used to cancel the effects of small interference currents. This is accomplished by taking a bridge reading for both normal and reverse voltage polarity conditions and averaging the readings. The switch reverses the polarity to the primary winding of high-voltage transformer T2. The OFF position on the reversing switch provides a means of de-energizing the high-voltage output without returning VOLTAGE CONTROL T1 to 0. This feature is extremely useful when making measurements in energized high-voltage substations where the speed of measurement is important to obtain a good reading. It permits a quick check of the interference current cancellation between reversals without readjusting the VOLTAGE CONTROL.

The NORM/OFF/REV POLARITY switch, used in conjunction with zero-start switch S3, also controls the operation of relays K3 and K4. Relay K3 opens or closes the circuit between the VOLTAGE CONTROL T1 and high-voltage transformer T2. The relay also controls a single-pole contact in the reference generator circuit A3 which in turn controls the source of the reference voltage, i.e., it is derived from a voltage that is exactly in phase with the test voltage during measurements or derived from the input supply line when there is no output voltage. Relay K4 has two contact poles in the detector circuit A2 and a single contact pole in the reference generator circuit A3. The relay maintains the same directional phase relationship for the capacitance M4 and dissipation factor M3 display meters for both the NORMAL and the REV settings of switch S2.

The high-voltage section of the test set consists of high-voltage transformer T2, capacitor C1, and resistor R3. The transformer is double shielded and housed within a metal guard enclosure which is insulated from ground. The capacitor is a compact and rugged three terminal type which uses a parallel plate electrode configuration. The metal enclosure is tied to the guard circuit. Extreme care has been given to the selection of appropriate materials for mechanical strength and long-term stability of the capacitance value. The capacitor is hermetically sealed in sulfur hexafluoride (SF_6) gas to eliminate insulation tracking problems caused by surface condensation when operating under adverse weather conditions. The dielectric loss is maintained less than 1×10^{-5} (0.001%). Resistor R3 is the high-voltage portion of a voltage divider circuit used for measuring the output voltage. Spark gaps E2 to E6 are included to prevent a shock hazard to the operator or damage to the test set in the event of a test specimen breakdown.

The 5 KV/10 KV switch S7 selects the high-voltage output range. The primary windings of T2 are connected in series for the 5 kV range (50 to 1 turns ratio) and in parallel for the 10 kV range (100 to 1 turns ratio). This doubles the output current capability with the same input current when operating on the 5 kV range.

Power supply PS1 provides the ±15 V dc necessary to energize printed circuit boards A2 through A5. It also provides the +5 V dc necessary to energize digital panel meters M1, M2, and M3. All panel meters are identical and may be interchanged for troubleshooting purposes without disturbing calibration of voltage, current or dissipation factor ranges.

Transformer T5 is a ring-core differential current transformer made of highly permeable material. The windings controlled by switches S10 and S11 as well as potentiometer R6 are the bridge capacitance measuring dials. Switches S10 and S11 are decade switches which provide adjustment in steps of 10 (10 + 1) windings. Potentiometer R6 is a continuously variable slide wire dial which permits balancing the measuring dial to any fraction of a winding. Resistor R9 is an adjustable trimmer used to calibrate variable slide wire R6. The winding controlled by switch S9 is the capacitance multiplier dial. It has a series of fixed windings to provide step ratio and adjustments for the magnitude of capacitance. The multiplier step-wise adjustment is in steps of 1, 2, 10, 20, 100, 200, 1000, and 2000. The SHORT position provides protection to the bridge circuit when initially testing specimens of questionable insulation. An additional multiplier setting of 10,000 is included on Cat. No. 670070 and 670070-R for use in measuring large capacitances with the Resonating Inductor, Cat. No. 670600. Three decks on switch S9, in conjunction with RANGE switch S6, are used to control the stage gain of detector board A2, the decimal point for meter M3, and the overrange of meter M3 for an incorrect combination of capacitance multiplier dial and watts/milliwatts setting. Spark gap E1 is used to prevent damage to the differential current transformer in the event of a test specimen breakdown. The winding connected to detector board A2 is the winding used to detect the state of bridge balance. The entire differential current transformer is electromagnetically shielded.

Transformer T4 is used to step-down the 120 V ac line voltage to 12.6 V ac for use in reference generator circuit A3. Transformer T3 is a precision ring-core current transformer which is used to measure the output current of the test set.

Test mode selector switch S8 is used to manipulate the guard and ground connections to the red (J4) and blue (J5) low-voltage cable receptacles as well as to differential current transformer T5 for the various settings of the test mode selector switch.

Detector circuit A2 is a plug-in printed circuit board which contains the detector circuitry, consisting of a high input impedance voltage follower, several active filter stages and several gain control stages. The output is transmitted to two separate phase-sensitive detector channels, one to detect the capacitance balance and the other the dissipation factor/watts/milliwatts balance. Meter M4 shows the capacitance balance; M3 shows the dissipation factor/watts/milliwatts balance.

The six-position RANGE switch S6, related to meter M3, controls the stage gain in detector A2 for the 20 and 200% DF ranges and also the LO and HI watt/milliwatt ranges. The RANGE switch, in conjunction with capacitance multiplier dial S9, also controls the decimal point for meter M3 as well as the overrange for an incorrect combination of capacitance multiplier and watts/milliwatts setting.

SENSITIVITY switch S4, associated with detector board A2, is used to regulate the amplitude deflection of capacitance null detector meter M4.

TEST kV switch S5, associated with detector board A2, is used to control the stage gain so that a calibrated circuit gain is provided to correspond to each of the indicated values of S5.

Reference generator circuit A3 is a plug-in printed circuit board which contains the circuitry for generating square wave reference signals for the two separate phase-sensitive detector channels of

A2. One reference voltage is in phase with the capacitance current and the other in near perfect quadrature (90° phase shift) with respect to the capacitance current. The in-phase reference voltage is applied to the capacitance detector channel of A2 and the quadrature reference voltage to the dissipation factor detector channel of A2. In practice, if the detector and reference signals are in phase, the output signal from the phase sensitive detector A2 is positive; if they are 180° out-of-phase the output signal will be negative; if they are 90° phase shifted the output signal will be zero.

Interference suppressor circuit A4 is a plug-in printed circuit board that contains the circuitry for generating the signals used to cancel the effects of both the capacitance and the dissipation factor currents. The phases of the signals are automatically synchronized to the phase-sensitive detector channels. CAP INTERFERENCE SUPPRESSOR control R54 and DF INTERFERENCE SUPPRESSOR control R53 are used to adjust the magnitude of the cancellation currents. Switches S12 and S13 select the respective CAP and DF suppressor range. Each switch has an OFF position.

The output kV and mA circuitry A5 is a plug-in printed circuit board that contains two full-wave precision rectifier circuits to drive kilovoltmeter M2 and milliammeter M1. The LO/HI milliammeter range switch S15 controls the range and decimal point of milliammeter M1.

Section 5
Setup and Operation

Safety Precautions

The output of this test set can be lethal. As with any high-voltage equipment, caution must be used at all times and all safety procedures followed. Read and understand Section 2, Safety, before proceeding. Be sure that the test specimen is de-energized and grounded before making connections. Make certain that no one can come in contact with the high-voltage output terminal or any material energized by the output. Use protective barriers if necessary. Locate the control unit and high-voltage unit in an area which is as dry as possible.

Be sure that adequate clearances are maintained 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 5 shows a typical setup for testing a high-voltage capacitor. The test set controls and connectors are identified in Figures 2 and 3. Refer to Section 6, Application Notes, for specific instructions on connecting other specimens 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 and then install safety ground jumpers, before making connections.

CAUTION

To prevent damage to the test set, always set the capacitance multiplier dial to SHORT, the capacitance measuring dials to 0, the UST/GST test mode switch to one of the UST positions, and the interference suppressor switches to OFF before connecting or disconnecting the test set cables.

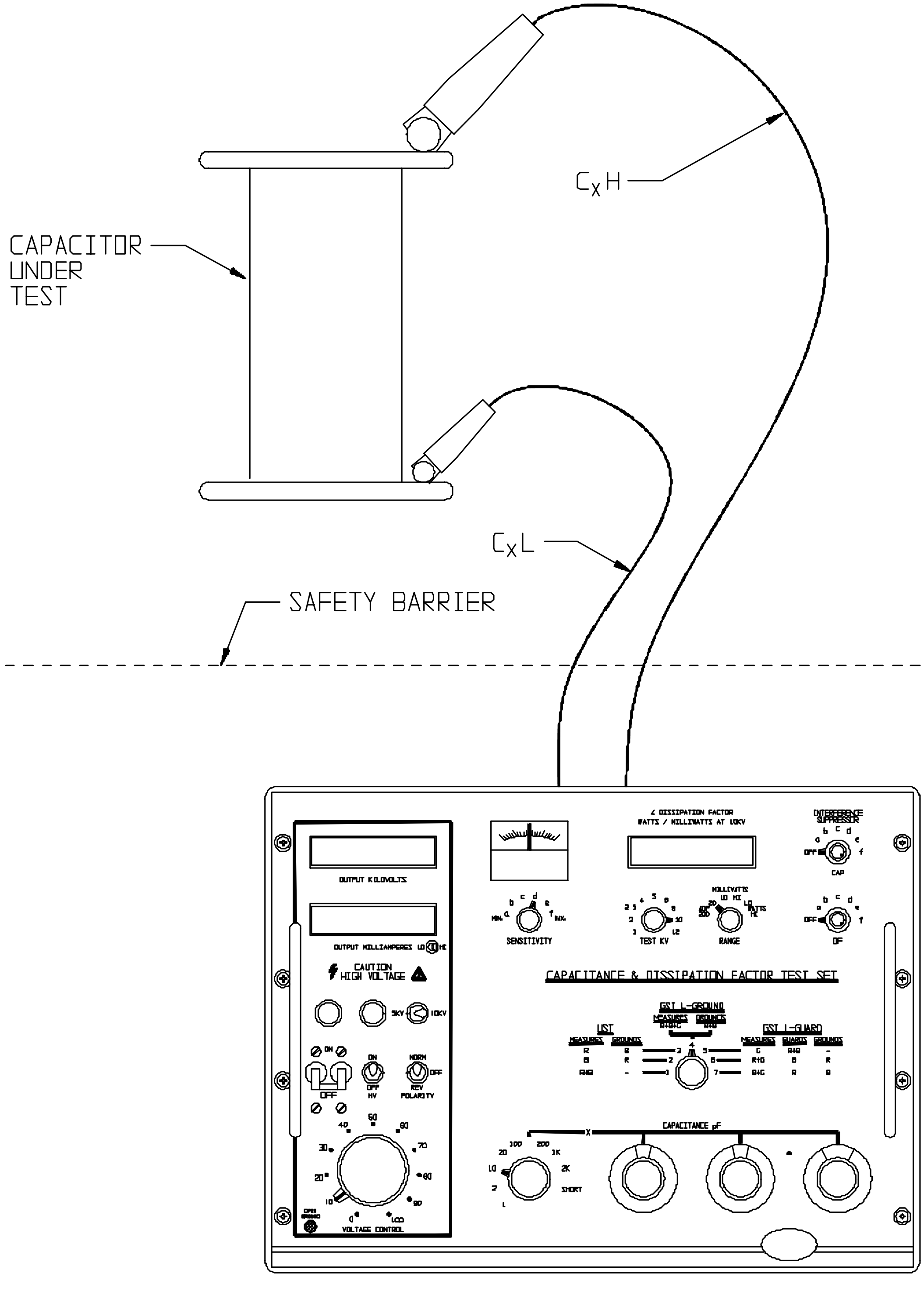


Figure 5: Typical Test Setup for Testing a High-Voltage Capacitor

1. Locate the test set at least 6 ft (1.82 m) from the specimen to be tested.
2. Connect the wing nut ground terminal of the test set to a low impedance earth ground using the 15 ft (4.5 m) ground cable supplied.
3. Connect the control unit to the high-voltage unit using the two 5-ft (1.5 m) shielded cables. Screw the plugs down fully on the receptacles.
4. Connect the low-voltage cable with red boot to the CxL RED terminal of the test set. Make sure the connection locks to the receptacle.
5. Connect the external interlock cable or a test area interlock system to the INTERLOCK terminal of the test set.
6. Connect the high-voltage cable with black boot to the high-voltage terminal of the high-voltage unit. Connect the pigtail for the outer shield to the black binding post (ground) on the high-voltage unit. Screw down the plug shell fully on the receptacle.

   Note: The exposed shield connection on the outboard end of the high-voltage output cable is at guard potential. Refer to Section 6, Application Notes, if a guarded test is to be run. 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.

7. With the main breaker switched OFF, plug the input power cord into the test set power receptacle and into a three-wire grounded power receptacle having the appropriate voltage rating and current capacity.
8. Connect the crocodile clip of the low-voltage cable to the low-voltage terminal of the specimen.
9. Connect the crocodile clip of the high-voltage cable to the high-voltage terminal of the
10. Proceed to Operating Procedure.

For transformer excitation current measurements, follow the same setup procedure except omit steps 7, 8, and 9. Connect the crocodile clip of the low-voltage cable to the low side of the transformer winding to be excited, H2 in Figure 6. Connect the crocodile clip of the high-voltage cable to the high side of the transformer winding to be excited, H1 in Figure 6. Proceed to Operating Procedure.

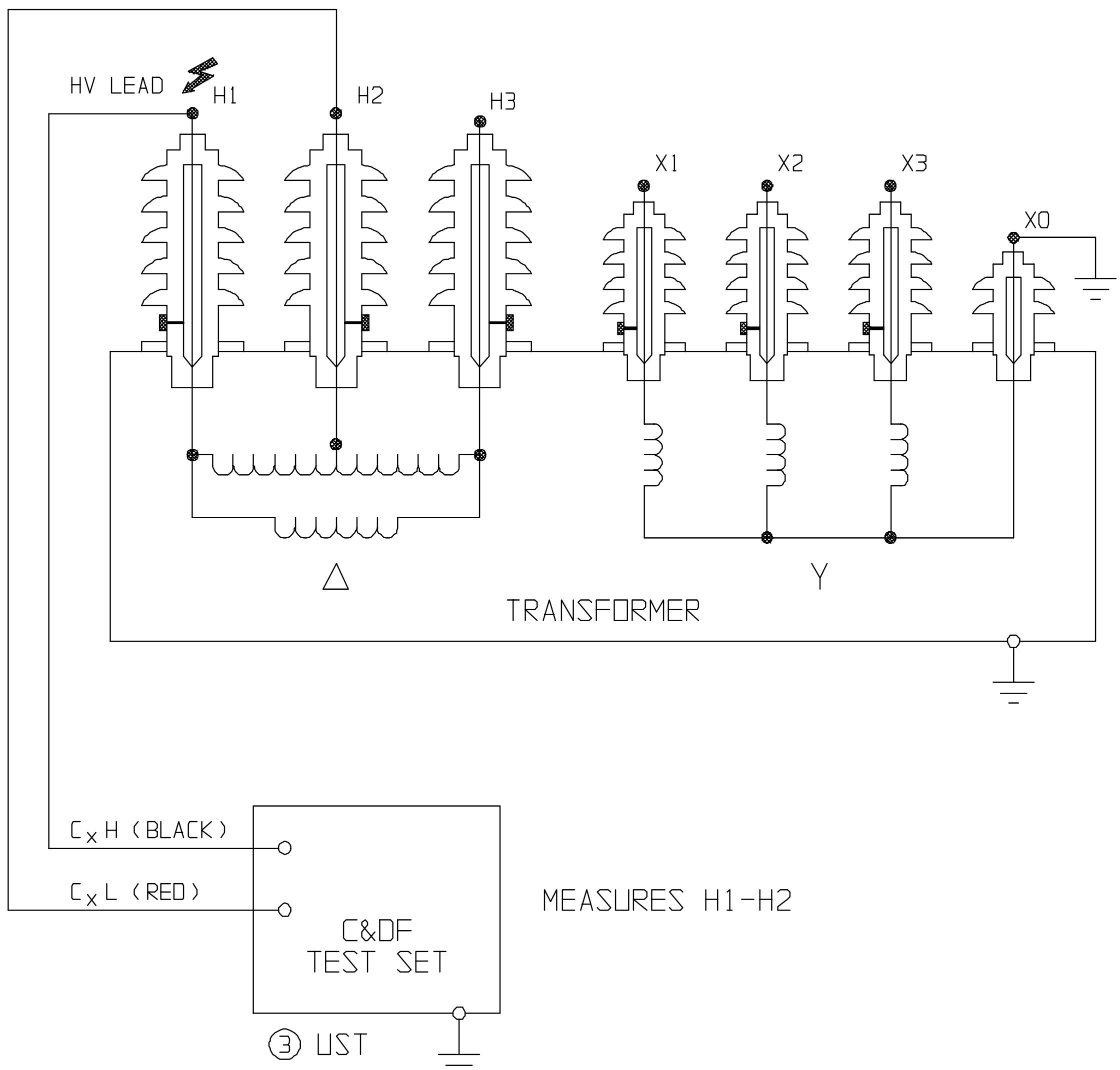


Figure 6: Typical Test Setup for Transformer Excitation Current Measurements

Operating Procedure in the Shop or Low-Voltage Substations

Proceed only after reading Section 2, Safety, and setting up the test set as described. An operator who is familiar with the contents of this manual, the test setup, and the operation of the test set may follow the condensed operating procedure in the lid of the test set. The following is a step-by-step procedure for conducting a test on a capacitance specimen.

1. Remove all safety grounds from the specimen to be tested.
2. Set the test set controls to the following initial settings:

Main breaker	OFF
HV ON/OFF switch	OFF
NORM/OFF/REV/POLARITY switch	NORM
VOLTAGE CONTROL	0
SENSITIVITY switch	d (normally)
Milliamperes LO/HI switch	LO (normally)
5 kV/10 kV switch	10 kV (normally)
TEST kV switch	10 kV (normally)
RANGE switch	20% (normally)
INTERFERENCE SUPPRESSOR switches	OFF
Capacitance multiplier switch	SHORT
Capacitance measuring dials	20.0

3. Set the UST/GST test mode selector switch to the required position for the particular test to be performed (UST 3 for this sample).
4. Energize the test set by switching the main breaker to ON. The green on indicator lamp and the three digital panel meters should light. If the OPEN GROUND lamp lights, it indicates that the ground circuit in the power cable is open, or that there is a high resistance ground between the ground cable and power cable ground. The test set cannot be energized with high voltage with an open ground.
5. Close the external interlock switch.
6. Set the HV ON/OFF switch to ON. The red high-voltage lamp should light. If this lamp does not light, ensure that the VOLTAGE CONTROL is set to 0.
7. Set the VOLTAGE CONTROL to desired test voltage, normally to 10 kV.
8. Turn the capacitance multiplier dial counterclockwise until the capacitance null detector indicator swings to the left, then increase setting of the capacitance measuring dials, starting with the highest value dial, to bring the null indicator to zero.

Note: If no reversal occurs when the capacitance multiplier dial reaches 1 pF, the value of the capacitance is less than 20 pF, and the setting of the capacitance measuring dials will have to be decreased to obtain a null balance. Turning the capacitance multiplier and measuring dials clockwise will move the meter pointer to the right.

If desired, the capacitance multiplier dial may be set at the range just before reversal, in which case the setting of the capacitance measuring dials will have to be decreased to obtain a null balance. For full accuracy, however, the left capacitance measuring dial should always have at least one step in the circuit at balance.

9. The sum of the three capacitance measuring dials multiplied by the setting of the capacitance multiplier dial gives the capacitance value of the test specimen.

10. Read the % dissipation factor value from the digital panel meter. Note the sign of the reading (+ or -). If the meter indicates an overrange, set the RANGE switch to 200% and increase the SENSITIVITY switch setting, normally position f.

11. Set the NORM/OFF/REV POLARITY switch to REV, momentarily pausing at the center OFF position. This can be done without disturbing the voltage control, for low value capacitance specimens. For high value specimens, the circuit breaker may trip out due to overload. When this happens it will be necessary to zero start the test voltage between reversals.

12. Rebalance the capacitance measuring dials, then read the capacitance and % Dissipation Factor values. The algebraic average of the NORM and REV polarity capacitance and dissipation factor readings gives the correct capacitance and dissipation factor values of the test specimen. If both readings are positive, add the two readings together then divide by two to find the average. When one reading is negative, subtract this value from the positive reading then divide by two to find the average.

    a. If a significant difference is observed between the NORM and REV polarity readings (>2%), use the INTERFERENCE SUPPRESSOR. Details on the use of this control are given in the following operating procedure.

CAUTION

The UST/GST configuration of the test set may be changed with full test voltage applied; however, care must be exercised to prevent damage to the specimen.

    b. Follow the same operating procedure for watts/milliwatts measurements. Use a LO watt/milliwatt range if possible. Use a HI watt/milliwatt range if the meter indicates an overrange. Use a high capacitance multiplier setting if the meter indicates an overrange when a HI watt/milliwatt range is used. Readings are equivalent to 10 kV watt/milliwatt values. This applies to all readings where the test voltage is adjusted to the exact nominal value as indicated by the setting of the TEST kV switch.

Note: The meter will overrange for an incorrect combination of capacitance multiplier dial and watt/milliwatt settings. A milliwatt range must be used for the 1 and 2 multiplier settings; a watt range must be used for the 10, 20, 100, 200 1K, 2K and SHORT multiplier settings. The desired watt/milliwatt range may be selected after a capacitance balance has been obtained.

13. When the test has been completed, gradually reduce the test voltage to zero, open the external interlock switch or switch the HV ON/OFF switch OFF, then turn the power OFF with the main breaker switch. The green on indicator lamp and the three digital panel meters should now be out.

IN CASE OF EMERGENCY —

POWER CAN BE INTERRUPTED IMMEDIATELY BY EITHER SWITCHING THE MAIN BREAKER OFF OR OPENING THE EXTERNAL INTERLOCK SWITCH.

14. Set the capacitance multiplier dial to SHORT, the capacitance measuring dials to 0, the UST/GST test mode selector switch to one of the UST positions, and the INTERFERENCE SUPPRESSOR switches to OFF.

WARNING

Discharge the 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.

Operating Procedure in Energized High-Voltage Substations

The normal measurement procedure, whereby the effects of small interference currents are cancelled by taking a normal and reverse voltage polarity reading, should not be used. The accuracy of this method may be seriously diminished since the average reading is commonly derived from two high value readings which are significantly different. Refer to Section 6, Application Notes, for additional information on electrostatic interference. Proceed as follows.

1. Make a preliminary measurement on the specimen for normal and reverse voltage polarity by following the preceding operating procedure. Set the SENSITIVITY switch to a. Adjust the capacitance multiplier and the two decade switches of the capacitance MEASURING dials for null balance. The same multiplier setting should be used for both voltage polarity readings.

2. Set the capacitance measuring dial to the approximate average reading of step 1, decade switches only.

3. Reset the SENSITIVITY switch to d, normally.

4. Set the NORM/OFF/REV POLARITY switch to OFF. An alternate procedure is to set the VOLTAGE CONTROL to 0. The red high-voltage lamp must remain lit.

5. Set the CAP and DF INTERFERENCE SUPPRESSOR switches to a.

6. Adjust the CAP INTERFERENCE SUPPRESSOR switch to obtain a null balance on the capacitance null detector meter, then adjust the DF INTERFERENCE SUPPRESSOR switch to obtain a zero reading on the % DISSIPATION FACTOR meter. Switch back and forth from CAP to DF control adjustment to obtain a finer balance, if required. If unable to reach zero with either control, set the CAP or DF switch to b or higher as necessary until both the CAP and DF switches can be adjusted for a zero reading. Always use the lowest possible range for each control.

7. Rebalance the capacitance measuring dials for normal and reverse polarity by following the basic operating procedure described previously. Read the capacitance and % DISSIPATION FACTOR (or watts/milliwatts) values.

    a. Avoid using the 1 and 2 capacitance multiplier dial settings when in the presence of a strong interference field.

    b. If unable to reach zero with either INTERFERENCE SUPPRESSOR control set to f, switch to a higher capacitance multiplier range. This will suppress the effects of interference pickup thereby reducing the amount of interference cancellation required.

    c. The INTERFERENCE SUPPRESSOR controls usually will have to be readjusted each time the capacitance multiplier range or UST/GST test mode selector switch is changed.

d. Turning the CAP INTERFERENCE SUPPRESSOR switch clockwise will move the meter pointer to the right. Turning the DF INTERFERENCE SUPPRESSOR clockwise will increase the digital meter reading.

e. The CAP and DF control adjustment need not be exact since the effect of any residual interference current will be cancelled by taking the average capacitance and dissipation factor (or watts/milliwatts) reading for normal and reverse voltage polarity.

f. In rare cases it may be necessary to set the capacitance multiplier to a range considerably higher than normal to cancel the effects of interference (capacitance measuring dial setting normally less than five steps on second measuring dial with first dial set to 0). It is strongly recommended that measurements be made using the LO or HI WATTS range rather than the 200% DF range. Adequate accuracy will be maintained with the second capacitance measuring dial set as low as 1, with the first measuring dial set to 0. When using a low capacitance measuring dial setting, the resolution on the interference suppressor controls will be considerably better on a WATTS range than on a % DF range. Operation in this manner should be limited to measurements in energized high-voltage substations only.

g. Tests should be made at 10 kV (specimen permitting) to suppress the effects of interference.

h. In some cases it may be desirable to compare a % DF reading to a previously recorded watts/milliwatts reading. Conversion formulas and charts are contained in Section 6. The exact method for converting % DF to watts/milliwatts is to convert separately the NORM and REV voltage polarity readings of C & DF to watts/milliwatts, then algebraically average the two readings. The exact method for converting watts/milliwatts to % DF is to use the algebraic average of the milliampere and watts/milliwatts readings to make the conversion.

Operating Procedure Intermediate Test Voltages

The test set is capable of making measurements at any test voltage, however, 500 V is the recommended minimum. The normal measurement procedure, whereby the effects of small interference currents are cancelled by taking a normal and reverse voltage polarity reading, should be used.

The capacitance measuring dials are direct reading for any test voltage, however, the % DF value (or watt/milliwatt value) must be calculated in accordance with the following formula:

$$\textit{\% DF value} = \textit{\% Dissipation Factor Reading x } \frac{\textit{TEST kV switch setting}}{\textit{OUTPUT KILOVOLTS reading}}$$

Example:

% Dissipation Factor reading = 1.6%

OUTPUT KILOVOLTS reading = 3 kV

TEST kV switch setting = 6 kV

% DF Value = 1.6 x 6/3 = 3.2%

Dissipation Factor Measurements Above 200%

The test set is capable of measuring a dissipation factor as high as 2000% by an indirect method. For this application a test voltage of less than 10 kV must be used. The 200% DF RANGE switch setting must also be used.

The normal measurement procedure, whereby the effects of small interference currents are cancelled by taking a normal and reverse voltage polarity reading, should be used.

The capacitance measuring dials are direct reading for any test voltage, however, the % DF value must be calculated in accordance with the formula given in the operating procedure for intermediate test voltages. Using the same TEST kV switch setting and output test voltage, the % DF range is increased to 400%. The 2000% DF maximum range is obtained by using the 10 TEST kV switch setting with an output test voltage of 1 kV. The same procedure can be used to increase the watt/milliwatt range.

Increased Dissipation Factor Resolution

The test set is capable of providing a dissipation factor resolution as small as 0.001% when testing samples which have an absolute value less than 2.0%. This feature is found to be useful for testing liquid samples where the dissipation factor is approximately 0.05% or less. For maximum resolution, a test voltage of 10 kV and a DF range of 20% must be used.

The normal measurement procedure should be used, whereby the effects of small interference currents are cancelled by taking a normal and reverse voltage polarity reading. The capacitance measuring dials are direct reading for any test voltage, however, the % DF must be calculated in accordance with the formula given in the operating procedure for intermediate test voltages.

To make a measurement with 0.001% DF resolution, adjust the output voltage to obtain a reading of 10 kV, then turn the TEST kV switch to 1 kV. Multiply the % DISSIPATION FACTOR meter reading by a factor of 1/10.

$$\frac{\text{1 kV switch setting}}{\text{10 kV output voltage}}$$

A resolution of 0.005% DF can similarly be obtained using an output voltage of 10 kV with a TEST kV switch setting of 5 kV. The same procedure is used for increased watt/milliwatt resolution.

Transformer Excitation Current Measurements

Proceed only after reading Section 2, Safety, and setting up the test set as described. An operator who is familiar with the contents of this manual, the test setup, and the operation of the test set may follow the condensed operating procedure in the lid of the test set.

To reduce the required charging current, conduct all tests on high-voltage windings only. Shorted turns will still be detected in the low-voltage windings. Low-voltage windings which are grounded in service (such as X_0) 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 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 is a step-by-step procedure for measuring transformer excitation current.

1. Proceed only after having read Section 2, Safety, and set up the test set as previously described.

2. Remove all safety ground jumpers from the transformer under test.

3. Set the test set controls as follows:

Main breaker	OFF
HV ON/OFF switch	OFF
NORM/OFF/REV POLARITY switch	NORM

VOLTAGE CONTROL	0
SENSITIVITY switch	a
Milliamperes LO/HI switch	LO (normally)
5 kV/10 kV switch	10 kV (normally)
TEST kV switch	10 kV (normally)
RANGE switch	200%
INTERFERENCE SUPPRESSOR switches	OFF
Capacitance multiplier switch	SHORT
Capacitance measuring dials	00.0

4. Connect the test set to the desired transformer winding as shown in Figure 7.

WARNING

During this test a voltage will be induced in all windings of the transformer. Treat all terminals as energized.

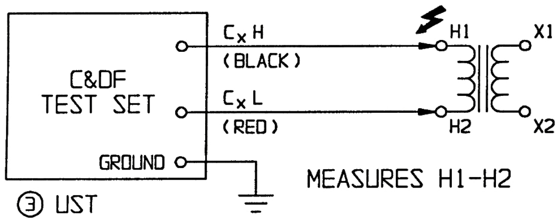
5. Set the UST/GST test mode selector switch to the required position for the particular test to be performed (normally UST-3).
6. Energize the test set by closing the main breaker switch.
7. Close the external interlock switch.
8. Set the HV ON/OFF switch to ON.
9. Advance VOLTAGE CONTROL to desired test voltage.
10. Read the value of transformer excitation current on the output milliammeter.

    Note: If the main breaker trips when advancing the VOLTAGE CONTROL, the output capabilities of the test set have been exceeded. Measure the transformer excitation current at a lower test voltage. The current capability is doubled by using the 5 kV voltage range.

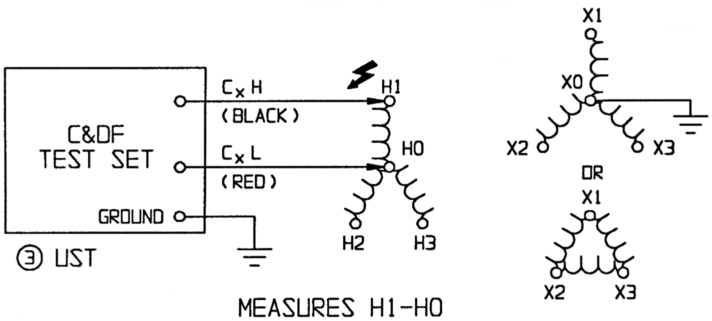
11. When the test has been completed, gradually reduce the test voltage to zero, open the external interlock switch or switch the HV ON/OFF switch OFF, then the main breaker to OFF.

IN CASE OF EMERGENCY —

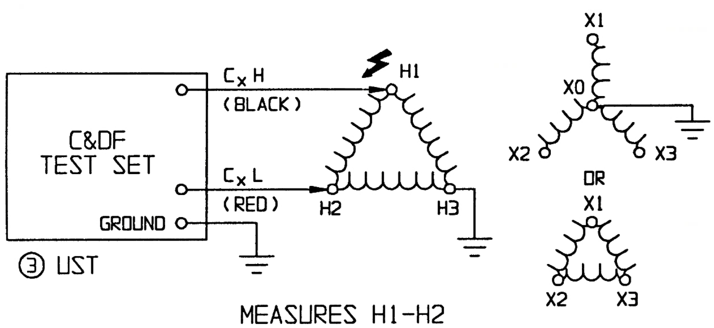
POWER CAN BE INTERRUPTED IMMEDIATELY BY EITHER SWITCHING THE MAIN BREAKER OFF OR OPENING THE EXTERNAL INTERLOCK SWITCH.



Measures	Test Lead Connections		
Terminal Symbol	Black	Red	Gnd
H1-H2 H2-H1	H1 H2	H2 H1	– –



Measures	Test Lead Connections		
Terminal Symbol	Black	Red	Gnd
H1-H0 H2-H0 H3-H0	H1 H2 H3	H0 H0 H0	– – –



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

Figure 7: Transformer Excitation Current Test Connections

WARNING

Discharge all 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.

Performance Check

General

This performance check is based on using a Cat. No. 670500-1 Capacitance and Dissipation Factor Standard to check the overall operation and accuracy of the test set. Proceed only after having read Section 2, Safety. Set up the test set as described except do not connect the outboard clip of the high-voltage or low-voltage cable to a test specimen. Suspend the exposed high-voltage cable termination in free air so that it is clear of all surrounding objects by at least 6 ft (1.82 m). Use dry nylon rope and secure cable at inboard side of shield clamp. Follow the general operating procedure for Capacitance and Dissipation Factor/Watts/Milliwatts Measurement in Shop or Low-Voltage Substations.

Power Supply and Digital Panel Meter Operation

Initially set the test set controls as described in the general operating procedure except set the capacitance measuring dial to 00.0. Set the UST/GST test mode selector switch to UST 3.

1. Set the main breaker to ON. The green ON lamp and the three digital panel meters should light. The output kilovoltmeter should read 0.00 ±0.01. The output milliammeter should read 00.0 ±0.1 for the LO milliammeter range and 000 ±1 for the HI milliammeter range. The % DISSIPATION FACTOR meter reading should be ignored at this point.
2. Set the VOLTAGE CONTROL to 10. Set the HV ON/OFF switch to ON and close the external interlock switch. The red high-voltage lamp should not light.
3. Set the VOLTAGE CONTROL to 0. The red high-voltage lamp should light.
4. Disconnect the ground lead at the GROUND terminal of the test set. The amber OPEN GROUND lamp should light and the red high-voltage lamp should go out.
5. Reconnect the ground lead. The amber OPEN GROUND lamp should go out and the red high-voltage lamp should light.
6. Advance the VOLTAGE CONTROL to 10. The red high-voltage lamp should remain lighted. The red high-voltage lamp should go out if either the HV ON/OFF switch is set to OFF or the external interlock switch is opened.

7. Re-energize the test set then advance the VOLTAGE CONTROL to 100 (maximum output). The kilovoltmeter should read nominally 6.3 kV on the 5 kV range and 12.6 kV on the 10 kV range when the input line voltage is 120.

8. With the test set still energized at nominally 12.6 kV, set the NORM/OFF/REV POLARITY switch to OFF. The output kilovoltmeter reading should drop to zero and the red high-voltage lamp should remain lighted. Now switch the NORM/OFF/REV POLARITY switch to REV. The kilovoltmeter should again read a nominal 12.6 kV. The main breaker should not trip-out during this test.

9. Gradually reduce the output voltage to zero, open the external interlock switch, set the HV ON/OFF switch to OFF, then switch the main breaker OFF. All lamps and digital displays should go out.

10. Connect the crocodile clip of the high-voltage cable to the crocodile clip of the low-voltage cable.

11. Set the 5 kV/10 kV switch to 10 kV and the milliammeter switch to HI.

12. Re-energize the test set and slowly advance the VOLTAGE CONTROL while observing the output milliammeter reading. Continue to advance the VOLTAGE CONTROL until the main breaker trips out. Note the milliammeter reading at the trip-out point. A normal reading is anywhere between 200 and 250 mA. A slight buzzing noise from the main breaker above 150 mA is normal.

13. De-energize the test set then switch the main breaker OFF.

14. Disconnect the high-voltage cable clip from the low-voltage cable clip.

15. If there are no malfunctions, proceed to Bridge Preliminary Check.

Bridge Preliminary Check

Initially use the same test setup as described in general performance check. Set the test set controls as follows:

Main breaker	OFF
HV ON/OFF switch	OFF
NORM/OFF/REV POLARITY switch	NORM
VOLTAGE CONTROL	0
SENSITIVITY switch	
Milliamperes LO/HI switch	LO
5 kV/10 kV switch	10 kV
TEST kV switch	10 kV
RANGE switch	20%

INTERFERENCE SUPPRESSOR switches	OFF
Capacitance multiplier switch	10
Capacitance measuring dials	20.0

1. Switch main breaker ON.
2. Observe the capacitance null detector pointer. It should read at zero within ±1/2 scale division for the UST 3 and GST 4 switch settings.
3. Observe the % DISSIPATION FACTOR meter reading. It should read as follows for the indicated switch settings.

% DISSIPATION FACTOR Meter Reading	CAPACITANCE Multiplier Setting	RANGE Switch Setting	UST/GST Switch Setting
0.00 ±0.10	10	20%	UST 3 & GST 4
00.0 ±0.1	10	200%	UST 3 & GST 4
00.0 ±2.0	1, 2	LO MILLIWATTS	UST 3
000 ±2	1, 2	HI MILLIWATTS	UST 3
OVERRANGE	10,20,100,200 1K,2K,10K,SHORT	LO MILLIWATTS	UST 3
OVERRANGE	10,20,100,200 1K,2K,10K,SHORT	HI MILLIWATTS	UST 3
OVERRANGE	1 & 2	LO WATTS	UST 3
OVERRANGE	1 & 2	HI WATTS	UST 3
0.000 ±0.001	10, 20	LO WATTS	UST 3
0.00 ±0.01	10, 20	HI WATTS	UST 3
0.00 ±0.01	100, 200	LO WATTS	UST 3
0.00 ±0.1	100, 200	HI WATTS	UST 3
00.0 ±0.1	1K,2K,10K,SHORT	LO WATTS	UST 3
000 ±1	1K,2K,10K,SHORT	HI WATTS	UST 3

Zero deviations greater than those indicated in steps 2 and 3 will not affect accuracy. These residual errors are cancelled by taking measurements for normal and reverse voltage polarity.

4. Set the RANGE switch to 20%, the SENSITIVITY switch to b, and the UST/GST test mode selector switch to UST 3.

5. Check the interference suppressor ranges for compliance to the following approximate values.

SUPPRESSOR Range	RANGE Setting	CAP. & DF Control Rotation	Capacitance Meter Reading	% DISSIPATION FACTOR Reading
a	20	max cw pos	1/4 div	0.6
b	20	max cw pos	1-1/4 div	3.0
c	20	max cw pos	2-1/2 div	6.0
d	200	max cw pos	1 div	20
e	200	max cw pos	3 div	60
f	200	max cw pos	7-1/2 div	145
a	20	max ccw pos	-1/4 div	-0.6
b	20	max ccw pos	-1-1/4 div	-3.0
c	20	max ccw pos	-2-1/2 div	-6.0
d	200	max ccw pos	-1 div	-20
e	200	max ccw pos	-3 div	-60
f	200	max ccw pos	-7-1/2 div	-145

6. If there are no malfunctions, proceed to Bridge Operation and Calibration Check.

Bridge Operation and Calibration Check

1. Initially set the test set controls to the settings as described in Bridge Preliminary Check except set the capacitance multiplier to 1 and the capacitance measuring dial to 100.0.

2. Set the UST/GST test mode selector switch to UST 3.

3. Connect the Capacitance and Dissipation Factor Standard to the test set as shown in Figure 8.

4. Set the % DF switch of the Capacitance and Dissipation Factor Standard to 0.

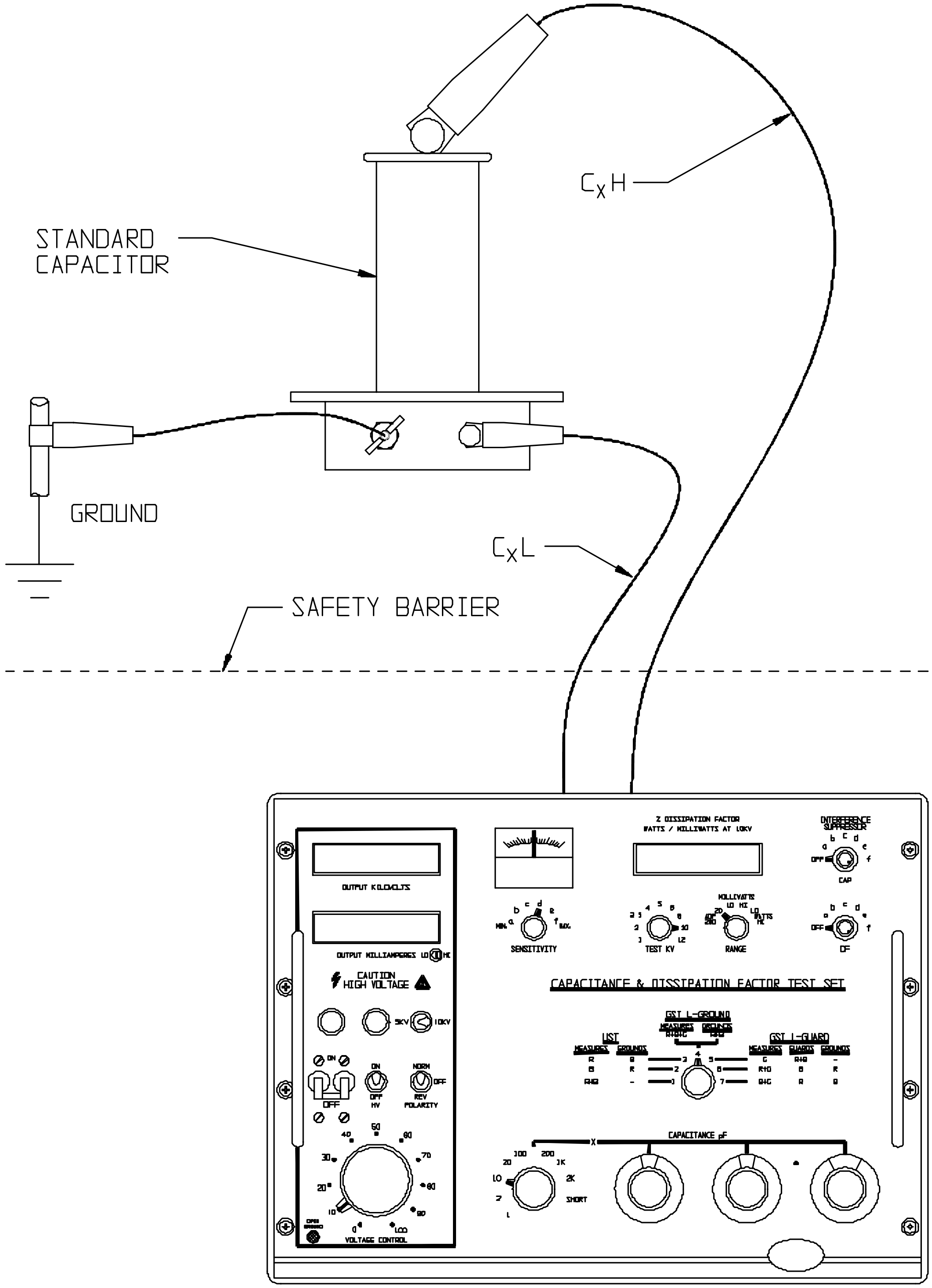


Figure 8: Test Setup for Calibration Check

5. Obtain capacitance and dissipation factor/watt/milliwatt readings on the test set for all the combinations of test set and standard dial settings as indicated in Table 2. Obtain all readings at a test voltage of exactly 10 kV, except as otherwise specified. All readings should be obtained for normal and reverse voltage polarity. If any difference is observed, the two readings should be average with due regard to the sign of the dissipation factor/watt/milliwatt reading. The readings for a new instrument should be within the tolerances indicated in Table 2 after correction is made for the errors of the capacitance and dissipation factor standard. Record the average readings on a work sheet as shown in Table 2.

6. Check the sensitivity of the capacitance measuring dial while making the first reading. A 0.1 pF change from null balance should cause approximately a two-division deflection on the capacitance null meter.

WARNING

Reduce the test voltage to zero, then de-energize the test set when changing the switch settings on the Capacitance and Dissipation Factor Standard.

7. Repeat the first three readings using the CxL blue cable instead of the CxL red cable. The respective UST/GST test mode selector switch settings are UST 2, GST 4 and GST 5.

This completes the performance check.

8. De-energize the test set, ground the high-voltage terminal of the standard, then disconnect the test set cables.

Table 2: Test Set Calibration Work Sheet

			Cap & DF Standard		Capacitance				% Dissipation Factor				Watts/Milliwatts			
Test No.	**Test Mode**	**Test kV**	**Nom pF**	**%DF Dial**	**Dial Rdng Norm/Rev**	**Mult**	**Cap pF**	**Rdng Tol Hi/Lo**	**Dial Rdng Norm/Rev**	**% Range**	**Meas %DF**	**Rdng Tol Lo/Hi**	**Dial Rdng Norm/Rev**	**Range**	**Meas W/mW**	**Rdng Tol Lo/Hi**
1	UST 3	10	100	0		1		99 101		0		-0.03 +0.03		LO mW		-1 +1
2	GST 4	10	132	0		2		126 138		20		0.0 0.5		LO mW		0 25
3	GST 5	10	32	0		1		27 37		20		0.0 1.5		Lo mW		0 25
4	UST 3	10	100	0		2		99 101		20		-0.03 +0.03		—		—
5	UST 3	10	100	0		10		99 101		20		-0.03 +0.03		—		—
6	UST 3	10	100	1.05		1		99 101		20		1.0 1.1		—		—
7	UST 3	10	100	3.2		1		98 102		20		3.1 3.3		LO mW		117 124
8	UST 3	10	100	3.2		2		98 102		20		3.1 3.3		LO mW		117 124
9	UST 3	10	100	3.2		10		98 102		20		3.1 3.3		LO W		0.117 0.124
10	UST 3	10	100	3.2		20		98 102		20		3.1 3.3		LO W		0.117 0.124
11	UST 3	10	100	10.5		1		97 103		20		10.3 10.7		—		—
12	UST 3	10	100	10.5		1		97 103		200		10.2 10.8		HI mW		385 407
13	UST 3	5	100	10.5		1		97 103		20		10.3 10.7		—		—
14	UST 3	2.5	100	10.5		1		97 103		20		10.3 10.7		—		—

Remarks:

Section 6
Application Notes

PRINCIPLE OF OPERATION

Most physical capacitors can be accurately represented as a two or three-terminal network as shown in Figure 9. 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) 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) the third terminal.

It is possible to have a complex insulation system which 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 10 shows a simplified measuring circuit diagram of the test set when operating in the UST 3 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 manual adjustment of the N_X and N_S turns.

The bridge is arranged so the capacitance dials vary N_S and the capacitance multiplier dial varies N_X. The reference capacitor (C_S) has a suitable fixed value of 100 pF to make the capacitance dials direct reading. A phase sensitive null detector connected to the third winding indicates the state of capacitance balance.

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 dials have been balanced. This represents the leakage (loss) component of current. This current component is extracted by a phase sensitive detector and is used to produce an automatic dissipation factor (watts/milliwatts) balance. The % dissipation factor/watts/milliwatts is displayed on a digital panel meter.

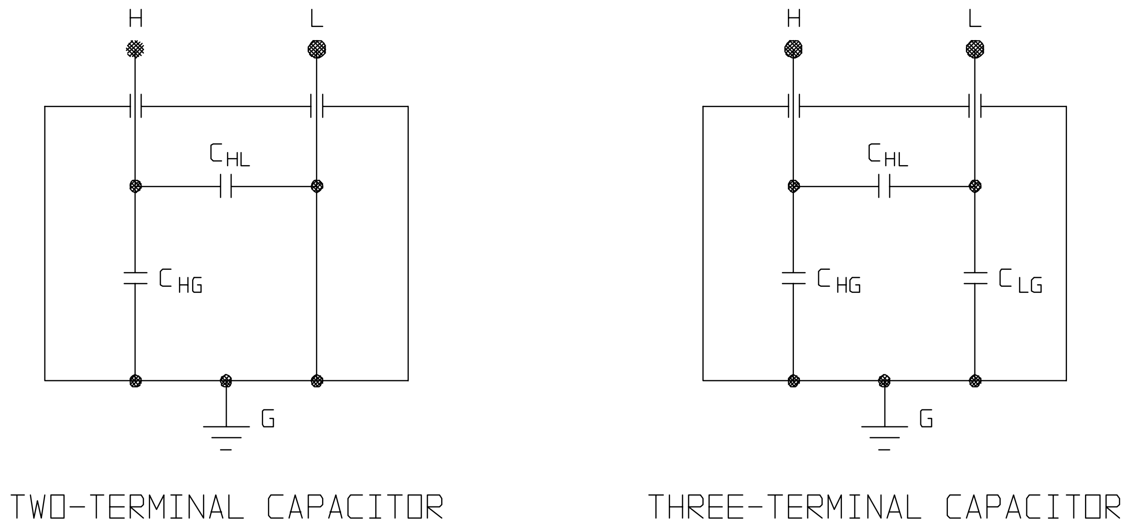


Figure 9: Two- and Three-Terminal Capacitors

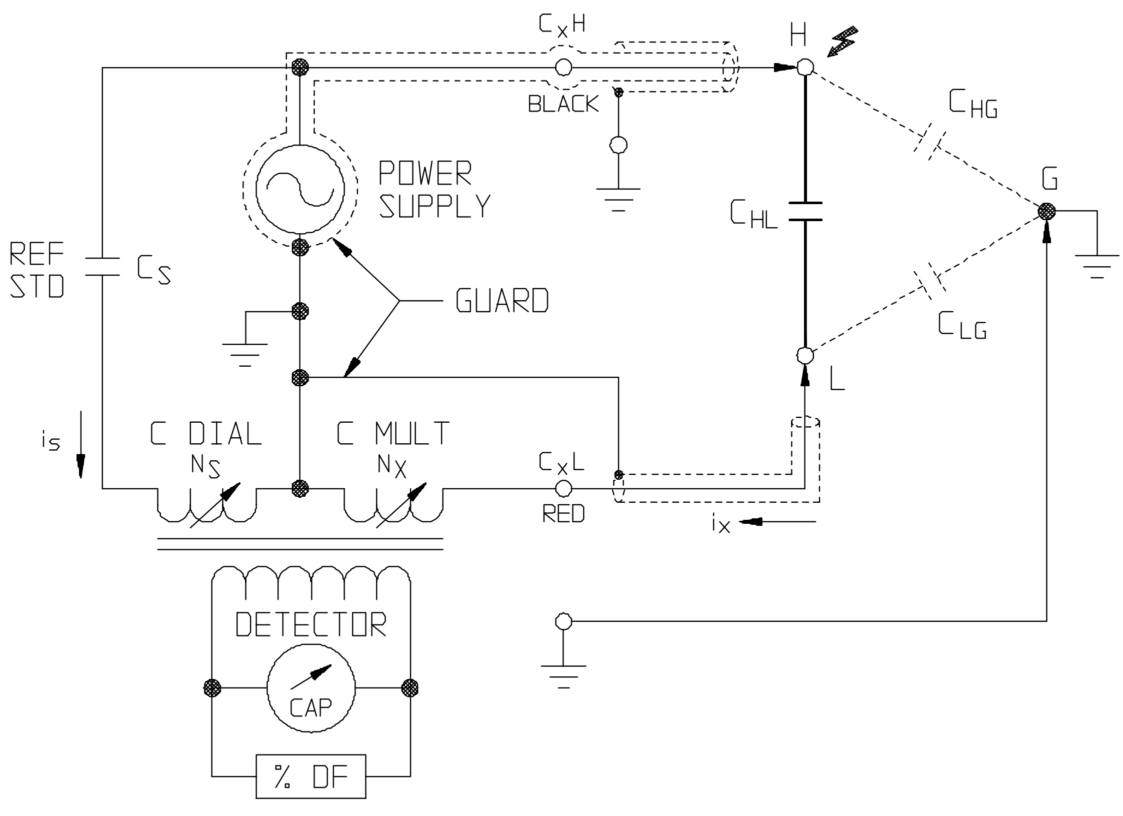


Figure 10: Simplified Measuring Circuit Diagram, UST 3 Test Mode

Figure 10 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 11 shows the measuring circuit and guarding for the GST L-GROUND 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 C_xH 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 12 shows the measuring circuit and guarding for the GST L-GUARD 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 shown in Figure 13.

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

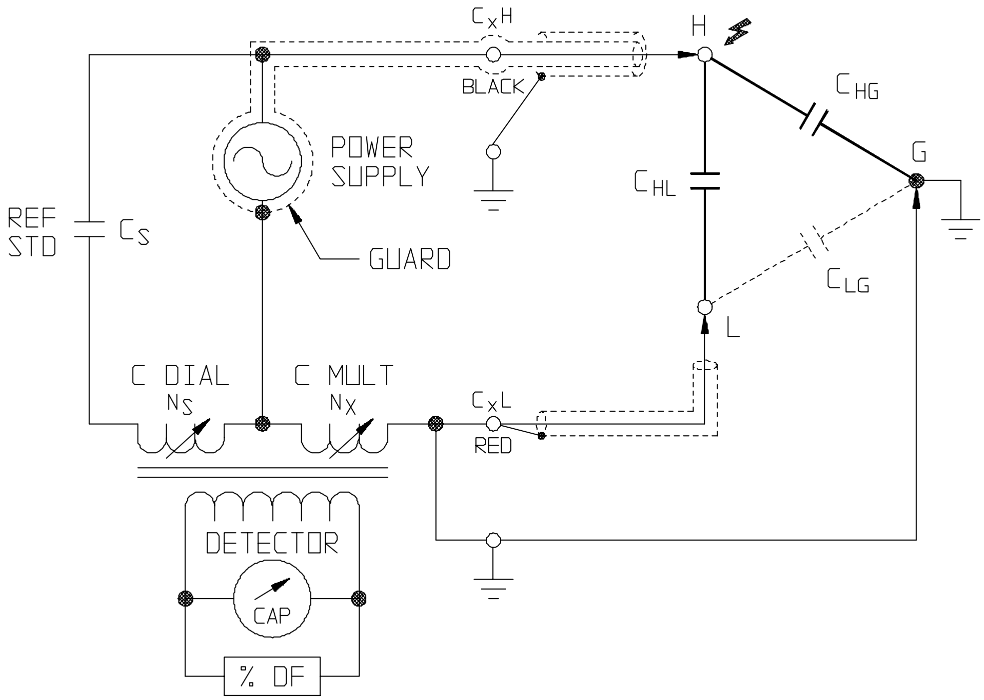


Figure 11: Simplified Measuring Circuit Diagram, GST L-GROUND 4 Test Mode

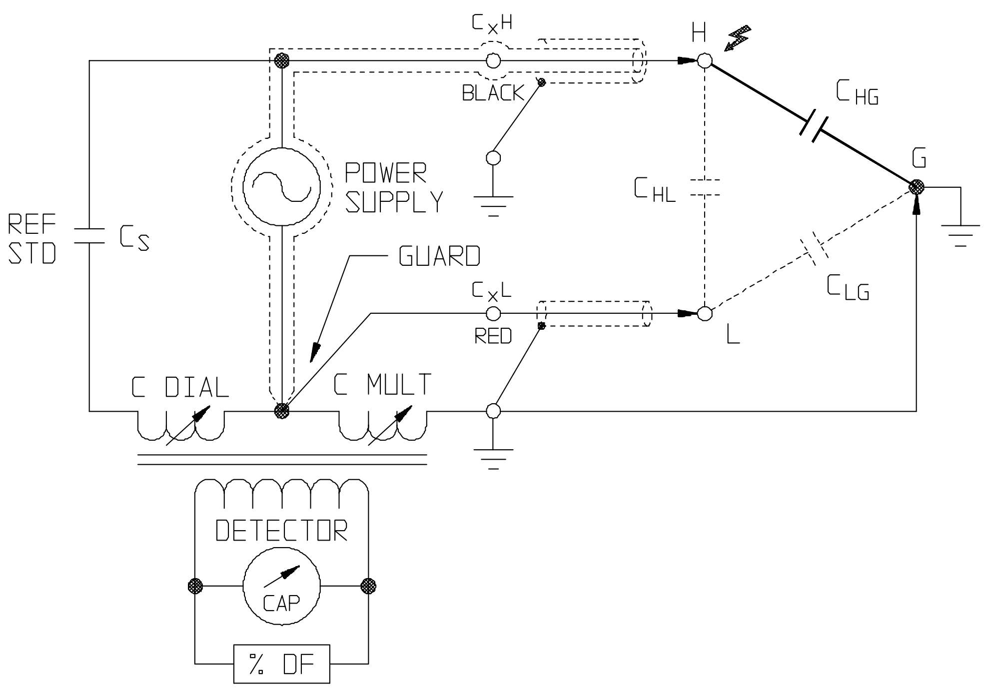
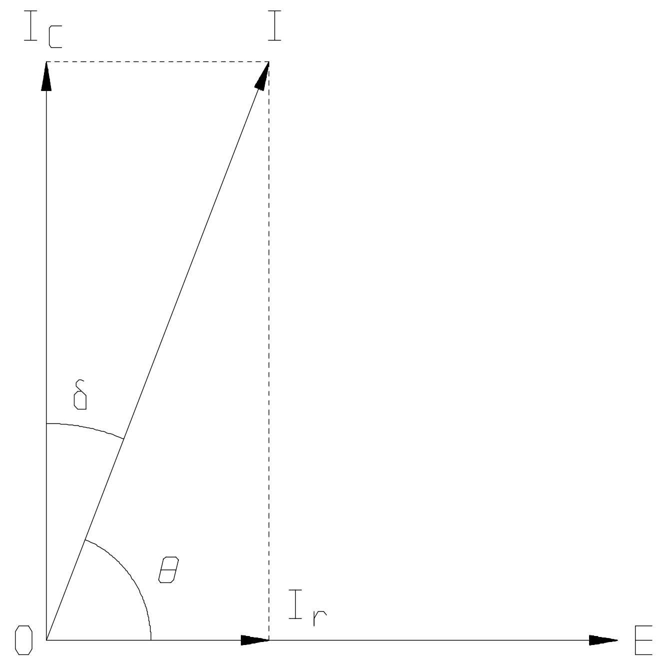
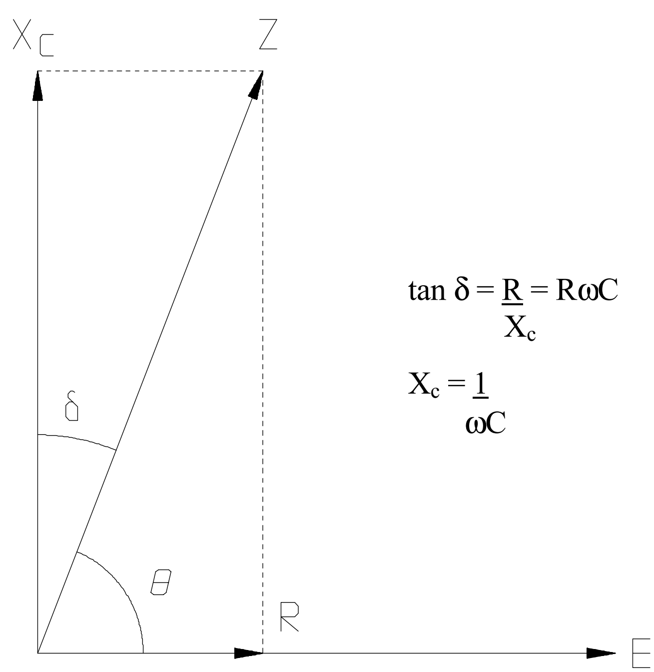


Figure 12: Simplified Measuring Circuit Diagram, GST L-GUARD 5 Test



Mode

Figure 13: Vector Diagram Insulation System



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

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

Figure 14: Vector Diagram Showing Resistance and Reactance

The power factor is defined as:

$$Power\,factor \;=\; \cos\,\theta \;=\; \sin\,\delta \;=\; \frac{I_r}{I}$$

and the dissipation factor is defined as:

$$Dissipation\,factor \;=\; \cot\,\theta \;=\; \tan\,\delta \;=\; \frac{I_r}{I_c}$$

his test set is calibrated for direct reading in terms of capacitance and dissipation factor (tan δ).

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 14.

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

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

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

$\tan\delta = R_{s\omega}\ C_s$

To find the equivalent parallel impedance C_p and R_p, the conversion formulas shown in Figure 16 must be used.

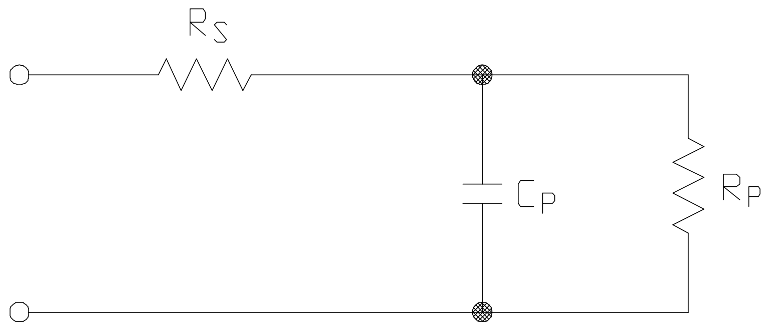


Figure 15: Equivalent Circuit for Capacitor Losses

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

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

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

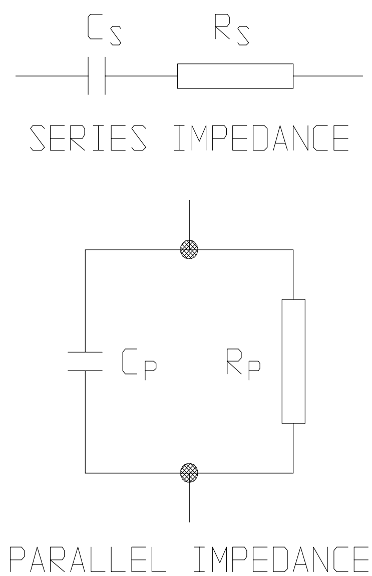


Figure 16: Series - Parallel Equivalent Circuit

CONVERSION FORMULAS

Use the following formulas and the chart shown in Figure 17 to compare the capacitance reading obtained on the Biddle test set against the milliampere reading obtained on the Doble test set as well as the Biddle dissipation factor reading versus the Doble watts loss reading. The Doble mVA 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). Relevant nomographs are contained in Appendix A.

Conversion Formulas for test at 2.5 kV, 60 Hz
(based on Doble equivalent 2.5 kV values)

$C_{pF} = mA \times 1061$

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

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

Applicable when DF (PF) is less than 20%

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

Conversion Formulas for test at 10 kV, 60 Hz
(based on Doble equivalent 10 kV values)

$C_{pF} = mA \times 265$

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

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

Applicable when DF (PF) is less than 20%

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

Conversion Formulas for test at 2.5 kV, 50 Hz
(based on Doble equivalent 2.5 kV values)

$C_{pF} = mA \times 1273$

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

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

Applicable when DF (PF) is less than 20%

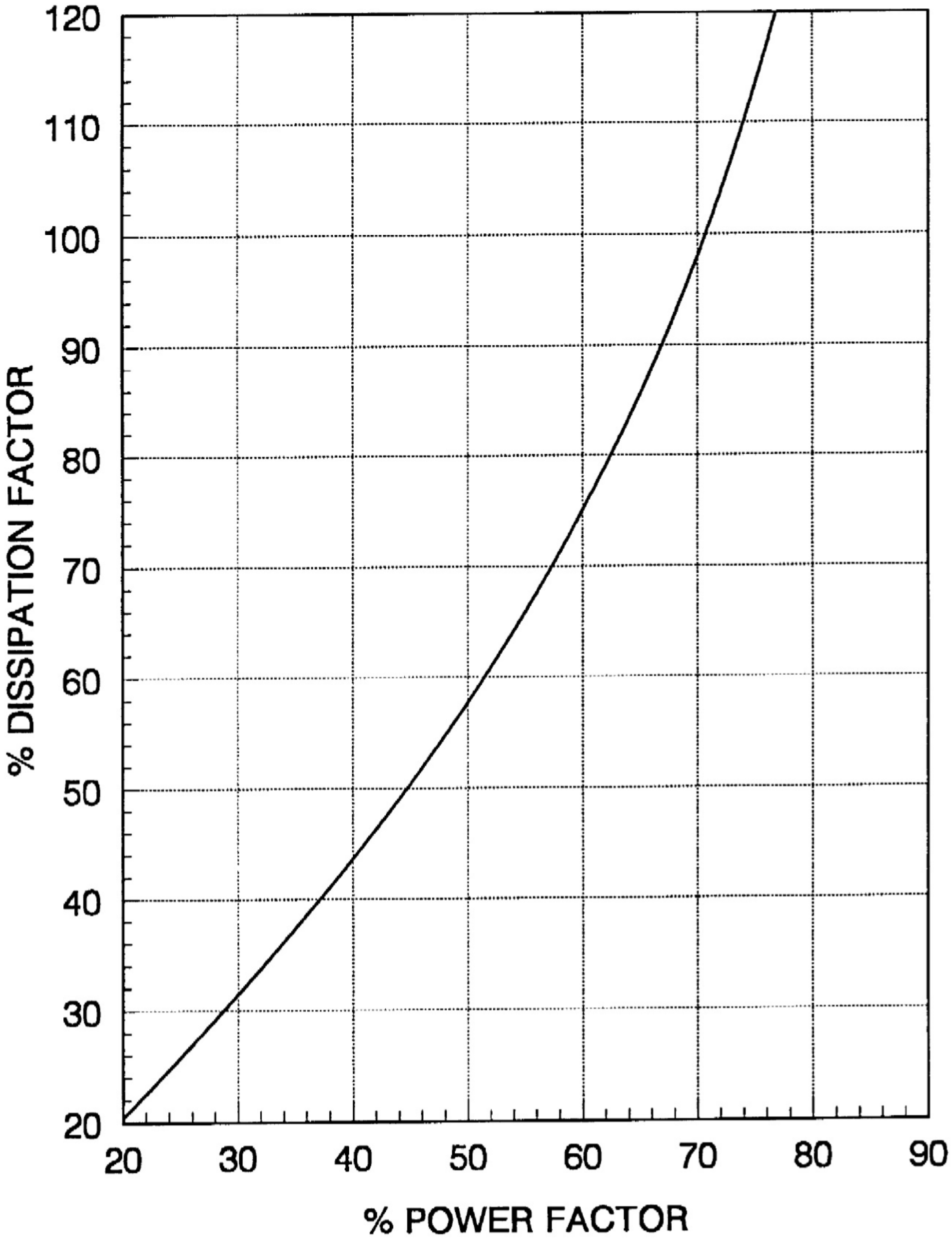


Figure 17: Graph for Converting Power Factor vs. Dissipation Factor

$W_{loss} = C_{pF}$ x %DF x 19.6 x 10^{-6} — No limitation

Conversion Formulas for test at 10 kV, 50 Hz (based on Doble equivalent 10 kV values)

C_{pF} = mA x 318

mA = C_{pF} x 314 x 10^{-5}

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

Applicable when DF (PF) is less than 20%

$W_{loss} = C_{pF}$ x %DF x 314 x 10^{-6} — No limitation

General Conversion Formulas

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

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

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

mA = kV ω C_{pF} x 10^{-6} — Applicable when DF (PF) is less than 20%

mA = kV x C_{pF} x 377 x 10^{-6} @ 60 Hz

mA = kV x C_{pF} x 314 x 10^{-6} @ 50 Hz

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

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

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

No limitation

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

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

No limitation

where:

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

CONNECTIONS FOR UST/GST TEST MODES

Figures 18 through 21 show the specific connections between the test set and specimen for each setting of the UST/GST test mode selector switch. The following chart shows the specific component of capacitance and dissipation factor that is measured for each setting of the UST/GST test mode selector switch, as well as how the test set automatically connects the low-voltage red and blue CxL test leads to either guard or ground in the bridge circuit. The component measured is shown by the heavy solid line in Figures 18 through 21. Measurements are always made between the CxH (black boot) high-voltage lead and the lead referenced in the Measures column.

UST/GST Test Mode Selector Switch Settings

Test Mode	UST		
	Measures	Grounds	
1	R + B	—	
2	B	R	
3	R	B	
	GST L-GROUND		
	Measures	Grounds	
4	R + B + G	R + B	
	GST L-GUARD		
	Measures	Guards	Grounds
5	G	R + B	—
6	R + G	B	R
7	B + G	R	B

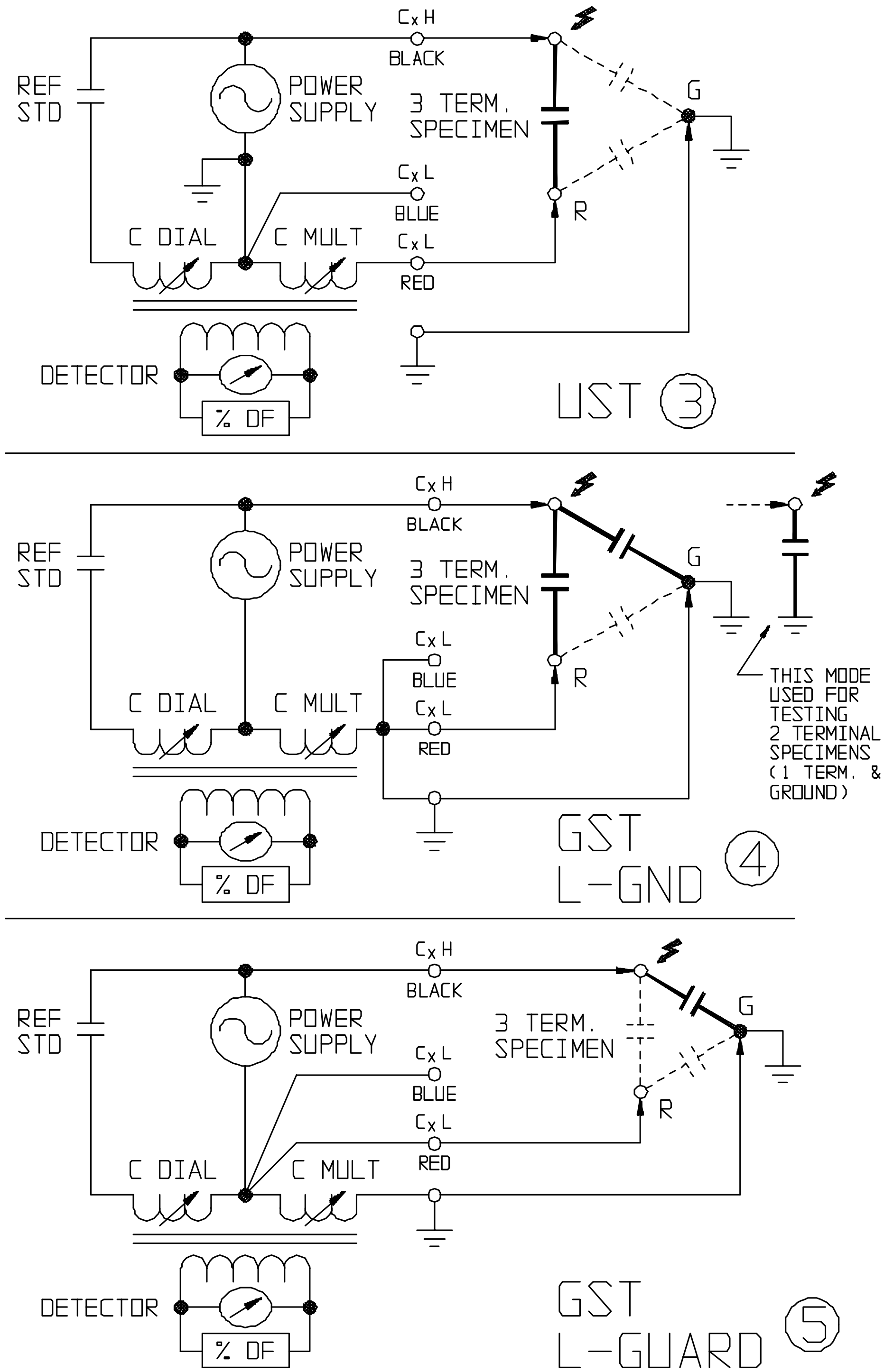


Figure 18: Connection for Three-Terminal Specimen, Test Modes 3, 4, and 5

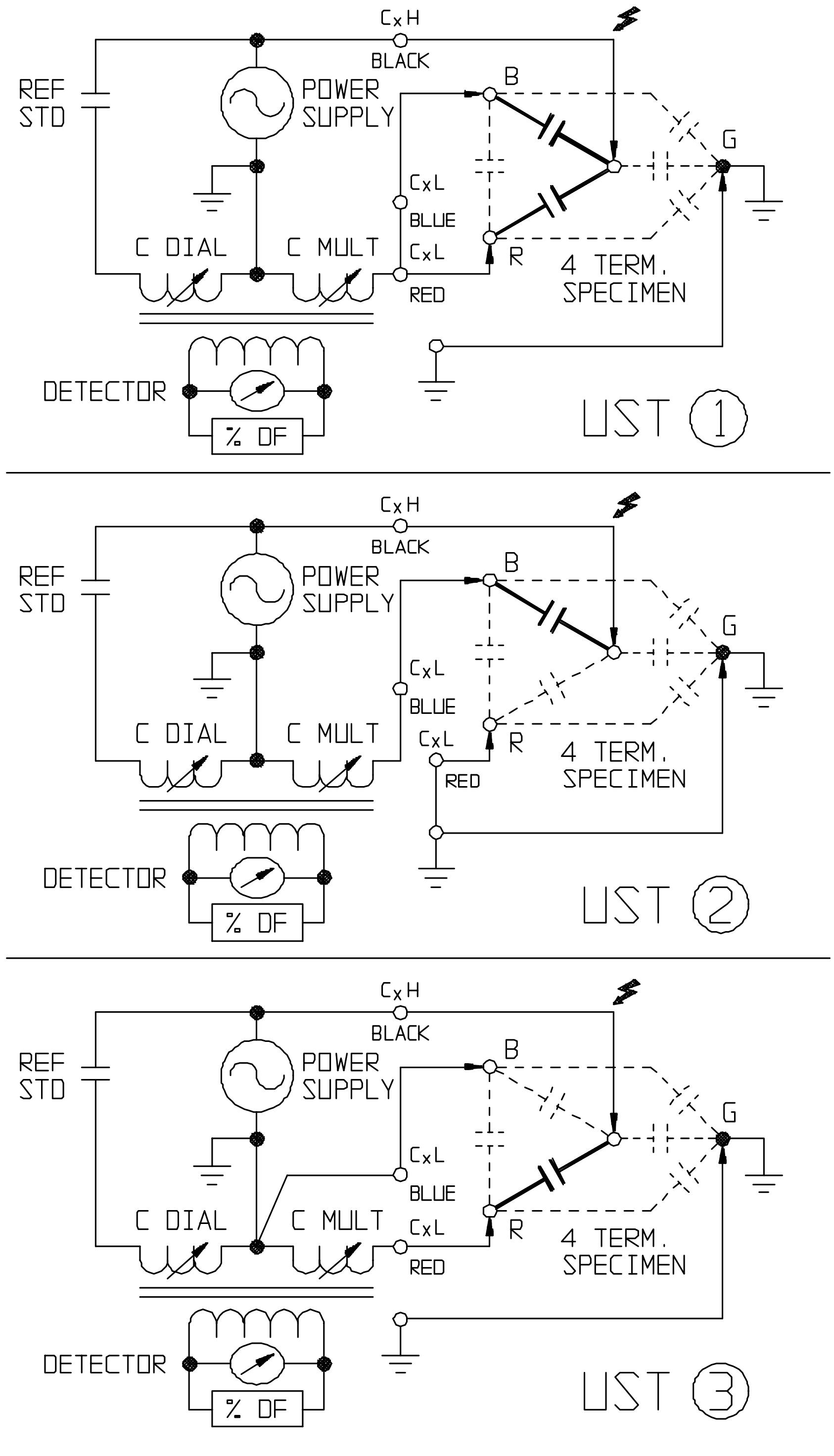


Figure 19: Connection for Four-Terminal Specimen, Test Modes 1, 2, and 3

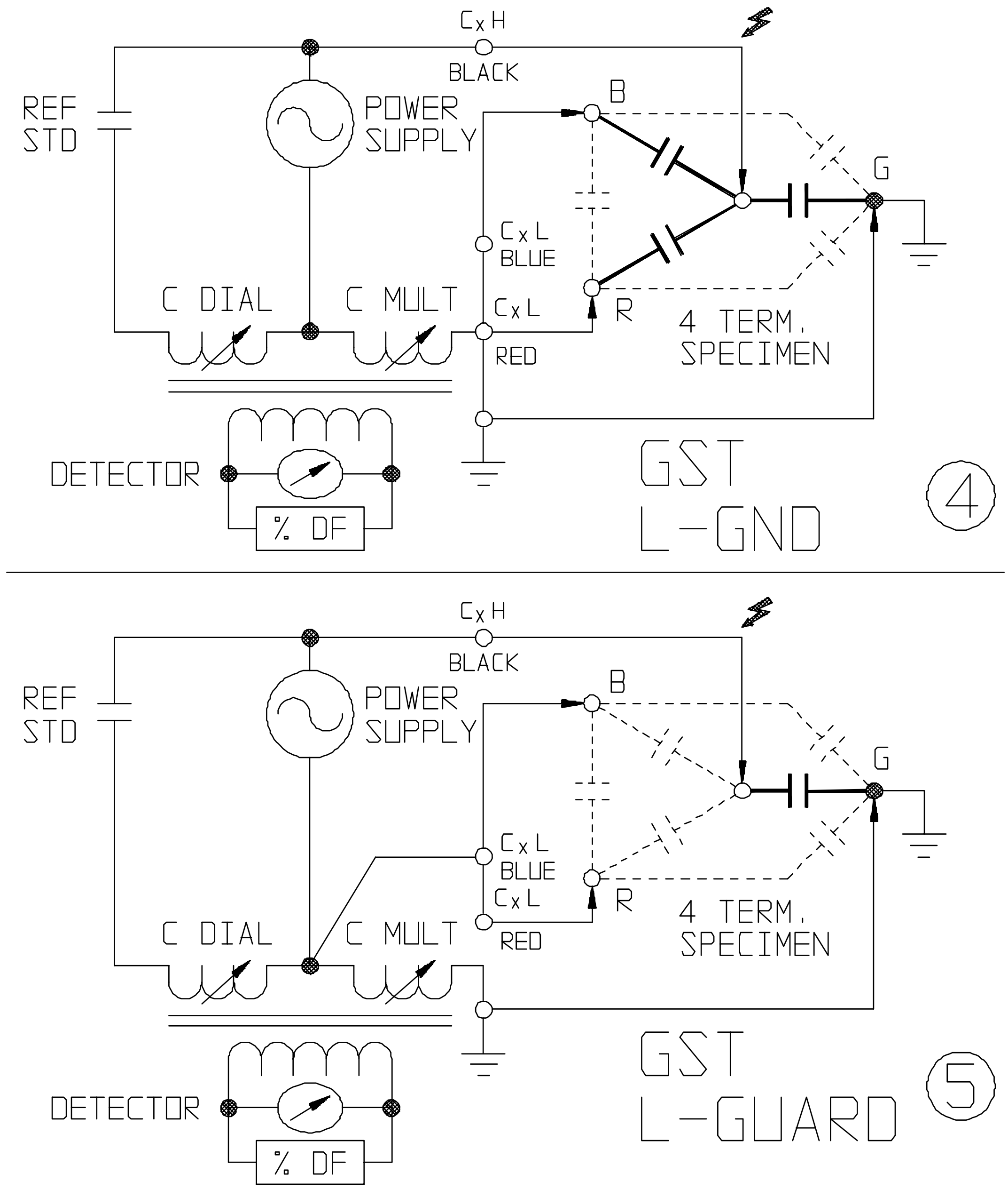


Figure 20: Connection for Four-Terminal Specimen, Test Modes 4 and 5

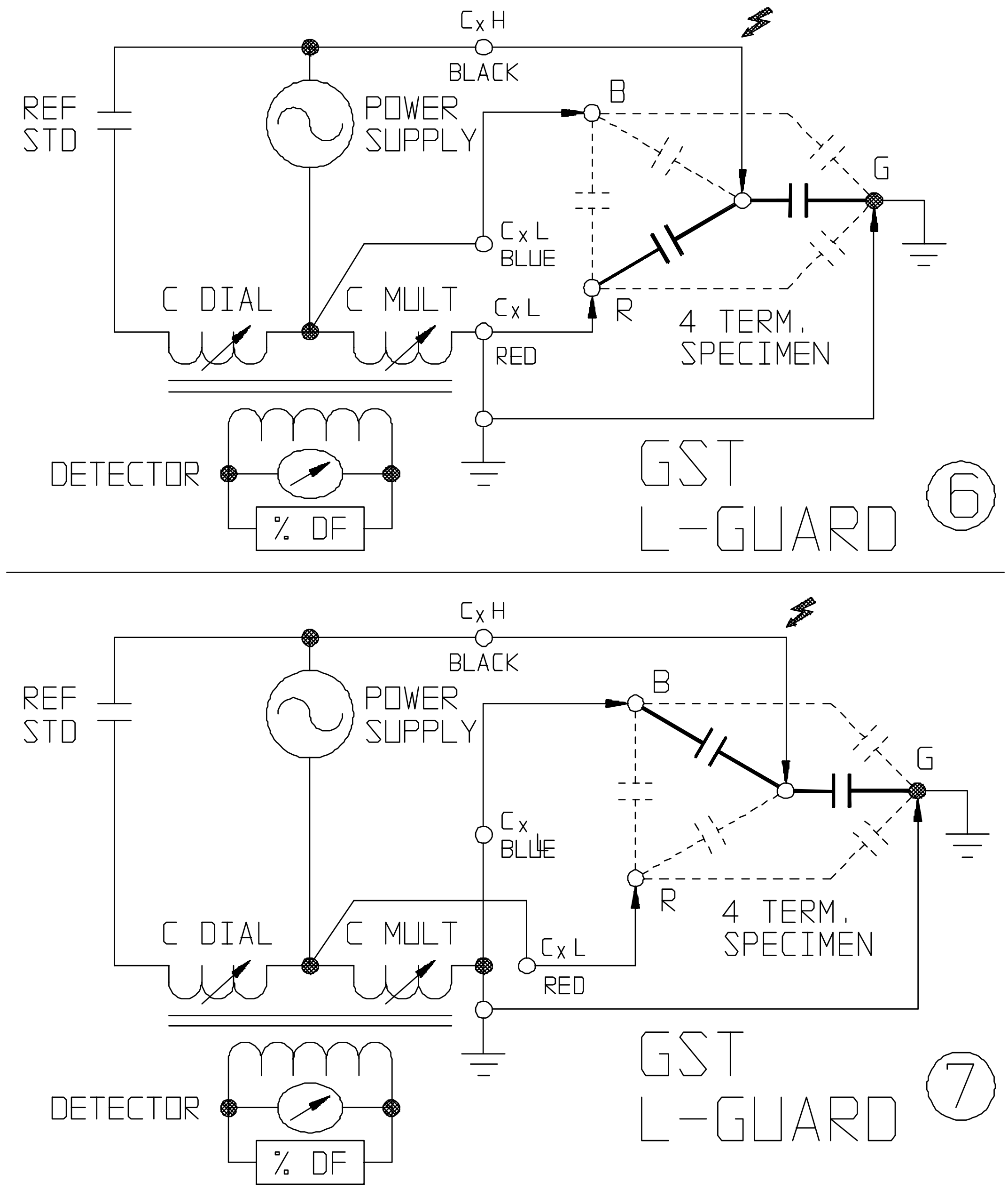


Figure 21: Connection for Four-Terminal Specimen, Test Modes 6 and 7

INTERPRETATION OF MEASUREMENTS

a. 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.

b. Dissipation Factor of Typical Apparatus Insulation

Values of insulation dissipation factor for various apparatus are shown in Table 3. 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 3: DF of Typical Apparatus Insulation

Type Apparatus		**% DF at 20EC**
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	.03 to 3.0

c. 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 4.

Table 4: Permittivity of Typical Insulating Materials

Material	**k**	**% DF 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 (0EC)

* 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.

d. 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 20EC (68EF). A column is provided on all Biddle test data sheets, shown in Appendix B, for listing the dissipation factor value at a 20EC reference temperature. Tables of multipliers for use in converting dissipation factors at test temperatures to dissipation factors at 20EC are normally available from the apparatus manufacturer.

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 before test, the temperature of the oil normally exceeds the ambient temperature. The bushing test temperature in 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.

e. 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.

f. 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.

g. 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 cancelled by taking normal and reverse voltage polarity readings. In high-voltage substations the effects of electrostatic interference currents can be cancelled by using the interference suppressor circuit. Normal and reverse voltage polarity 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.
- Using lower than normal detector sensitivity, especially if the interference signal varies.
- Using the 200% dissipation factor range or high watt/milliwatt range.
- Using a higher than normal capacitance multiplier dial setting. This will suppress the effects of interference pickup.
- 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 corona 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 corona 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.

h. 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 L-GUARD 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.

TYPES OF APPARATUS

a. 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 L-GUARD test). In a two-winding transformer, a measurement should also be made between each winding and ground with the remaining winding grounded (GST L-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 L-GUARD test). 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 22 shows a typical setup for testing a two-winding transformer, Table 5 outlines the specific connections between the test set and two-winding transformer for each position of the UST/GST test mode selector switch. Table 6 specifies the connections for three-winding transformers. Note that each winding should be shorted on itself at its bushing terminals. It is recommended that the Measurement Intercheck calculations, specified on test connection charts of Tables 5 and 6 be performed to validate all measurements. The calculated intercheck values should agree with the direct measurement values within reasonable limits. A sample test data report form is shown in Appendix B.

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 20EC.

b. 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.

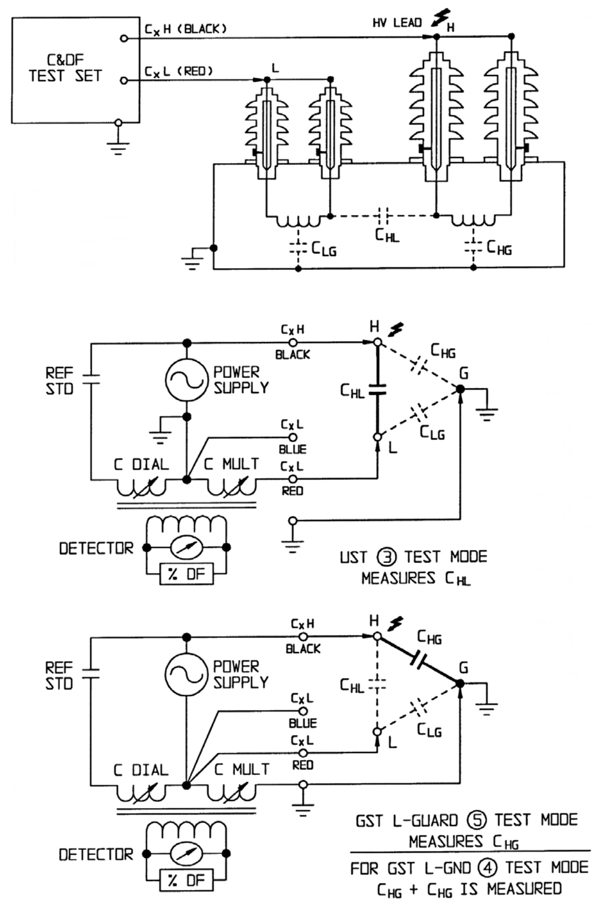
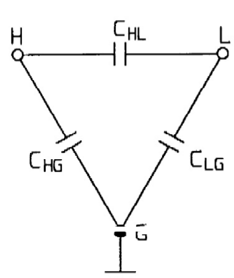


Figure 22: Two-Winding Transformer Tests

Table 5: Two-Winding Transformer Test Connections

Test No.	**UST-GST Mode**		**Measures**		**Test Lead Conn**			**Remarks**
	Test Type	**Pos**	**Cap. Symbol**	**Bridge Symbol**	**Black**	**Red**	**Blue**	
1	UST	3	C_{HL}	R	H	L	—	
2	GST L-GND	4	$C_{HL}+C_{HG}$	R+B+G	H	L	—	L grounded
3	GST L-GUARD	5	C_{HG}	G	H	L	—	L guarded
4	UST	3	C_{HL}	R	L	H	—	
5	GST L-GND	4	$C_{HL}+C_{LG}$	R+B+G	L	H	—	H grounded
6	GST L-GUARD	5	C_{LG}	G	L	H	—	H guarded
7	GST L-GND	4	$C_{HG}+C_{LG}$	R+B+G	H & L	—	—	
8								
9								
10								

Equivalent Circuit



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

Note: Short each winding on itself.

Measurement Interchecks (Calculated)

$$C_1 = C_2 - C_3$$

$$C_4 = C_5 - C_6$$

$$DF_1 = \frac{C_2 DF_2 - C_3 DF_3}{C_2 - C_3}$$

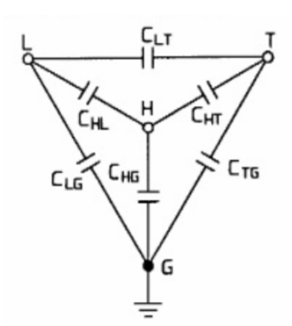
$$DF_4 = \frac{C_5 DF_5 - C_6 DF_6}{C_5 - C_6}$$

Note: Subscripts are test numbers.

Table 6: Three-Winding Transformer Test Connections

Test No.	UST-GST Mode		Measures		Test Lead Conn			
	Test Type	Pos	Cap. Symbol	Bridge Symbol	Black	Red	Blue	Remarks
1	UST	3	C_{HL}	R	H	L	T	T grounded
2	GST L-GUARD	6	$C_{HL}+C_{HG}$	R+G	H	L	T	T guarded L grounded
3	GST L-GUARD	5	C_{HG}	G	H	L	T	L & T guarded
4	UST	3	C_{LT}	R	L	T	H	H grounded
5	GST L-GUARD	6	$C_{LT}+C_{LG}$	R+G	L	T	H	H guarded T grounded
6	GST L-GUARD	5	C_{LG}	G	L	T	H	T & H guarded
7	UST	3	C_{HT}	R	T	H	L	L grounded
8	GST L-GUARD	6	$C_{HT}+C_{TG}$	R+G	T	H	L	L guarded H grounded
9	GST L-GUARD	5	C_{TG}	G	T	H	L	H & L guarded
10	GST L-GND	4	$C_{HG}+C_{LG}+C_{TG}$	R+B+G	H+L+T	—	—	

Equivalent Circuit



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

Note: Short each winding on itself.

Measurement Interchecks (Calculated)

$$C_1 = C_2 - C_3$$

$$C_4 = C_5 - C_6$$

$$C_7 = C_8 - C_9$$

$$DF_1 = \frac{C_2 DF_2 - C_3 DF_3}{C_2 - C_3}$$

$$DF_4 = \frac{C_5 DF_5 - C_6 DF_6}{C_5 - C_6}$$

Note: Subscripts are test numbers.

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 2.5 kV watts/milliwatts regardless of the test voltage used. To obtain watts from a measurement of capacitance and dissipation factor, refer to the conversion formulas.

Table 7, Oil Circuit Breaker Test Connections, outlines the specific connections between the test set and breaker as well as the series of measurements which should be performed on the breaker. A sample circuit breaker test data form is shown in Appendix B.

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 will also 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 disturbed differently. Table 8 summarizes 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.

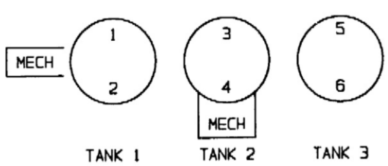
Oil circuit breakers are composed of many different materials each having its own temperature coefficient. For this reason it may be difficult to correct tank-loss indexes for a standard temperature. On this basis, an attempt should be made to conduct tests at approximately the same time of the year to minimize temperature variations. The measurements on the bushings, however, may readily be corrected to the base temperature, usually 20EC. 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 7: Oil Circuit Breaker Test Connections

	UST-GST Mode		**Measures**		**Test Lead Conn**			
Test No.	**Test Type**	**Pos**	**Cap. Symbol**	**Bridge Symbol**	**Black**	**Red**	**Blue**	**Remarks**
1	GST L-GUARD	5	C_{1G}	G	1	2	—	2 guarded
2	GST L-GUARD	5	C_{2G}	G	2	1	—	1 guarded
3	GST L-GUARD	5	C_{3G}	G	3	4	—	4 guarded
4	GST L-GUARD	5	C_{4G}	G	4	3	—	3 guarded
5	GST L-GUARD	5	C_{5G}	G	5	6	—	6 guarded
6	GST L-GUARD	5	C_{6G}	G	6	5	—	5 guarded
7	GST L-GND	4	$C_{1G}+C_{2G}$	R+B+G	1 or 2	—	—	
8	GST L-GND	4	$C_{3G}+C_{4G}$	R+B+G	3 or 4	—	—	
9	GST L-GND	4	$C_{5G}+C_{6G}$	R+B+G	5 or 6	—	—	
10								

<u>Diagram</u>



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

<u>Measurement Interchecks (Calculated)</u>

$C_7 = C_1 + C_2$

$C_4 = C_3 + C_4$

$C_9 = C_5 + C_6$

$$DF_7 = \frac{C_1 DF_1 + C_2 DF_2}{C_1 + C_2}$$

$$DF_8 = \frac{C_3 DF_3 + C_4 DF_4}{C_3 + C_4}$$

$$DF_9 = \frac{C_5 DF_5 + C_6 DF_6}{C_5 + C_6}$$

Note: Subscripts are test numbers.

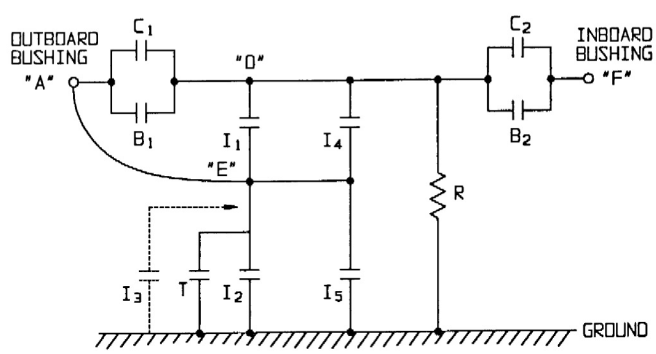
Table 8: Tank-Loss Index of Oil Circuit Breakers (Equivalent to 10 kV Losses)

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

Table 9: Circuit Breaker (Air-Blast Type) Test Connections

Test No.	UST-GST Mode		Measures		Test Lead Conn			Remarks
	Test Type	Pos	Cap. Symbol	Bridge Symbol	Black	Red	Blue	
1	UST	3	$C_2 + B_2$	R	D	F	A	A grounded
2	UST	2	$C_1 + B_1 + I_1$	B	D	F	A	F grounded
3	UST	1	$C_2 + B_2 + C_1 + B_1 + I_1$	R&B	D	F	A	
4	GST L-GUARD	5	R(or $R + I_3$)	G	D	F	A	F&A guarded
5*	GST L-GUARD	6	$I_2 + T$	R&G	A	F	D	D guarded F grounded

* Test performed only on units with current transformer.



Measurement Intercheck

$$C_1 = C_3 - C_2$$

$$DF_1 = \frac{C_3 DF_3 - C_2 DF_2}{C_3 - C_2}$$

Note: Subscripts are test numbers.

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

c. Bushings

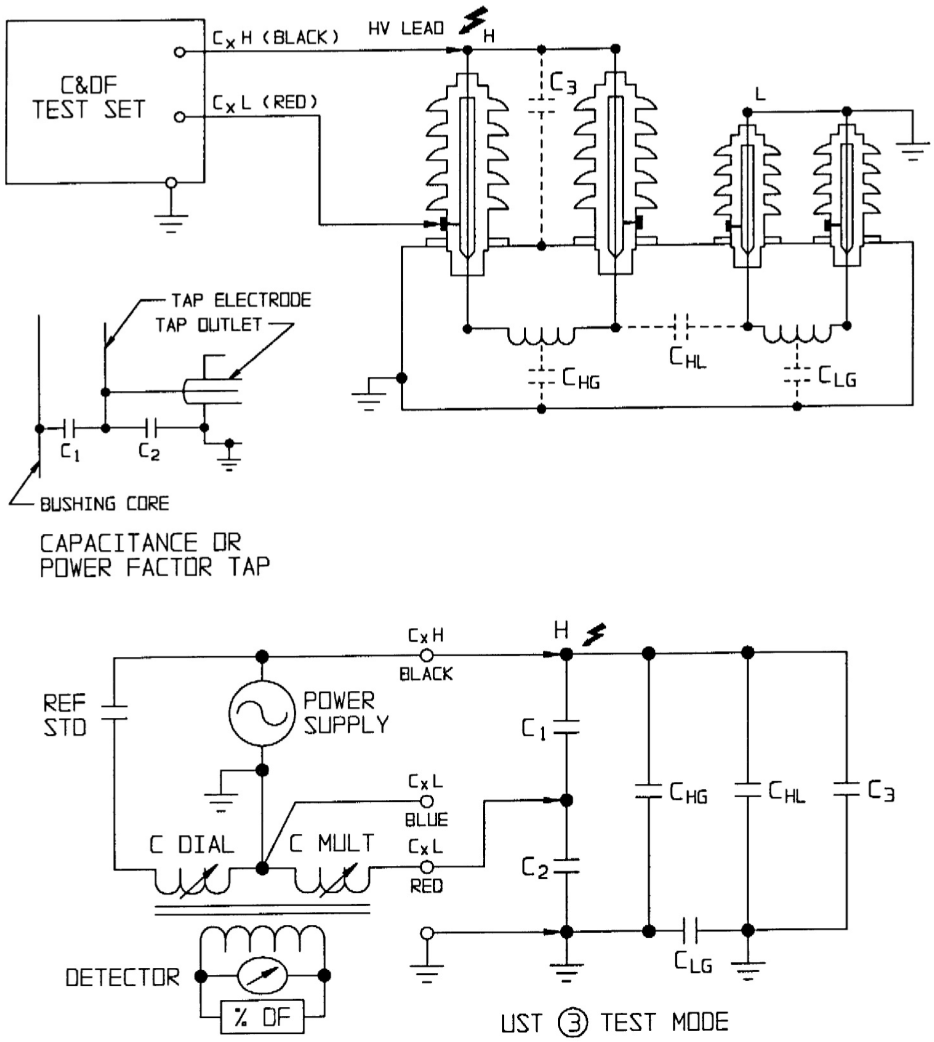
All modern bushings rated 23 kV and higher have a power factor or a capacitance tap which permits dissipation factor testing of the bushing while it is in place on the apparatus without disconnecting any leads to the bushing. The dissipation factor is measured by the ungrounded specimen test (UST) which 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 23 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 3 test mode setting. A sample test data report form, Miscellaneous Equipment, is shown in Appendix B.

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

Hot Collar Test

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



Measures main bushing insulation C_1

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

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

Figure 23: 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 L-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 corona problems at the interface. Refer to Application Notes on the 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 L-GUARD test method. For this test the high-voltage lead is connected to the tap, the low-voltage 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 effected 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 5kV. 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 20EC. 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.

d. 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 10 shows the specific connections between the test set and a typical generator three-phase stator winding as well as the routine series of measurements performed on the windings. It is assumed that the connection between the winding phases and also neutral are opened. The phase-to-ground insulation tests are made by the GST 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 may be made at a reduced voltage level. The Resonating Inductor (Cat. No. 670600) can be used with the Capacitance and Dissipation Factor Test Sets (Cat. No. 670070 and 670070-R) to perform high-voltage tests on high-capacitance specimens.

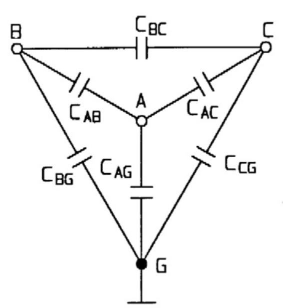
The temperature of the windings should be above and never below the ambient temperature to avoid the effects of moisture condensation on the exposed insulating surface. Temperature measurements when using temperature correction curves should be based on that at the winding surface.

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 10: Three-Phase Generator Stator Test Connections

	UST-GST Mode		Measures		Test Lead Conn			
Test No.	Test Type	Pos	Cap. Symbol	Bridge Symbol	Black	Red	Blue	Remarks
1	UST	3	C_{AB}	R	A	B	C	C grounded
2	GST L-GUARD	5	C_{AG}	G	A	B	C	B&C guarded
3	UST	3	C_{BC}	R	B	C	A	A grounded
4	GST L-GUARD	5	C_{BG}	G	B	C	A	C&A guarded
5	UST	3	C_{AC}	R	C	A	B	B grounded
6	GST L-GUARD	5	C_{CG}	G	C	A	B	A&B guarded
7	GST L-GROUND	4	$C_{AG}+C_{BG}+C_{CG}$	R+B+G	A+B+C	—	—	may exceed test set kVA rating

Equivalent Circuit



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

Note: Short each winding on itself.

Remarks

e. 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 L-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 L-GROUND test). A third test should be made between all conductors connected together and ground (GST 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 :F per phase per mile) so that for long lengths the kVA capacity of the test set power supply may be exceeded. For this case, tests will have to be made at a reduced voltage level unless you are using a Capacitance and Dissipation Factor Test Set (Cat. No. 670070 or 670070-R) in conjunction with the Resonating Inductor (Cat. No. 670600). Refer to Section 3, Specifications, for maximum specimen capacitance measurable at a particular test voltage.

f. 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 20EC. The temperature measurement should be based on that at the arrester surface. The air temperature should also be recorded. The surface of the arrester should be at a temperature above the dew point to avoid moisture condensation.

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

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

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

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

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

where: C_{pF} = capacitance in picofarads

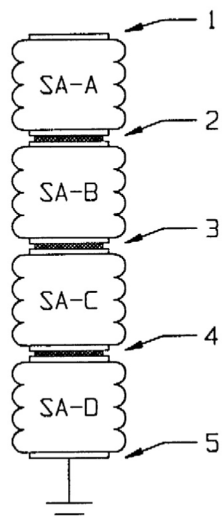
%DF = percent dissipation factor

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.

Table 11: Surge Arrester Test Connections

Test No.	UST-GST Mode		Measures		Test Lead Conn			Remarks
	Test Type	**Pos**	**Surge Arrester Symbol**	**Bridge Symbol**	**Black**	**Red**	**Blue**	
1	UST	2	SA-A	B	2	3	1	Red lead grounded
2	UST	3	SA-B	R	2	3	1	Blue lead grounded
3	UST	3	SA-C	R	4	3	—	—
4	GST L-GUARD	5	SA-D	G	4	3	—	Red lead guarded

Note: All tests normally made at 10 kV.



Typical Multi-Unit Arrester Stack

Watts loss @ 2.5 kV = 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.

g. Liquids

To measure the dissipation factor of insulating liquids, a special test cell such as the Biddle Oil Test Cell (Cat. No. 670511) 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 its instruction manual.

h. 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 24 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.

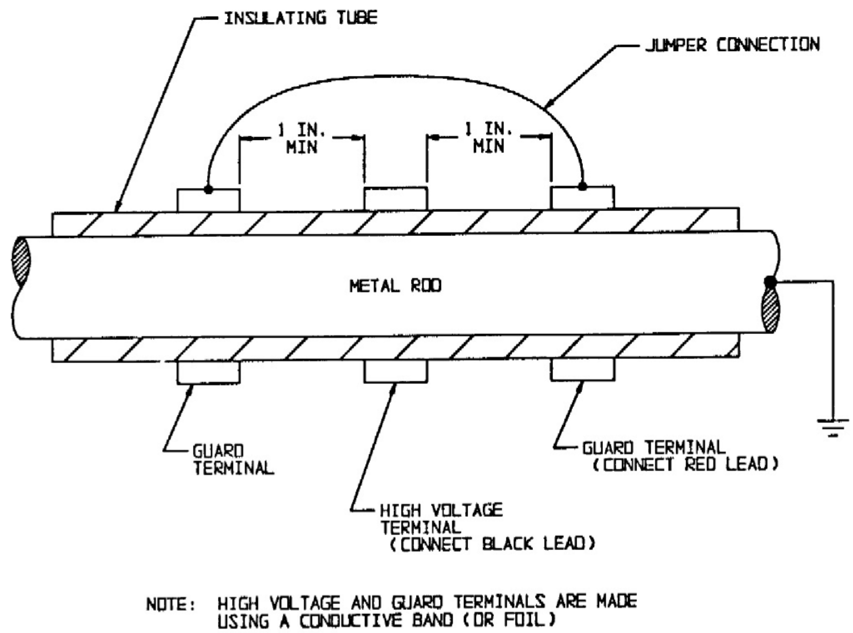


Figure 24: GST L-GUARD Test on Insulated Tube Covering Metal Rod

Section 7
Service

GENERAL

Maintenance, troubleshooting and repair 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.

MAINTENANCE

Routine maintenance is all that is required for this test set. 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.

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 dissipation factor meter reading. Cleaning these sensitive parts removes the leakage paths causing the unwanted leakage current.

Clean the outside of the carrying case with detergent and water. Dry with a clean cloth.

The control panel can be cleaned with a cloth dampened with detergent and water. Water must not be allowed to penetrate panel holes, because it may adversely effect components on the underside. An all-purpose household spray cleaner can also be used to clean the panel. Polish with a soft, dry cloth.

The cables and mating panel receptacles can be cleaned with isopropyl or denatured alcohol applied with a clean cloth. Stubborn dirt may require cleaning with xylol which should then be rinsed with alcohol.

The need for cleaning of the capacitance dial slide wire is indicated by erratic deflection of the capacitance null meter when smooth dial rotation is applied while at or near meter null balance. Rotate the slide wire dial several times over its full travel to break through the oxidation on the slide wire surface. On severely oxidized slide wires, gently polish the full length of slide wire and the contact with crocus cloth then clean the slide wire surface with isopropyl or denatured alcohol applied with a clean cloth. Lubricate by rubbing lightly with a soft cloth sparingly impregnated with petroleum jelly or white vaseline.

A complete Performance Check, as described in Section 5, should be made at least once a year. This will ensure that the test set is functioning and calibrated properly.

TROUBLESHOOTING

The Troubleshooting Guide shown in Table 12, is arranged to follow the sequence of the Performance Check described in Section 5. The table gives possible equipment malfunctions observed during operation or checkout, the possible cause, and the means of determining the defective component. See the schematic diagram of Figure 4 and the internal views of Figures 25 and 26 for help locating the components.

WARNING

This is high-voltage equipment containing dangerous voltages; repairs should only be made by personnel who are well qualified to deal with such hazards and who are familiar with routine precautions required to prevent injury.

A complete Performance Check should be performed on the test set prior to attempting to make any repairs. This check will also be helpful when contacting our Customer Service department for assistance.

REPAIR

AVO International offers a complete repair service and recommends that its customers take advantage of this service in the event of any equipment malfunction. Please indicate all pertinent information including problem, symptoms and attempted repairs. Equipment returned for repair must be shipped prepaid and insured and marked for the attention of the Repair Department.

For those users who prefer to make their own repairs, replacement parts are available from the factory. Refer to Section 8 when ordering replacement parts.

When replacement of internal parts is required in the high-voltage unit it is important that all parts be installed in their originally located positions. It is also important that all high-voltage terminations be made in the same manner as originally made. Failure to observe these precautions may result in an internal flashover within the high-voltage circuit at a voltage below rated output voltage.

Table 12: Troubleshooting Guide

Malfunction	Possible Cause
Main breaker trips on closure	Short circuit in wiring Power supply PS1 defective Transient suppressor CR1 shorted Step-down transformer T4 defective Step-down transformer T6 defective Step-down transformer T7 defective (240 V units only)
Green on indicator lamp does not light	No service power Defective line cord Main breaker K1 not closed Fuse F1 defective Green on lamp DS1 defective Step-down transformer T7 defective (240 V units only)
Amber OPEN GROUND lamp lights	Open ground circuit High resistance ground circuit Defective relay K5
Digital panel meters do not light or continuously overrange	Panel meters M1, M2, or M3 defective Connection terminal for M1, M2, or M3 defective Connection terminal not mated properly to panel meters M1, M2, or M3 Power supply PS1 defective
Kilovoltmeter "0" reading exceeds 5 LSDs	Panel meter M2 defective Output kV and mA PCB A5 defective TEST kV switch S5 defective
Milliammeter "0" reading exceeds 5 LSDs	Panel meter M1 defective Output kV and mA PCB A5 defective Current transformer T3 defective
Red high-voltage indicator lamp does not light	Voltage control T1 not at "0" External interlock open Relay K2 defective or contacts require cleaning HV ON switch S1 defective Zero start switch S3 defective Red high voltage on switch S14 defective
Main breaker trips on closure of HV ON switch	Voltage control transformer T1 defective Relay K2 defective Short circuit in wiring

Malfunction	**Possible Cause**
Main breaker or HV relay trip-out when output voltage is increased	Short circuit in test specimen Short circuit in wiring Defective high-voltage insulation Short circuit in HV output cable Voltage control transformer T1 defective HV transformer T2 defective HV capacitor C1 defective HV resistor R3 defective Relay K3 or K4 defective NORM/OFF/REV/POLARITY switch S2 defective 5 kV/10 kV switch S7 defective
No output voltage or inability to reach rated output voltage	Test specimens defective Defective high-voltage insulation HV output cable defective HV transformer T2 defective HV capacitor C1 defective HV resistor R3 defective Panel meter M2 defective Output kV and mA PCB A5 defective Defect in wiring
No output current	Panel meter M1 defective LO/HI switch S15 defective Output kV and mA PCB A5 defective Current transformer T3 defective Specimen capacitance below 100 pF Defect in guard circuit Defect in wiring
Output kilovolt meter reading erratic	Test specimen failing Defective high-voltage insulation HV output cable defective (open circuit or poor connection) Low-voltage cable defective HV transformer T2 defective HV capacitor C1 defective HV resistor R3 defective Panel meter M2 defective Output kV and mA PCB A5 defective Voltmeter resistor R4 defective Defect in wiring Poor regulation of power source

Malfunction	**Possible Cause**
Output milliammeter reading erratic	Test specimen failing Large variations in specimen capacitance or DF Defective high-voltage insulation Dirty HV output cable at termination Panel meter M1 defective Output kV and mA PCB A5 defective Current transformer T3 defective Milliammeter resistor R10 defective Defect in wiring
Capacitance null detector or DF meter "0" readings significantly greater than stated in Performance Check section of manual	Wrong connection of hot and neutral power source wires Detector PCB A2 defective or requires adjustment Reference generator PCB A3 defective or requires adjustment Output kV and mA PCB A5 defective or requires adjustment Capacitance meter M4 defective DF meter M3 defective Defect in guard circuit
Interference suppressor range significantly different than stated in Performance Check section of manual	Interference suppressor PCB A4 defective or requires adjustment Detector PCB A2 defective or requires adjustment Reference generator PCB A3 defective or requires adjustment INTERFERENCE SUPPRESSOR switches S12, S13 defective Interference suppressor control R53, R54 defective Capacitance meter M4 defective DF meter M3 defective

Malfunction	Possible Cause
Unable to obtain C or DF reading	Defective specimen Capacitance or DF value exceeds range of test set Detector PCB A2 defective Reference generator PCB A3 defective Differential current transformer T5 defective Voltage protector E1 shorted Capacitance dial switch S9, S10, S11 defective Capacitance slide wire dial R6 defective UST/GST test mode switch S8 defective SENSITIVITY switch S4 defective TEST KV switch S5 defective HV output cable defective Low-voltage cable defective Capacitance meter M4 defective DF meter M3 defective Relay K3, K4 defective Defect in wiring
Unstable C or DF reading	Defective specimen Variable specimen surface leakage Reading influenced by electrostatic interference field (see Section 6) Portable generator used to supply power to test set (see Section 6) Wrong connection of hot and neutral power source wires Detector PCB A2 defective Reference generator PCB A3 defective Interference suppressor PCB A4 defective Output kV and mA PCB A5 defective
C and DF reading can be obtained in UST test mode but not GST test mode	Defective specimen Defective ground circuit Defect in guard circuit Voltage protector E2-E6 shorted HV output cable defective UST/GST test mode switch S8 defective
Poor C or DF sensitivity	Wrong setting of SENSITIVITY switch Wrong setting of RANGE switch Wrong setting of TEST KV switch Detector PCB A2 defective Reference generator PCB A3 defective
C or DF reading can be obtained for NORM voltage polarity but not REV polarity and vice versa	Detector PCB A2 defective Relay K3 defective or contacts require cleaning Relay K4 defective

Malfunction	**Possible Cause**
C or DF/watt/milliwatt readings exceed twice the tolerance values indicated in Table 2	Detector PCB A2 requires adjustment Reference generator PCB A3 requires adjustment TEST KV switch resistors R18-R22 out of tolerance Resistors R23-R32 on switch S10 out of tolerance Resistors R43-R52 on switch S11 out of tolerance Resistors R63-R64 on switch S9 out of tolerance Slide-wire dial requires adjustment Rheostat R56 on slide-wire dial defective
Erratic deflection of capacitance null meter when adjusting slide-wire dial	Slide-wire dial R6 requires cleaning

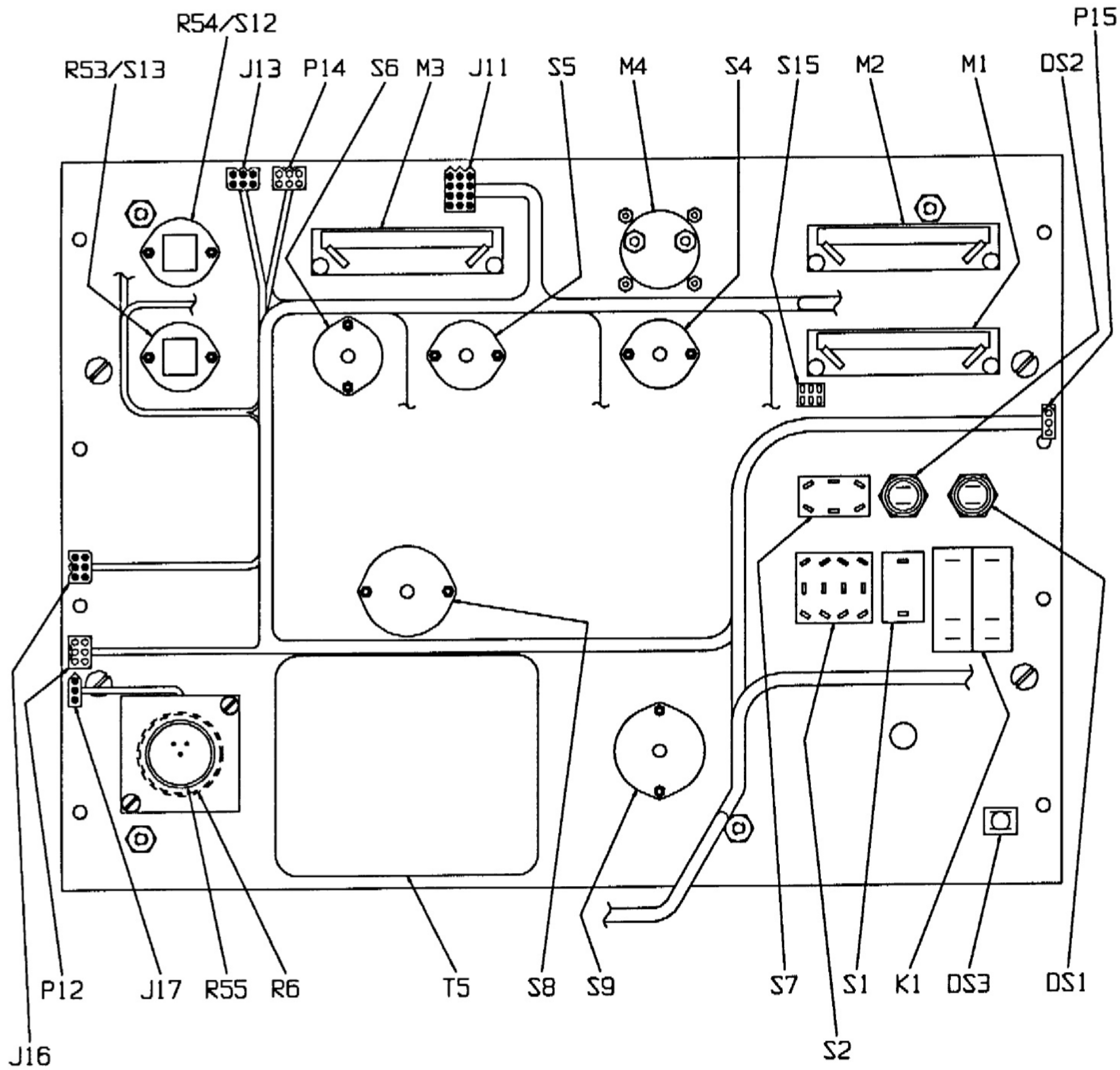


Figure 25: Control Panel Component Identification, Internal View

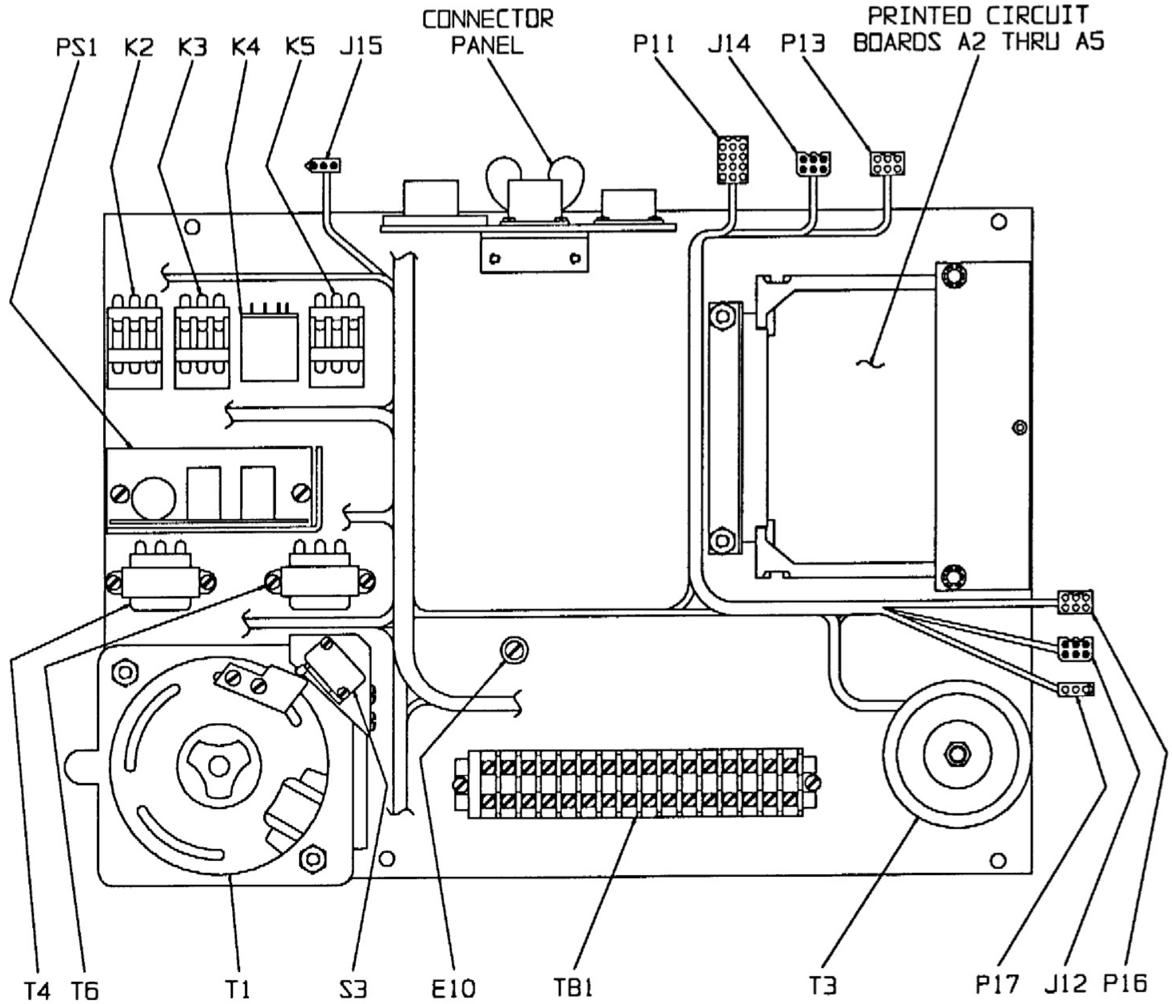


Figure 26: Subpanel Component Identification, Catalog No. 670065

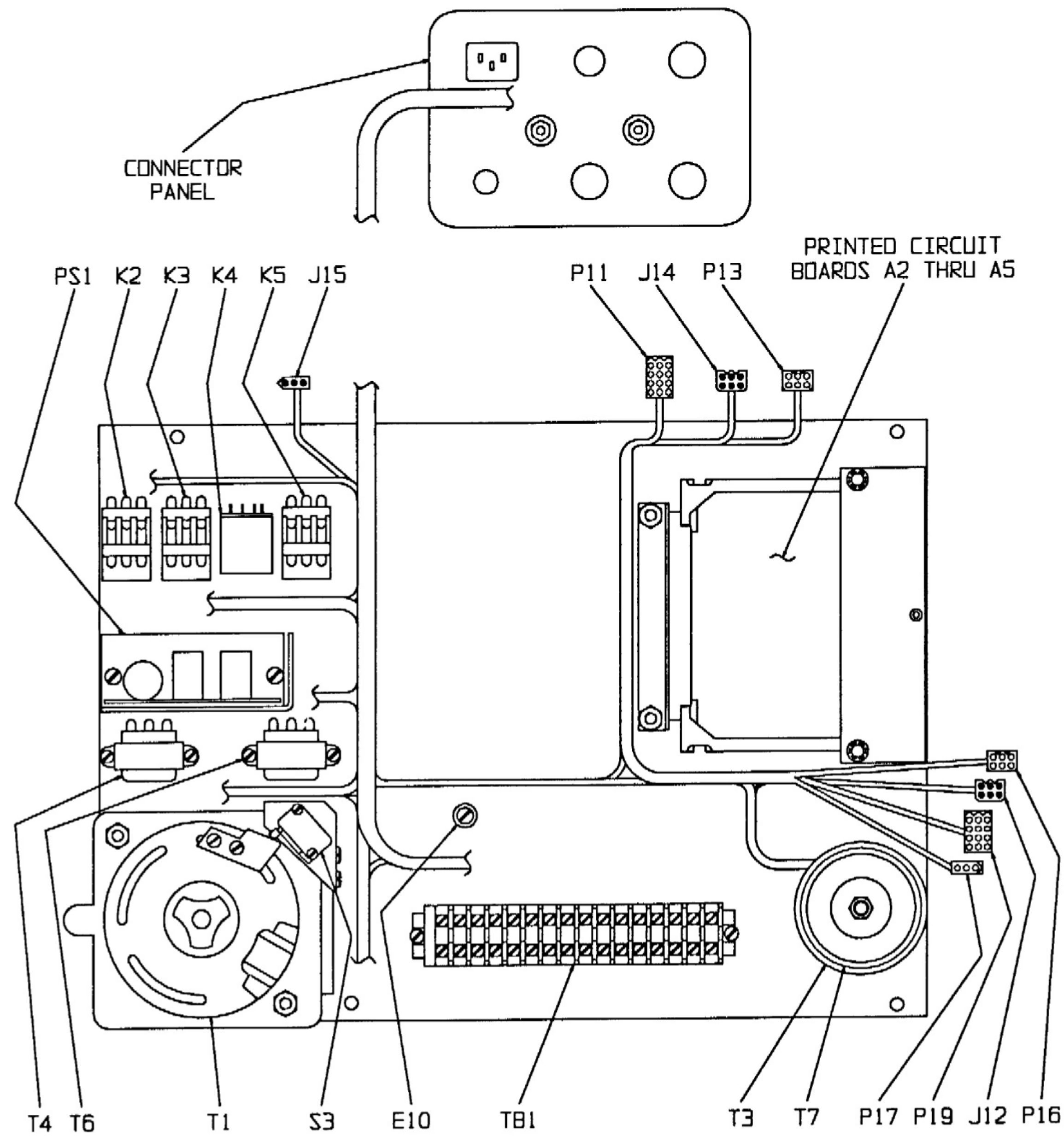


Figure 27: Subpanel Component Identification, Catalog No. 670070 and 670070-R

Section 8
Parts List

Symbol	Description	Vendor Part No.	Biddle Part No.
—	Case and lid (control unit)	—	25825-1
—	Case and lid (HV unit)	—	25825-2
M1, M2, M3	Meter, voltage, current, %DF	—	18310
M4	Meter, capacitance	—	22904
K1	Circuit breaker	—	6807-16
K2, K3	Relay, open type (Potter & Brumfield)	KA14AG-120 V ac	9270
K4	Relay, enclosed type (Struthers Dunn)	C281XDX320-S2-120 V ac	12357-5
K5	Relay, open type (Potter & Brumfield)	KA14AG-12 V ac	9270-1
T1	Transformer voltage control (Superior Electric)	116BU	15713
T2	Transformer, high voltage	—	23273
T3	Transformer, toroidal, current meas	—	22905
T4, T6	Transformer, isolation (signal)	241-3-12	15573-13
T5	Transformer, toroidal, bridge ckt	—	22906
T7*	Transformer, toroidal, range extension	—	29204
T8	Transformer, toroidal, step-down (240 V test sets only)	—	25762
F1	Fuse, 15 A Slo Blo (Bussman) (240 V test sets only)	MDA	2567-35
PS1	Power supply	—	22962
S1	Switch, HV ON/OFF (Cutler Hammer)	7501K13	2539
S2	Switch, NORM/OFF/REV Cutler Hammer)	7693K2	8406-3
S3	Switch, zero start (Honeywell)	V3-1	9235
—	Switch, actuator (Honeywell)	JV-5	9266
S4	Switch, sensitivity (Centralab)	SA-2002	1524-1
S5	Switch, TEST KV (Centralab)	SA-2004	1524-5

Symbol	Description	Vendor Part No.	Biddle Part No.
S6	Switch, RANGE (Centralab)	SA-2022	1524-6
S12/R54, S13/R53	Switch, potentiometer, suppressor	—	23265
S7	Switch, 5 kV/10 kV (Cutler Hammer)	7565-K5	8406-1
S8	Switch, UST/GST (Centralab)	2522	19886-3
S9	Switch, capacitance multiplier	—	19886-5
S9*	Switch, capacitance multiplier	—	19886-11
S10, S11	Switch, capacitance dials (Centralab)	2512	19886-2
S15	Switch, LO/HI milliammeter (C & K)	7201P3YZQ	12119-28
DS1	Lamp, green lens (Dialco)	95-0410-3172-301	7449-7
DS2	Lamp, red lens (Dialco)	95-0410-3171-301	7449-8
DS1, DS2	Bulb (GE or Westinghouse)	1820	3612-8
DS3	Pilot light, amber lens (Leecraft)	45NG3-2113	4499-9
A2	PC board assembly, detector (60 Hz)	—	22857-2
A2	PC board assembly, detector (50 Hz)	—	22857-3
A3	PC board assembly, reference generator (60 Hz)	—	22859-2
A3	PC board assembly, reference generator (50 Hz)	—	22859-3
A4	PC board assembly, interference suppressor (60 Hz)	—	22861
A4	PC board assembly, interference suppressor (50 Hz)	—	22861-1
A5	PC board assembly, output kV and mA (50 and 60 Hz)	—	23024-1
—	PC board polarizing key (Amphenol)	225-594	12178
—	PC board locking rod	—	23231
—	Knob, UST/GST switch (Buckeye)	PS-95PL-2	4690-8
—	Knob, Cap. and DF interference suppressor (Buckeye)	PS-50D/70CPL-1-2	4690-27
—	Knob, sensitivity, test kV, range (Buckeye)	PS-70PL-2	4690-12
—	Knob, voltage control (Buckeye)	PS-210PL-4	4690-6
—	Knob, capacitance multiplier (Buckeye)	PS-125PL-2	4690-25
—	Knob/dial, capacitance step switches	—	23027

Symbol	Description	Vendor Part No.	Biddle Part No.
—	Knob/dial, capacitance slide-wire	—	23009
J1	Receptacle, input power (Hubbell)	2615	4457
J1*	Receptacle, input power	—	27733
J2	Receptacle, interlock (Amphenol)	MS3102A-16-105	10225
J2*	Receptacle, interlock	—	16999-4
J4, J5	Receptacle, CxL red and blue (Switchcraft)	B3M	12831
J6	Terminal, ground wing nut (Malleable Iron Corp)	709B	5026-2
J6*	Terminal, ground wing nut grn/yellow (HCK)	8131-83569	29911-9
J7, J21	Receptacle, interconnection 5 pin (Amphenol)	MS3102A-18-11S	9018-57
J7*	Receptacle, 8 socket (ITT Cannon)	KPTO2E16-8S	16999-3
J8, J22	Receptacle, interconnection 4 pin (Amphenol)	MS3102A-16-9S	9018-26
J8*	Receptacle, 5 socket (ITT Cannon)	KPTO2E14-5S	16999-6
J20	Receptacle, high voltage	—	26277
P18	Plug, crimp type (Hollingsworth)	S05078	15075-4
J18	Receptacle, crimp type (Hollingsworth)	S05077	15075-3
J21*	Receptacle, 8 pin (ITT Cannon)	KPTO2E16-8P	16999-7
J22*	Receptacle, 5 pin (ITT Cannon)	KPTO2E14-5P	16999-8
J30*	Terminal, wing nut, black (HCK)	8131-83561	29911-1
P15, P17, P19, P20	Plug, 3 circuit male (Molex)	03-09-2031	17167-8
P12, P13, P14	Plug, 6 circuit male (Molex)	03-09-2062	17167-5
P11, P16	Plug, 12 circuit male (Molex)	03-09-2121	17167-6
J15, J17, J19, J20	Receptacle, 3 circuit female (Molex)	03-09-1032	17167-7
J12, J13, J14	Receptacle, 6 circuit female (Molex)	03-09-1064	17167-2
J11, J16	Receptacle, 12 circuit female (Molex)	03-09-1126	17167-3
—	Terminal pins male, P11-17 plug (Molex)	02-09-2118	17168-1
—	Terminal pins female, J11-17 receptacle (Molex)	02-09-1118	17168-2
C1	Capacitor assembly, high voltage	—	23399-2

Symbol	Description	Vendor Part No.	Biddle Part No.
C5, C6	Capacitor, Mylar, 0.015 µF, ±10% (Cornell-Dubilier)	WMF1S15	4559-17
C7, C8	Capacitor, Mylar, 0.047 µF, ±10% (Cornell-Dubilier)	WMF2S47	4559-5
CR1	Varistor, 150 V rms, 0.85 W (General Electric)	V150LA20A	3384-1
E1-E6	Voltage protector, 90 V (C.P. Clare)	CG-90L	4446-3
R6	Potentiometer assembly, slide-wire dial	—	23016
R55	Potentiometer, 200 Ω (Spectrol)	132-2-0-201	22182-1
R53, R54	Potentiometer, Cap. & DF interference suppressor (Bourns)	84C1DE24J16	23233
R1, R2	Resistor, MF, 1 k Ω, 5%, 12 W (Ohmite "Brown Devil")	—	4500-90
R3	Resistor, MF, 50 M Ω, 1%, 15 W (Caddock)	MG815N	10646-9
R4	Resistor, MF, 4.99 k Ω, 1%, 1/4 W (RN60D)	—	12026-29
R5	Resistor, MF, 200 k Ω, 1%, 1/4 W (RN60D)	—	12026-11
R7	Resistor, MF, 10 Ω, 1%, 1/4 W (RN60D)	—	12026-62
R9	Resistor, trimmer, 20 Ω (CTS)	375V200B	5183-9
R10	Resistor, MF, 499 Ω, 1%, 1/4 W (RN60D)	—	12026-143
R11	Resistor, MF, 2 k Ω, 1%, 1/2 W (RN65D)	—	11445-5
R12, R60-R62	Resistor, MF, 2 k Ω, 1%, 1/8 W (RN55D)	—	12398-3
R13, R14	Resistor, MF, 4.87 k Ω, 1%, 1/8 W (RN55D)	—	12398-33
R15, R16	Resistor, MF, 8.45 k Ω, 1%, 1/8 W (RN55D)	—	12398-164
R18, R21, R22	Resistor, MF, 1 k Ω, 1%, 1/8 W (RN55D)	—	12398-16
R19	Resistor, MF, 499 S, 1%, 1/8 W (RN55D)	—	12398-26
R20	Resistor, MF, 1.5 k Ω, 1%, 1/8 W (RN55D)	—	12398-96
R23-R32	Resistor, MF, 1.78 k Ω, 0.5%, 1/8 W (RN55D)	—	12398-165
R43-R52	Resistor, MF, 178 Ω, 0.5%, 1/8 W (RN55D)	—	12398-166
R56	Resistor, MF, 100 k Ω, 1%, 1/4 W (RN60D)	—	12026-51
R63, R64	Resistor, MF, 2.32 k Ω, 0.5%, 1/8 W (RN55D)	—	12398-201
—	Bumper feet, case (3M Co.)	SJ-5123	5599-1

Symbol	Description	Vendor Part No.	Biddle Part No.
—	Handle, front panel (US Engineering)	1007	6441-2
—	Adapter, right angle for C1 capacitor (Amp Inc.)	329517	6500
—	Instruction card, case lid	—	22972
—	Line cord (120 V input) (Belden)	17255	17032-4
—	Line cord (240 V input) (Belden)	17566	17032-2
—	Cable assembly, C_xH high voltage, 70 ft	—	15704-3
—	Cable assembly, C_xL red low voltage, 70 ft	—	25572-1
—	Cable assembly, C_xL blue low voltage, 70 ft	—	25572-2
—	Cable assembly, interconnection, (4 cond)	—	25574
—	Cable assembly, interconnection,(3 cond)	—	25575
—	Cable assembly, external interlock	—	10229-1
—	Cable assembly, ground	—	4702-5
—*	Cable assembly, ground	—	4702-6
—	Canvas cable carrying bag	—	18313
—	Transit case, test set	—	670626
—	Transit case, cables	—	218744-1
—	Hook for use with high voltage cable	—	23641
—	Hot-collar belt (three)	—	670505
—	Power factor tap connectors (two)	—	670506

** Used on Cat. No. 670070 and 670070-R.*

APPENDIX A

NOMOGRAPHS

NOMOGRAPHS

% DISSIPATION FACTOR vs WATTS LOSS

The % dissipation factor can be converted rapidly to watts loss by using the appropriate nomograph (see Figures Al to Al2). When the value of capacitance and % dissipation factor is known, draw a straight line through these two known values. The watts loss is found where this line intersects the watts loss scale.

The nomographs and the ranges covered are as follows:

Figure No.	Capacitance Range (pF)	%DF Range	Doble Equivalent Test Voltage	Test Frequency (Hz)
A1 A2 A3	10 to 1000 10 to 1000 100 to 10,000	0.1 to 10 1 to 100 0.1 to 10	2.5 2.5 2.5	60 60 60
A4 A5 A6	10 to 1000 10 to 1000 100 to 10,000	0.1 to 10 1 to 100 0.1 to 10	10 10 10	60 60 60
A7 A8 A9	10 to 1000 10 to 1000 100 to 10,000	0.1 to 10 1 to 100 0.1 to 10	2.5 2.5 2.5	50 50 50
A10 A11 A12	10 to 1000 10 to 1000 100 to 10,000	0.1 to 10 1 to 100 0.1 to 10	10 10 10	50 50 50

Example (Figure A1)

Capacitance measurement = 370 pF

Dissipation factor measurement = 1.60%

The unknown watts loss = 14.0 mW

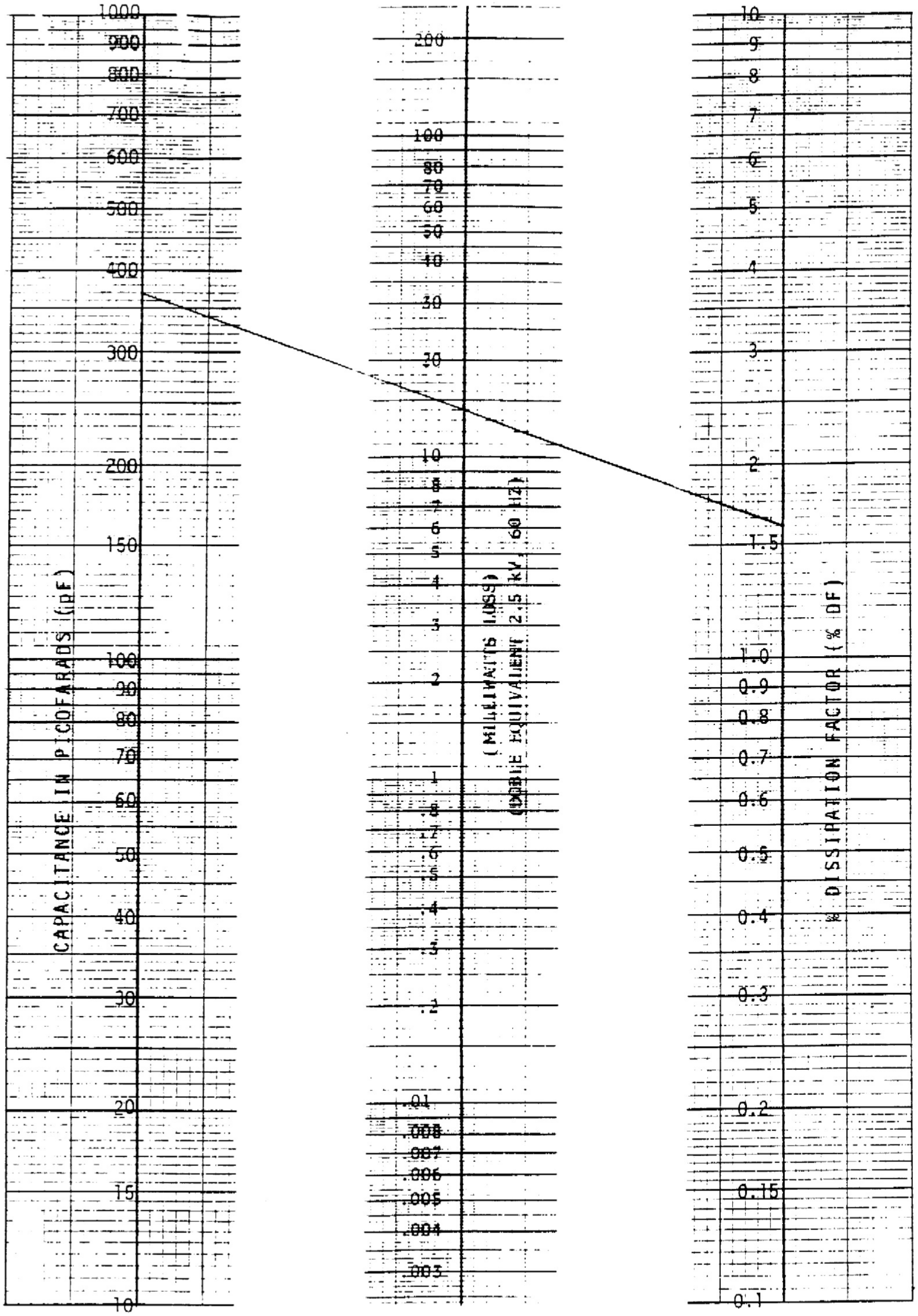


Figure A1: %DF vs. Milliwatts Loss (2.5 kV, 60 Hz)

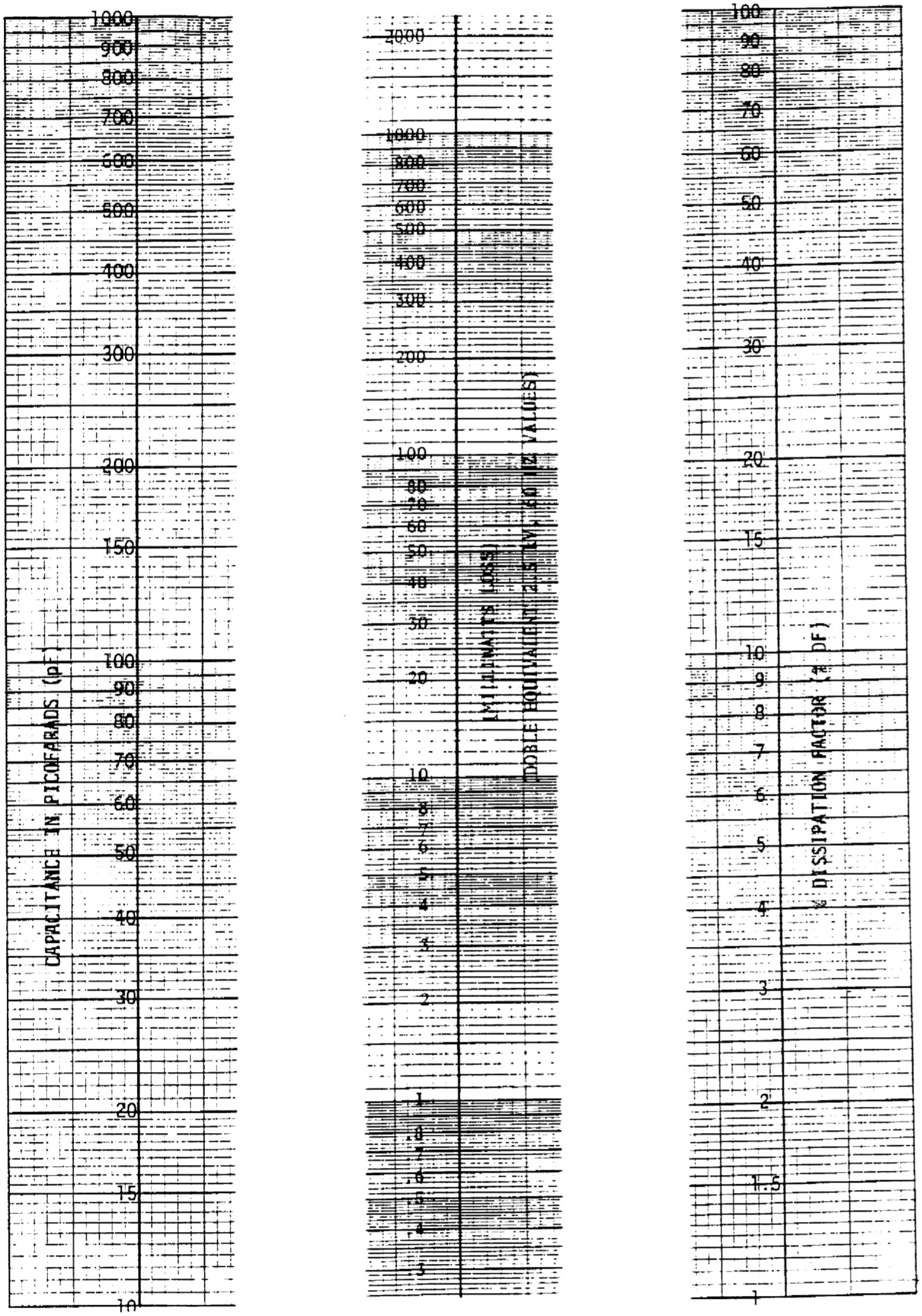


Figure A2: %DF vs. Milliwatts Loss (2.5 kV, 60 Hz)

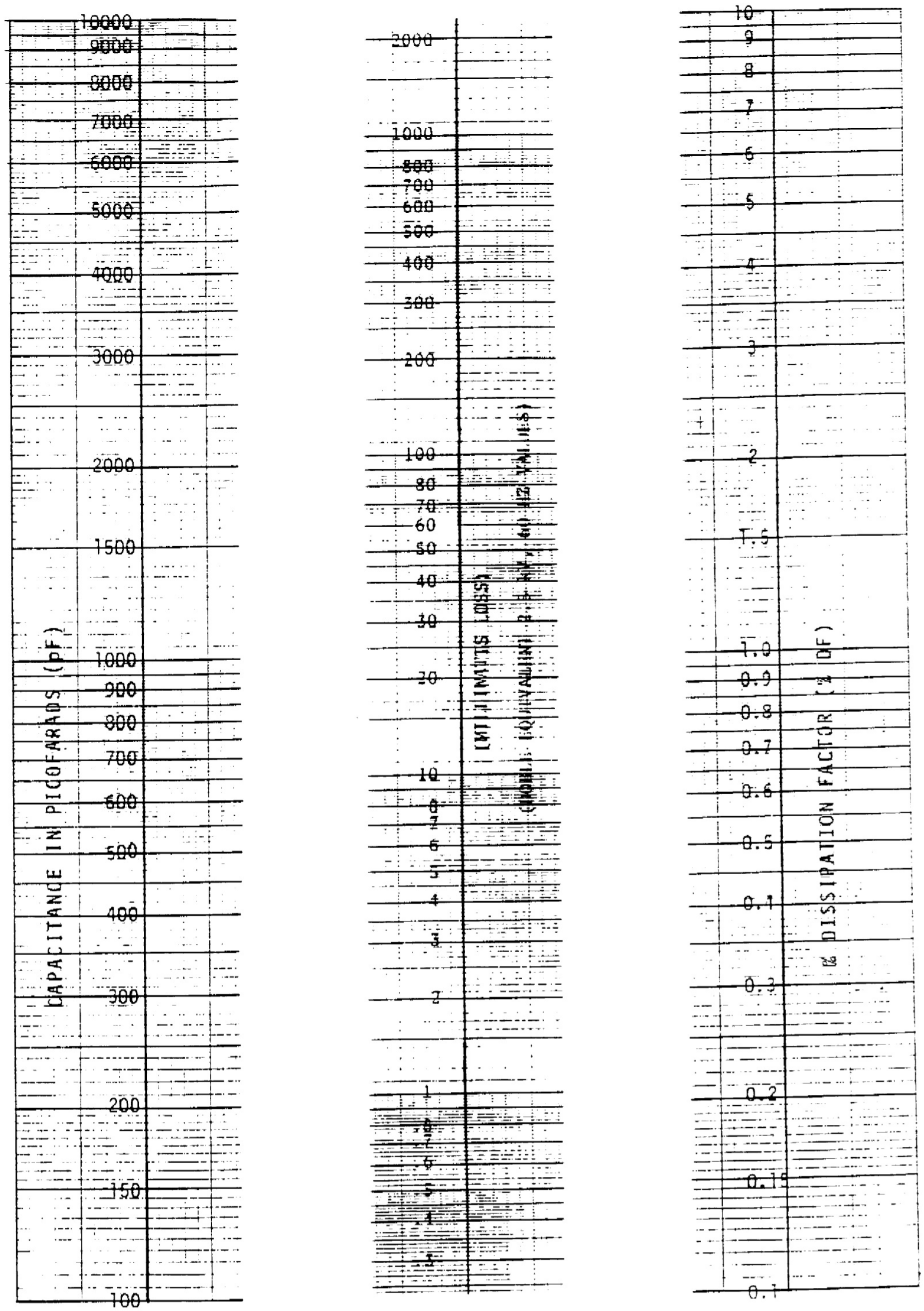


Figure A3: %DF vs. Milliwatts Loss (2.5 kV, 60 Hz)

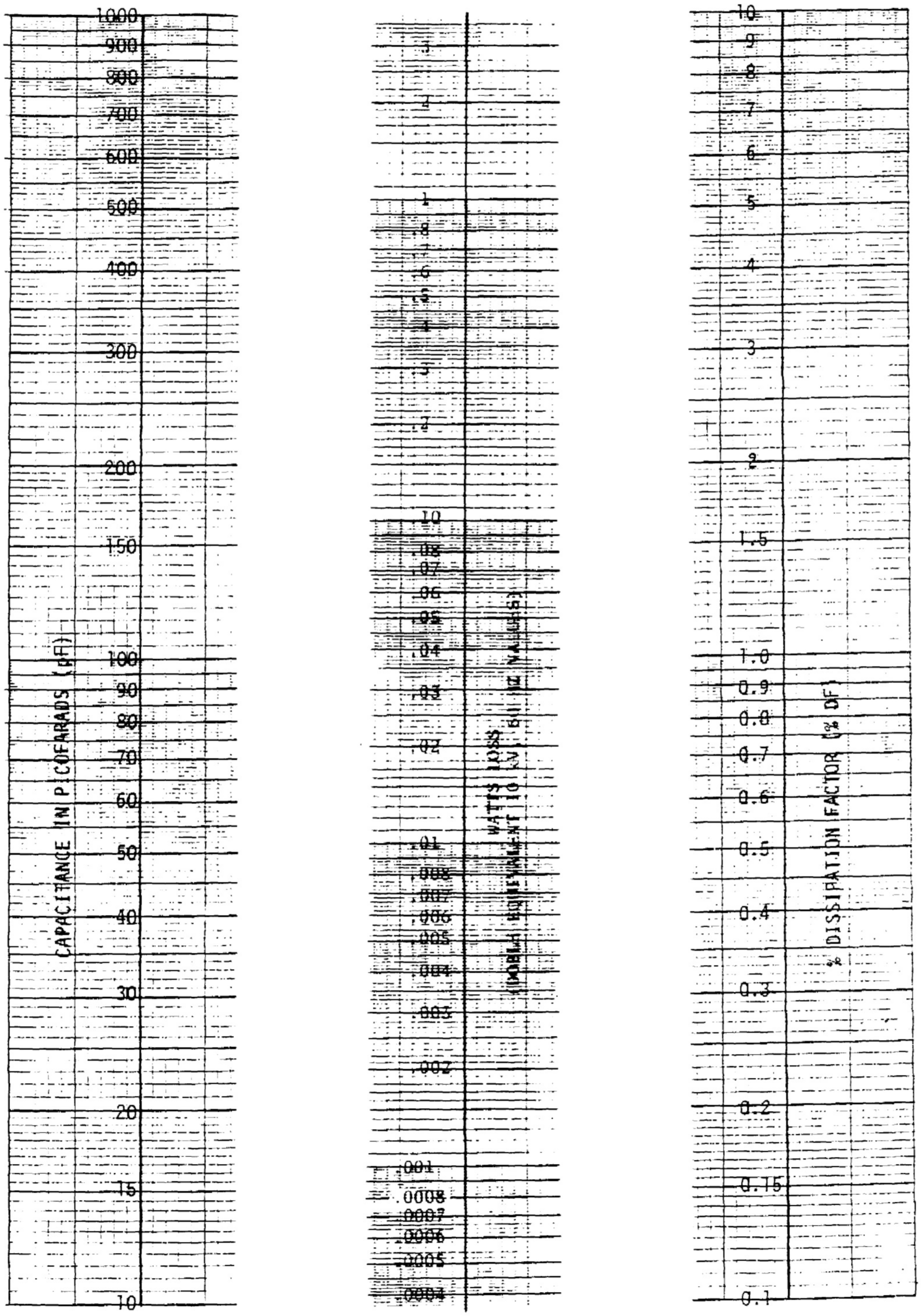


Figure A4: %DF vs. Watts Loss (10 kV, 60 Hz)

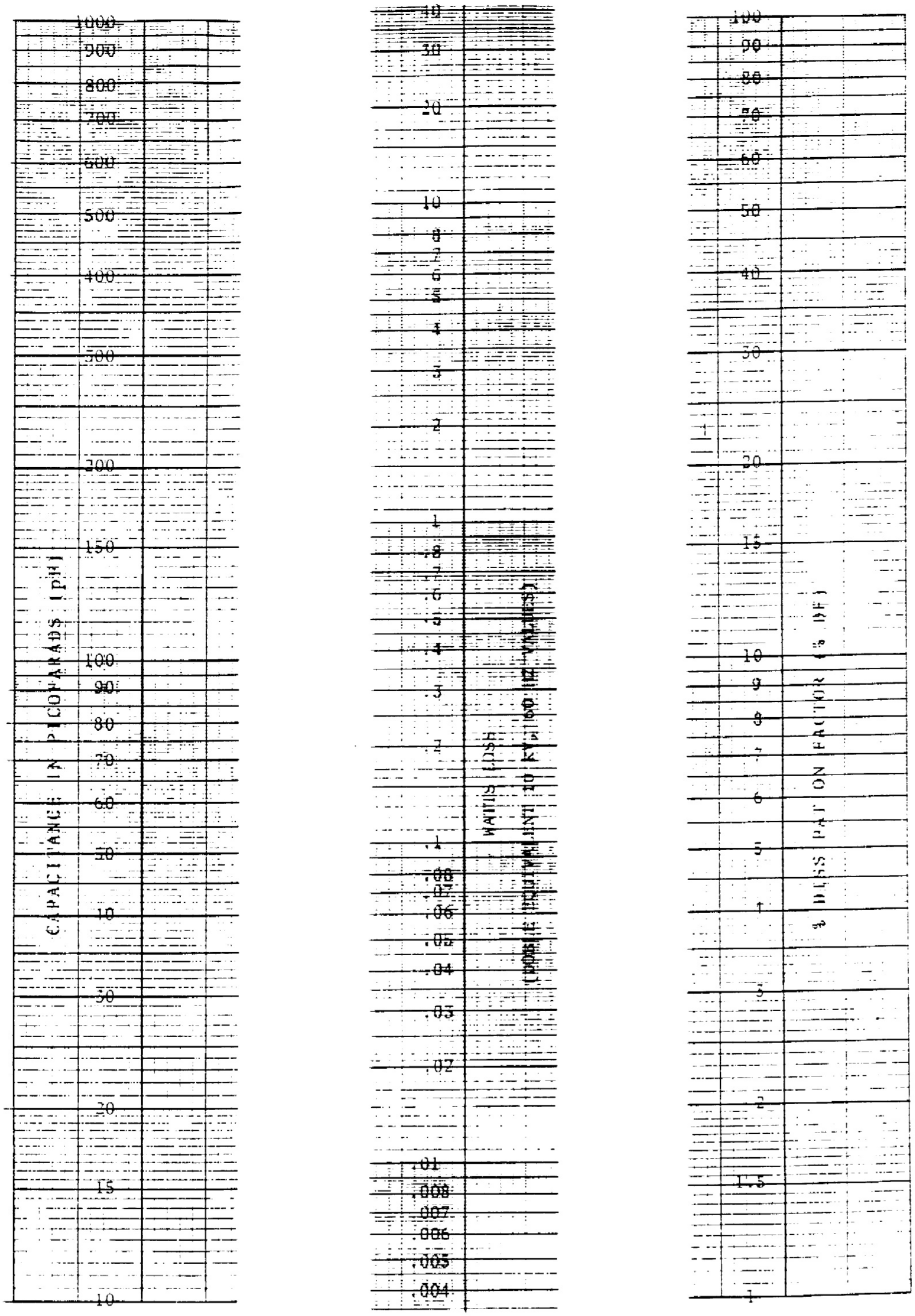


Figure A5: %DF vs. Watts Loss (10 kV, 60 Hz)

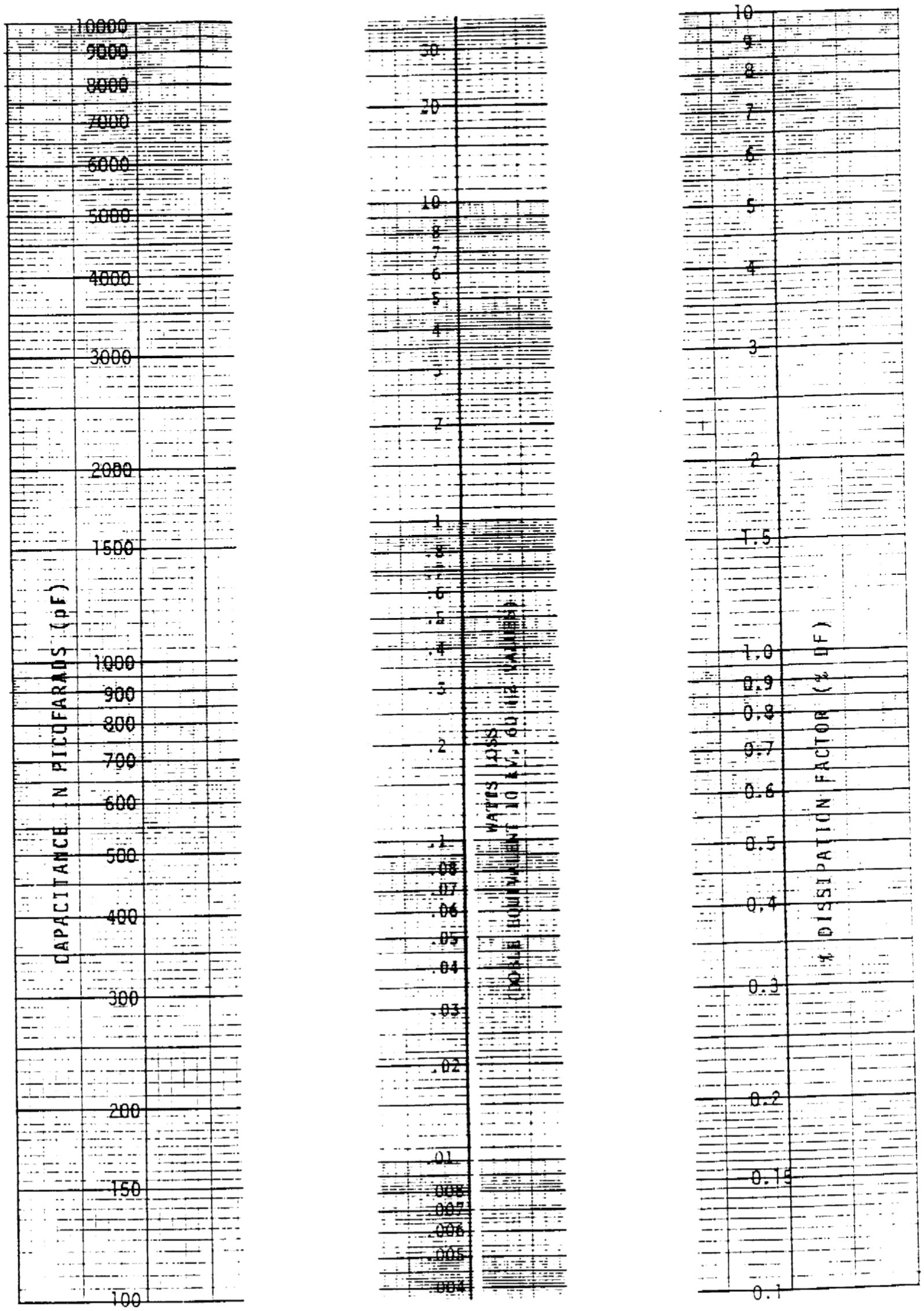


Figure A6: %DF vs. Watts Loss (10 kV, 60 Hz)

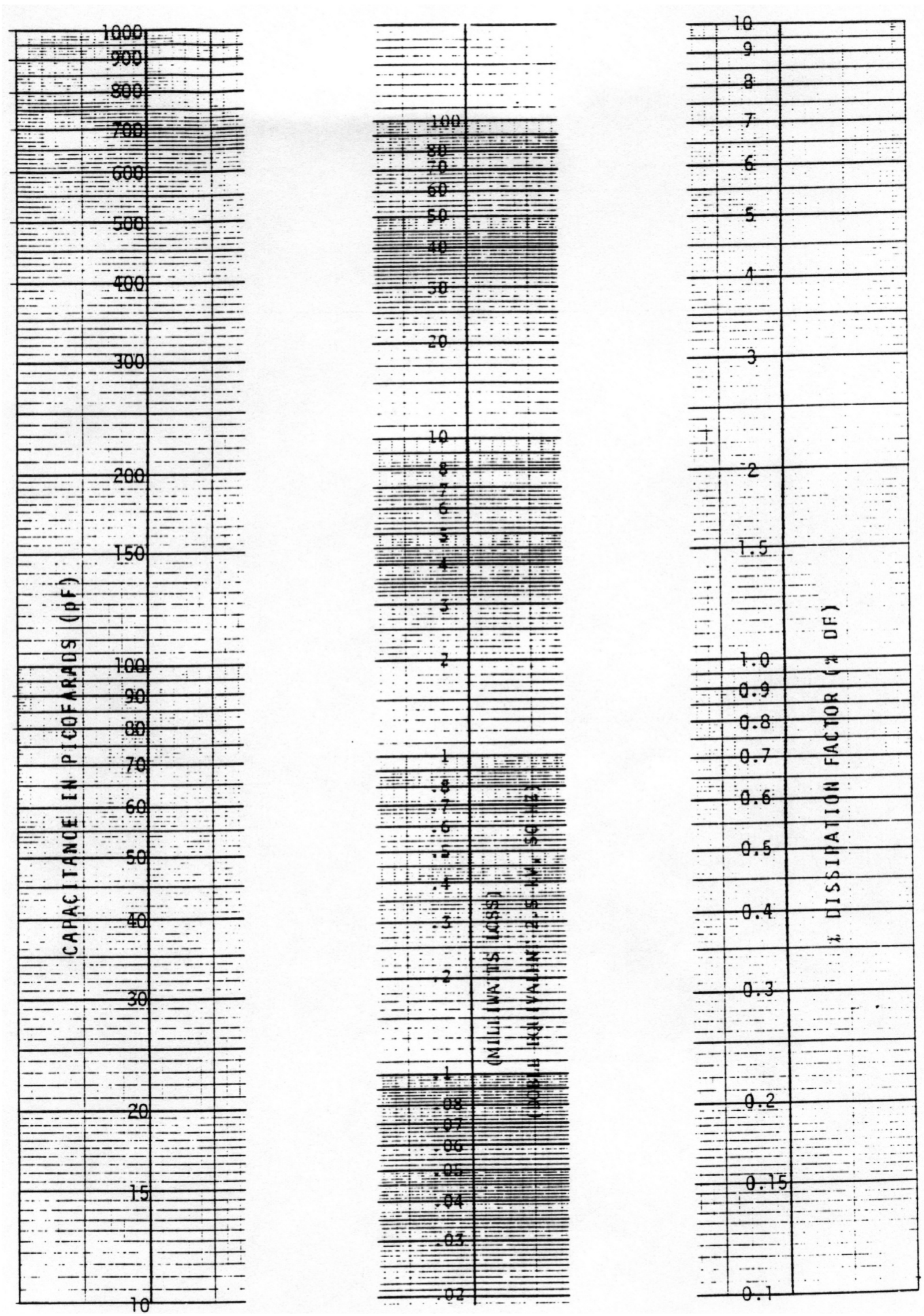


Figure A7: %DF vs. Watts Loss (10 kV, 60 Hz)

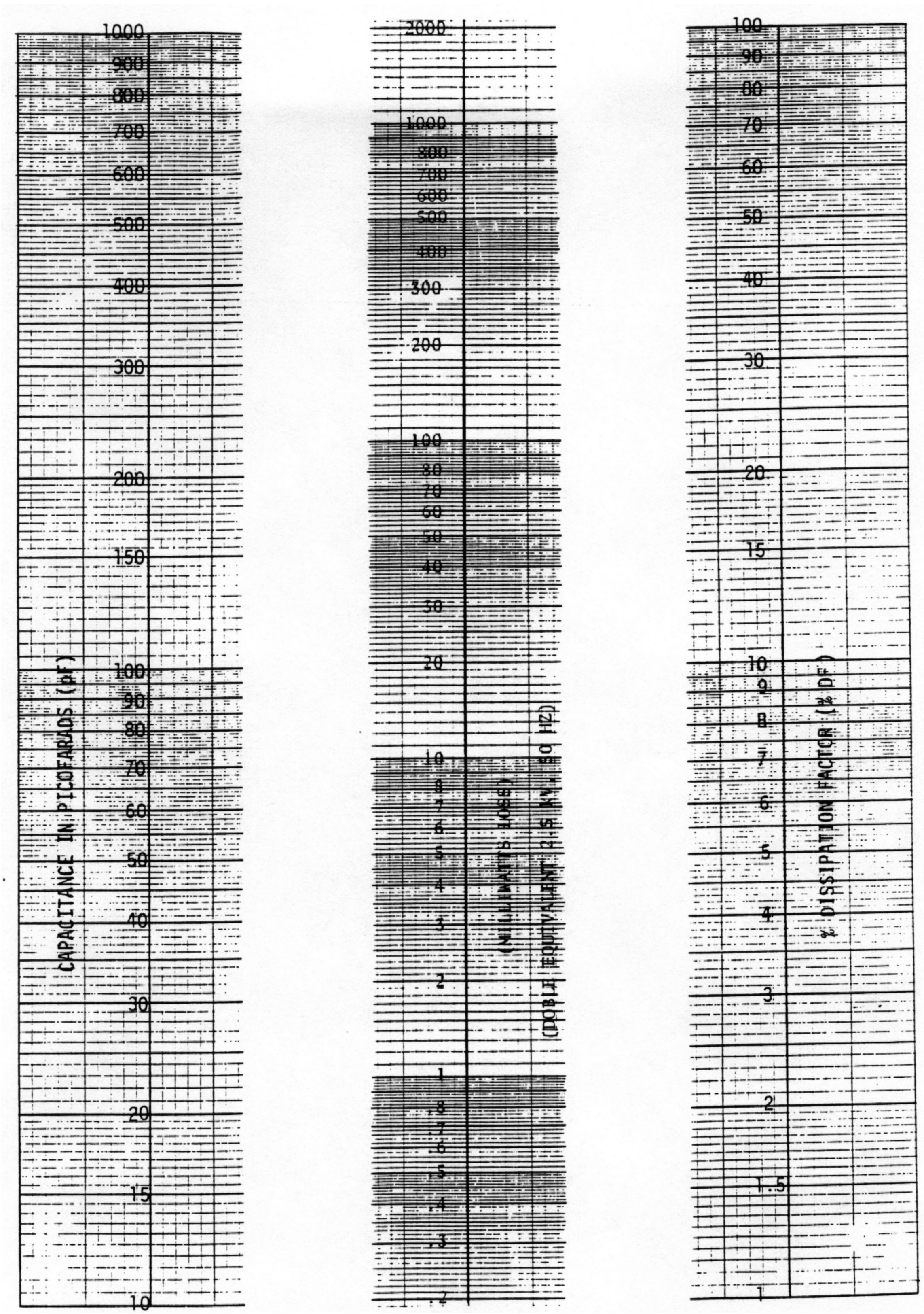


Figure A8: %DF vs. Milliwatts Loss (2.5 kV, 50 Hz)

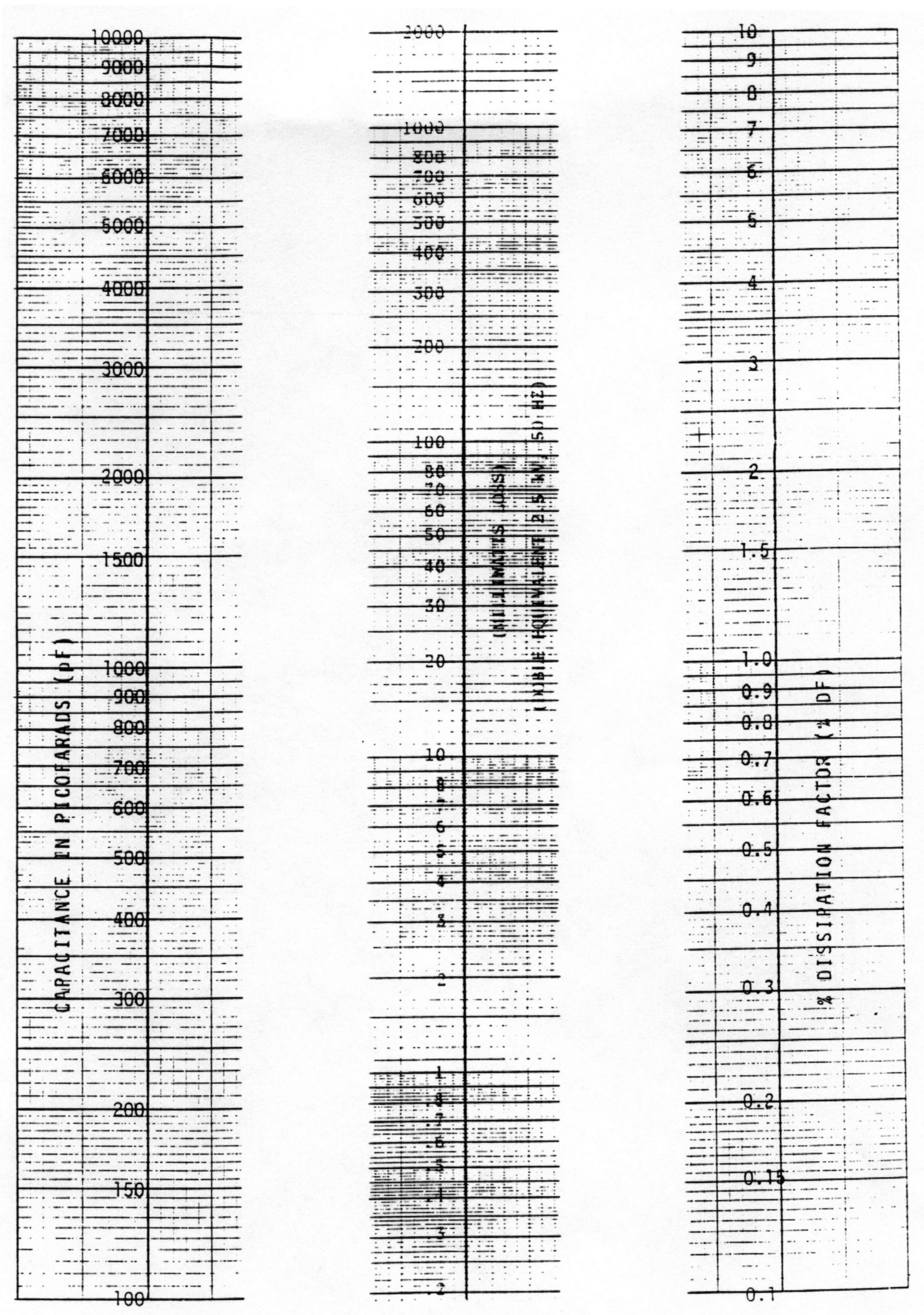


Figure A9: %DF vs. Milliwatts Loss (2.5 kV, 50 Hz)

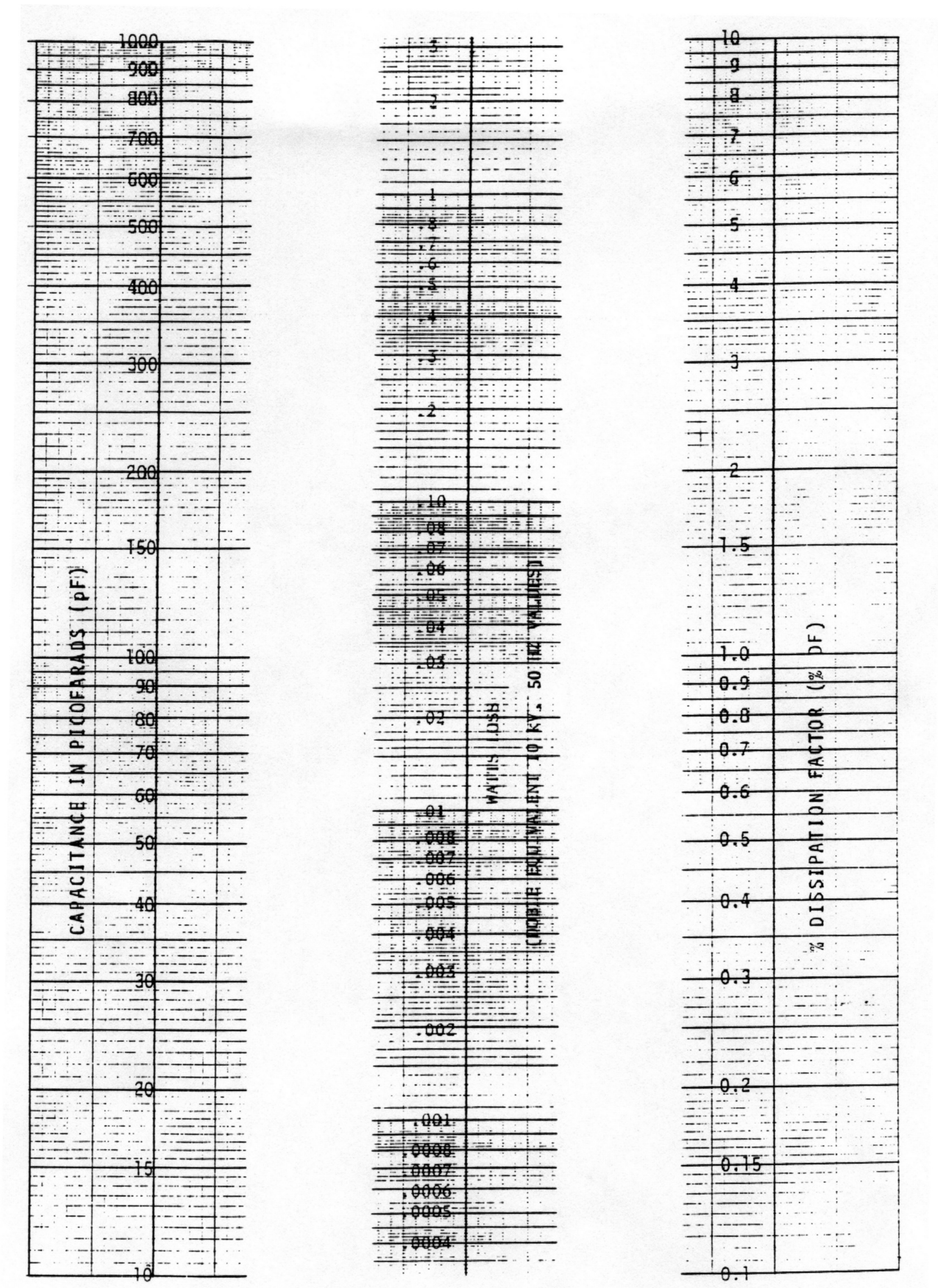


Figure A10: %DF vs. Milliwatts Loss (2.5 kV, 50 Hz)

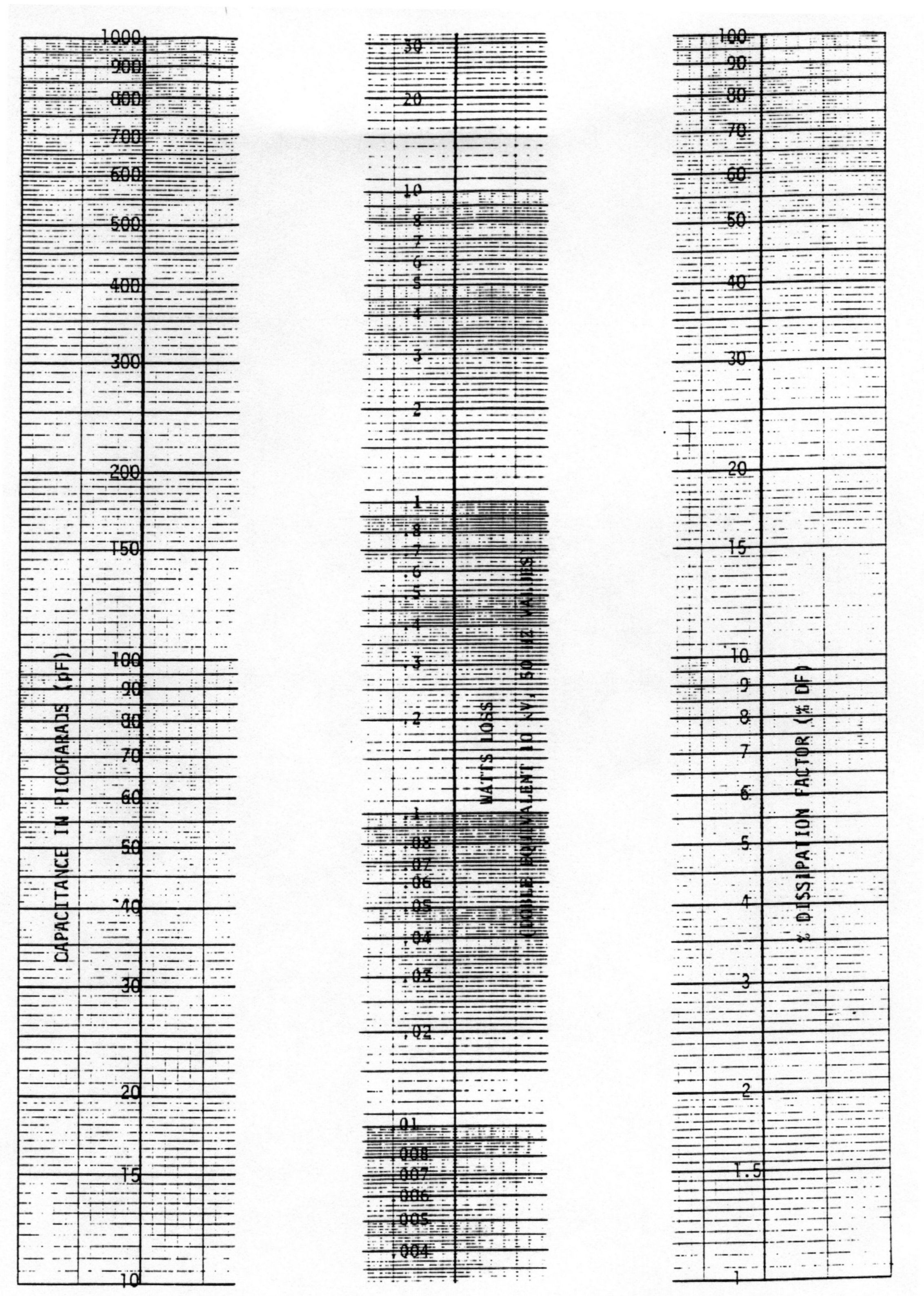


Figure A11: %DF vs. Watts Loss (10 kV, 50 Hz)

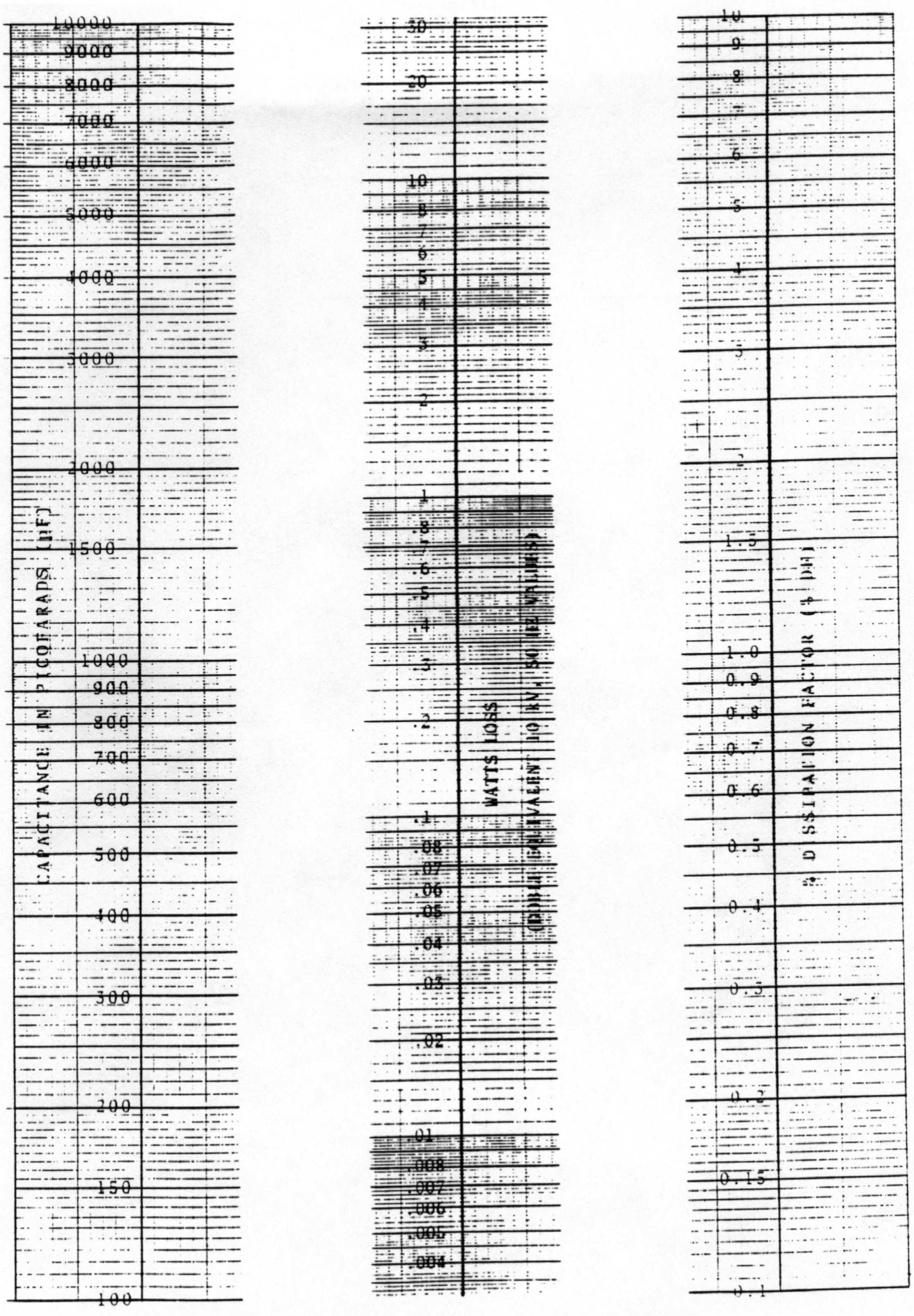


Figure A12: %DF vs. Watts Loss (10 kV, 50 Hz)

APPENDIX B

TEST DATA FORMS

TRANSFORMER

EXCITATION CURRENT TESTS

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

TEST NO.	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	

DIAGRAM

REMARKS

FORM 67C10

TWO & THREE WINDING TRANSFORMERS

CAPACITANCE & DISSIPATION FACTOR TESTS

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

TRANSFORMER OVER-ALL TESTS

TEST NO.	INSULATION TESTED	TEST MODE	TEST KV	CAPACITANCE DIAL READING NORM	CAPACITANCE DIAL READING REV	CAPACITANCE MULTR	CAPACITANCE CAP (PF)	% DISSIPATION FACTOR DIAL READING NORM	% DISSIPATION FACTOR DIAL READING REV	% DISSIPATION FACTOR MEAS % DF	% DISSIPATION FACTOR 20°C % DF	WATTS/MILLIWATTS DIAL READING NORM	WATTS/MILLIWATTS DIAL READING REV	WATTS/MILLIWATTS MEAS WATTS mW	INSUL RTG	REMARKS
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																

BUSHING TESTS

	TEST NO.	BUSHING NO.	BUSHING I.D.															
HIGH KV	11																	
HIGH KV	12																	
HIGH KV	13																	
HIGH KV	14																	
LOW KV	15																	
LOW KV	16																	
LOW KV	17																	
LOW KV	18																	
TERTIARY	19																	
TERTIARY	20																	
TERTIARY	21																	
TERTIARY	22																	
	23	OIL TEST																

INSULATION RATING KEY

G - GOOD
F - FAIR
I - INVESTIGATE
B - BAD

FORM 67C7

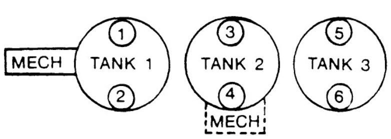
CIRCUIT BREAKER

CAPACITANCE & DISSIPATION FACTOR TESTS

COMPANY	DATE
TEST LOCATION	TEST BY
EQPT. IDENT.	TEST SET NO.
BUSHING MFR. TYPE	AIR TEMP.
C.B. MFR. TYPE KV	OIL TEMP.
	% RH
	WEATHER
	SERIAL NO.

	BUSH NO.	BUSHING SERIAL NUMBER	TEST MODE	TEST KV	CAPACITANCE			% DISSIPATION FACTOR			WATTS/MILLIWATTS		INSUL RTG	REMARKS
					DIAL READING NORM/REV	MULTR	CAP (PF)	DIAL READING NORM/REV	MEASURED % DF	20°C % DF	DIAL READING NORM/REV	MEASURED WATTS mW		
CIRCUIT BREAKER OPEN	1													
	2													
	3													
	4													
	5													
	6													
C B CLOSED	TANK 1													
	TANK 2													
	TANK 3													
TEST NO.														
	1													
	2													
	3													
	4													
	5													
	6													

DIAGRAM



INSULATION RATING KEY

G - GOOD
F - FAIR
I - INVESTIGATE
B - BAD

FORM 67C8

GLOSSARY

	Use only in accordance with Instruction Manual.
	High-voltage warning
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).
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.
LED	Light-emitting diode
nomograph	A graphic representation consisting of several lines marked off to scale and arranged so that by using a straightedge to connect known values on two lines, an unknown value can be read at the intersection with another line.
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	Temporary connection (not supplied) made between the high-voltage conductor and the ground of the apparatus under test.
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
xylol	(Xylene) toxic, flammable, oily, isomeric aromatic hydrocarbons used as solvents.

WARRANTY

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