Gas analysis is the analysis of the dissolved gasses found in the insulating oil. It is used to determine if the dissolved gasses are a result of atmospheric leaks, internal faults or are normal. If the gasses are the result of an electrical fault, the analysis can help identify the cause and severity of the fault.

The gas analysis begins with an oil sample obtained from the device under study. The sample of oil is introduced into an evacuated gas-extraction apparatus. Upon introduction to the very high vacuum, the dissolved gases are liberated quickly from the oil. By use of a series of valves, a portion of the gas is separated from the oil and pressurized to atmospheric pressure.

The collected gas is injected into a device called a gas chromatograph which separates it into its various components and quantifies them. The appearance of abnormal amounts of these gases indicates the presence of an incipient fault.

6.4.5 The Fault Gases and Their Meaning

The gas chromatograph can identify a variety of gases dissolved in the oil. The nine gases listed in Table 6-1 are of key interest in this analysis. Included in Table 6-3 are the approximate concentrations of each gas which indicate an incipient fault and the possible cause or source of these gases.

6.4.6 Diagnosis

There is no single criterion for interpreting the results of a fault gas analysis test. The decision as to whether the unit should remain in service is made by examining the trend of the results. Increases in the amounts of the various gases indicate the continued existence of the incipient fault, increase in the rate of gas formation indicates a worsening of the fault

The actual gas composition tells what particular type of problem is developing. Examination of the ratios of various gases to each other by such methods as the Rogers Ratio or Dorneberg Methods can give further insight into the source or cause of the problem. These methods while being extremely helpful, are not totally accurate and must be tempered with the knowledge gained through other diagnostic tests or past operating characteristics of the apparatus.

1 **Corona** is a low energy electrical fault. Electrical discharges result in the ionization of the oil surrounding the fault creating hydrogen gas.

2 **Sparking** is an intermittent high voltage flashover without high current Sparking generally results in increasing levels of methane and ethane gas.

3 **Over heating** of oil may be caused by overloads, core problems, etc. Overheating

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generally results in the formation of hydrogen, methane, ethane and ethylene gas.

4 **Arcing** is the most severe fault process. It involves high voltages, high currents and high temperatures. Arcing is characterized by the formation of acetylene gas.

5 **Cellulose** or paper may be involved in any of the above fault activities. Its involvement is characterized by the formation of carbon monoxide and carbon dioxide gas.

6.4.7 Example

Table 6-1 and table 6-2 illustrate the format used to display the results of a Fault Gas Analysis Test. The test is divided in the following five sections.

1 Nameplate and Sampling Information

This first section includes apparatus identification information, sample date and location, and miscellaneous test data.

2 Test Results

The second or middle section contains all the test results regarding the nine (9) individual gas components.

Column 1 - Contains the name of each gas and symbol. Total Gas, total Combustible Gas, Equivalent TCG Reading (%).

Column 2 - Date sample collected, report number, and list of all test results for each gas either in ppm or % Vol.

Volume percent in oil; states the volume percent of the gas dissolved in the oil for each gas component This information is used in the diagnosis of the problem.

Volume percent in gas; of the total gas dissolved in the oil, this column lists the percentage: each gas that make up the total gas volume.

3 Comments

The third section lists the possible causes or sources of the problem, it is based on the information listed under "Volume % in Gas" or "PPM" (abnormally high amounts of each gas will be indicated by an asterisk (•) or (") after each gas).

In the example listed in Table 6-3, the following gases are beyond their normal limits:

Ethylene Ethane Acetylene Methane

Ethylene and methane indicate severe local overheating of the oil; ethane indicates sparking and acetylene reveals the presence of more powerful arcing.

With the presence of these gases, it is hypothesized that there is a fault, probably arcing relatively high energy taking place. This arcing is between two conductors insulated by oil but not paper.

4 Suggested Action

The first course of action is to verify that the sample was correct and not from a tap changer or other device where arcing is normal. Many times an immediate resample is prudent. After verifying the sample it must be determined whether to leave the apparatus in service with fault gas analysis being continued on a more frequent basis (monthly or weekly) or to take the apparatus out of service for more diagnostic testing or repair. If the apparatus is left in service, all subsequent tests should be carefully analyzed and the rate of gassing determined. An increase in the gassing rate generally indicates a worsening of the problem, a leveling off or decrease in the rate of gassing should be guarded with suspicion.

In general, most incipient faults do not clear up by themselves and typically becomes worse as time goes by. When acetylene gas appears, the incipient fault should be classified as permanent and severe and corrective actions readied for implementation.

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Fault GAS Analysis Result Sheet

Dissolved Gas-In-Oil Analysis (DGA)	ppm	%	%
Data Collected			
Report Number			
Oil Temperature			
Hydrogen (H_2)			
Methane (CH_4)			
Ethane (C_2H_6)			
Ethylene (C_2H_4)			
Acetylene (C_2H_2)			
Carbon Monoxide (CO)			
Carbon Dioxide (CO_2)			
Nitrogen (N_2)			
Oxygen (O_2)			
Total Gas			
Total Combustible Gas			
Equivalent TCG Reading (%)			
Comments			

Table 6-1

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Physical and Chemical Tests				
ASTM Method	Particulars	Unit	Result	Remarks
D-15338	Moisture in Oil	ppm		
D-971	Interfacial Tension	dynes/cm		
D974	Acid Number	mg KOH/g		
D-1500	Color Number	Relative		
D-1524	Visual Exam	Relative		
D-887	Dielectric Breakdown Voltage	KV		
D-1816	Dielectric Breakdown Voltage	KV		
D-445	Viscosity	SUS		
D-1298	Specific Gravity	Relative		
D-924	Power Factor @ 25°C	%		
D-924	Power Factor @ 100°C	%		
D-2668	Oxidation Inhibitor	%		
D-1807	Refractive Index	Relative		
D-097	Pour Point	°C		
D-92	Flash Point	°C		
PPM	PCB CONTENT AROCLOR	METALS IN OIL (PPM) ALUMINUM COPPER IRON LEAD SILVER TIN ZINC		

Table 6-2

6.5 SEQUENCE FOR OBTAINING TRANSFORMER OIL SAMPLES FOR DISSOLVED GAS ANALYSIS USING GLASS SYRINGES

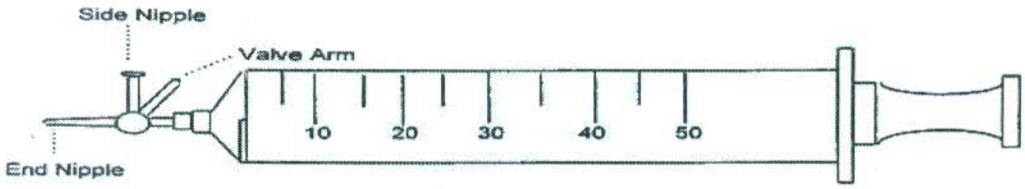
1. Connect tubing to sampling valve on transformer and allow approximately 4 liters of oil to drain into a waste-oil container. Close transformer valve

2. Connect free end of tubing to end nipple of glass syringe. Open transformer valve. Turn syringe valve so that arm is pointing toward side nipple. Draw approximately 10 ml of oil into syringe. Close transformer valve.

3. Hold the syringe in a vertical position with the end nipple pointing up. Turn the syringe valve so that the arm is pointing toward the end nipple. Expel the oil out of the side nipple into a waste oil container. Try to remove all bubbles when performing this step so that only oil fills the "dead space" between the end of the plunger and the base of the syringe barrel.

4. Turn the syringe valve so that the arm is again turned toward the side nipple. Open transformer valve. Slowly draw in oil from the transformer. Any "air" bubbles that form are from degassing of the oil. Do not try to remove these from the syringe.

5. After drawing in approximately 55mls close the system by turning the syringe valve toward the glass barrel of the syringe.



50 ml. Glass syringe

Figure 6-1

Dissolved Gas Sampling Instructions For Filling Stainless Steel or Plastic Cylinders

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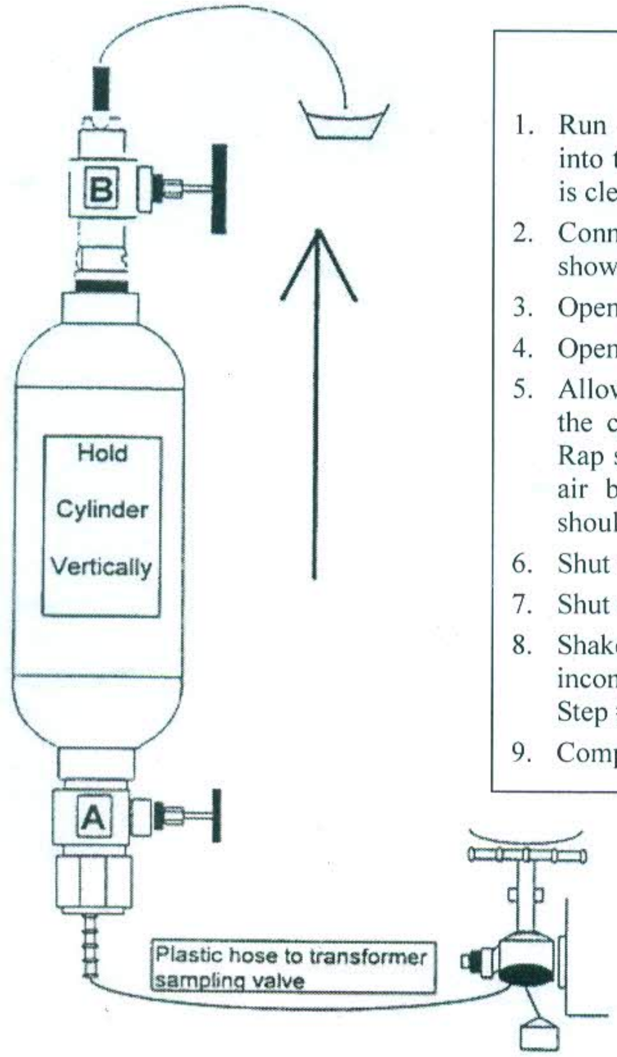

FILLING SEQUENCE

1. Run 4 liters of oil from the transformer into the oil waste container. Drain until oil is clean and clear.
2. Connect the cylinder with plastic hose as shown.
3. Open valve A
4. Open valve B.
5. Allow about 1 liter of oil to flow through the cylinder into the oil waste container. Rap sides of cylinder with tool to dislodge air bubbles. Oil running through tubing should be free of bubbles.
6. Shut valve B.
7. Shut valve A.
8. Shake cylinder and listen/feel for signs of incomplete filling. If present, redo from Step #2.
9. Complete paperwork and ship cylinder.

Figure 6-2

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APPROXIMATE GAS LIMITS

Gas Name	Gas Formula	PPM	(Vol. of Gas to Vol. of Oil) Percent	Cause or Source
Hydrogen	H_2	400	0.0400%	Hydrolysis of water; corona or partial discharge in oil
Oxygen	0_2	35,000	3.5000%	Atmospheric leaks
Nitrogen	N_2	None	None	Atmospheric leaks for conservator type equipment, normal for nitrogen blanketed units
Methane	CH_4	80	0.0080%	Severe local over-heating or sparking
Carbon Monoxide	CO	750	0.0750%	Thermal decomposition of paper or cellulose
Carbon Dioxide	CO_2	10,000	1.0000%	Corona in paper or cellulose
Ethylene	C_2H_4	75	0.0075%	Overheated oil
Ethane	C_2H_6	60	0.0060%	Low energy sparking in oil
Acetylene	C_2H_2	20	0.0020%	Arcing with, power follow through

Table 6-3. Fault gases, approximate concentrations indicating a fault and possible causes at 20^0C.

6.6 INFRARED SCANNING

The majority of all electrical failures are preceded by an abnormal temperature rise. The use of thermography for detecting potential failures in electrical equipment has proved invaluable. There is no other maintenance procedure available today that can give an evaluation of an operating electrical system as efficiently and effectively as thermography. A routine inspection every four years using thermographic inspection

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can substantially reduce the frequency of equipment failures and unplanned power interruptions.

Overheating due to high resistance connections causes the majority of electrical failures. Some of the factors contributing to the development of these high resistance connections are; poor equipment application, improper installation, vibration, expansion and contraction of circuit parts due to load cycling and oxidation of conducting material surfaces. The overheating of electrical equipment is a self-compounding problem. As the temperature rises, so does the resistance.

This rise in heat and resistance leads to mechanical and insulation breakdown with eventual failure of the electrical equipment. This failure can result in injury to personnel, lost production time, and expensive labor and material costs for equipment repair or replacement. An added advantage to an infrared inspection is that it is performed under normal loaded conditions with no interruption to the electrical system.

Scan all equipment & connections, looking for any abnormal variances in temperature.

All electrical contact points and welded or mechanical connections on switches are thermally scanned. Infrared anomalies are then classified and acted upon according to the following system.

Classifications of Heat Rise and action to be taken:

Grade 1: If any connection exceeds 60° C ΔT above local ambient, equipment should be removed from service immediately to determine the cause and effect repair. Extent of damage at this point may require replacement of parts.

Grade 2: If any connection exceeds 40° C ΔT above local ambient, equipment should be removed from service as soon possible (as scheduling permits) to determine the cause and effect repair. The problem can normally be corrected with minimal or no damage having occurred to the component.

Grade 3: If any connection exceeds 10° C ΔT as compared to the remaining corresponding phases, or if any connection is more than 20° C ΔT above local ambient, measures are taken to determine the cause and effect repair. These are problems that should be looked at under normal maintenance schedules or under routine equipment outages

The weather conditions on the day of an inspection may result in a lower temperature rise on the electrical equipment. Following the thermographer's analysis, this

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equipment may be assigned a higher priority rating.

Items to focus on when conducting an infrared scan

Switches and parts

Bolted connections

Pressed-on connections

Welded connections

6.7 PROCEDURES.

Procedures suggested herein are intended to apply to all substations. These suggested procedures may be modified and additional checks, tests, records and more frequent inspections may be performed as considered necessary or desirable. For additional suggestions, see Section 23 - REFERENCE MATERIAL.

6.8 FIELD PERSONNEL

Field personnel are to be trained in proper and safe procedures. They must be familiar with and knowledgeable about the following:

(i) operating procedure of the sub-station

(ii) protective and interlocking scheme

(iii) capabilities of the equipment

(iv) safety procedures

(v) first aid procedures

(vi) equipment grounding techniques.

Field engineers or other authorized personnel may examine substations during any inspection or maintenance period.

6.9 WORK ORDERS

To assure adequate follow-up, the appropriate work orders or job orders should be prepared immediately following the inspection of each substation.

6.10 RECORDS

Records of substation inspections should include readings of all indicated and recorded electrical quantities, times and dates, ambient weather conditions and reference to work orders or job orders showing remedial work performed as a result of each inspection (see Substation Monthly Information Sheet - Section 22 - SUBSTATION INSPECTION AND MAINTENANCE FORMS). These records also evaluate the serviceability of equipment.

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6.11 INSPECTION CHECK LIST

This list contains all items to be inspected during periodic inspections. Formats are provided in Section 22.

6.12 FILES

Files for each substation should include up-to-date drawings of substation single line diagram, substation wiring, structures, equipment, manufacturer's descriptive literature, instruction books, part lists and locations. See Section 22 - REFERENCE MATERIAL for more details.

6.13 SAFETY

All inspections procedures are to be fulfilled in a safe and proper manner. Safety regulations must be observed all the times. Proper distances must be maintained from energized equipment. The following distances are the minimum clearances that must be maintained between personnel and energized equipment.

MINIMUM SAFETY CLEARANCES

Voltage Range	Minimum Clearance
301 to 750 volts	31 cm (1 ft)
751 to 15,000 volts	67 cm (27 in)
15,001 to 36,000 volts	86 cm (34 in)
36,001 to 46,000 volts	96 cm (38 in)
46,001 to 121,000 volts	120 cm (47 in)
121,001 to 145,000 volts	150 cm (59 in)
145,001 to 169,000 volts	171 cm (68 in)
169,001 to 242,000 volts	227 cm (90 in)

Table 6-4

**Voltages listed above are measured phase to phase. On a single phase tap, use the phase to phase voltage of the system it's fed from.

**Proper safeguards are to be employed for safety of persons close to but not engaged, in the work to be performed.

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7.0 POWER TRANSFORMERS

7.1.1 GENERAL

Power transformers require inspection and maintenance on a regular schedule even though they have no moving parts while in operation, unless they have an on-load tap-changing mechanism.

7.2 MONTHLY INSPECTIONS

Monthly inspections, principally visual, should cover the following items as a minimum. Manufacturer's recommendations should also be reviewed in conjunction with inspections. All inspections should be made from ground level maintaining safety clearance as depicted in Section 6. Binoculars should be used to view insulators and lightning arresters of the power transformer.

(Keep in mind that most transformers will be energized and dangerous during inspections. Also treat all neutral and ground conductors as if they were energized, particularly if any ground connection appears to be loose).

1. Look for loose, broken or contaminated bushing, oil leakage from bushings and evidence of heating at terminals. If bushings have oil gauges or sight glass, check for proper oil level indication.
2. Record oil level indicated by oil gauge on main tank and on any conservator or other auxiliary tanks that may be on the transformer.
3. Record oil temperature and position of maximum temperature indicator. Reset maximum temperature indicator.
4. Record gas pressure. Refer to the appendix in this section or to manufacturer's instructions for maximum and minimum acceptable values.
5. Check for padlock on off-load tap-changer operating handle.
6. Check for indication of pressure relief device operation.
7. Inspect general condition including tightness of all connections, oil leaks at gaskets, valves and welds, tank and accessory paint finish, rust formation, any breakage of glass covers in gauges and instruments, dryness of control cabinet, proper operation of heaters, control and current transformer wiring condition, condition of the desiccant, etc.
8. Check operation of auxiliary cooling fans (if installed)
9. Listen for any unusual noises and vibration

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10. Observe condition of foundation for evidence of spelling, cracking or settling
11. Check for bird nests and any other evidence of wildlife activity on or near transformer
12. Observe clearances to trees, vines, or other vegetation in the area
13. Record ambient weather, wind, temperature, etc. conditions

NOTE: *Any symptoms of trouble such as unusual noises, high or low oil levels, pressure relief operation, high gas pressure, etc. should be investigated immediately. Most other items need only to be recorded and reported, thus allowing correction or repair to be scheduled and performed at a convenient time.*

7.3 ANNUAL INSPECTIONS

Annual inspection should be performed to cover important items not included in the monthly inspection, but they could be performed to coincide with one of the monthly inspections. All annual inspections should include at least the following items:

7.3.1 Oil Sampling

1. Introduction

Proper oil sampling is critical for accurate test results. The method outlined is to be used for the sampling of oil from power transformers, regulators, oil filled reactors, etc. The sample will be as performing fault gas analysis, dissolved water content and any such test that requires the sample come in content with the atmosphere.

2. Precautions

The important considerations to observe when obtaining samples are as follows:

a. Oil readily absorbs air and water.
b. The apparatus being sampled must be under positive pressure.
c. The valve and plumbing through which the oil is sampled must be cleaned and thoroughly flushed with oil.
d. The oil sample should be taken from the bottom of the tank.
e. The filled sampling cylinder (sampling bomb) should contain no air and be protected from extreme heat
f. Sampling identification paperwork must be completed and accompany the sample.
g. This method is not suitable for PCB (Poly Carbonate Biphenyl) analysis since contamination from previous samples is highly possible.

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3. **Sampling Equipment**
   a. Stainless steel sampling cylinder (bomb).
   b. Tubing and fittings for connection between the apparatus and the sampling cylinder.
   c. Bucket for collecting flushed oil.
   d. Sealable container for waste oil.
   e. Rags and solvent for spills.
   f. Funnel.
   g. Wrenches.
   h. Insulating Oil-Lab Analysis data sheet.

4. **Sampling Procedure**
   a. Remove the valve plug and flush at least one (1) liter of oil through the valve into the bucket.
   b. Attach the appropriate bushing adaptor to the valve or re-install the valve plug and use the sampling port.
   c. Connect the sampling hose to the valve and flush with at least one (1) liter of oil in order to insure a good sample. Flush until there is no sign of air bubbles, sludge or free water.
   d. Close drain or sampling valve.
   e. Connect the sampling hose to the bottom serrated brass fitting of the oil sampling cylinder.
   f. Connect the sample discharge hose to the top end of the oil sampling cylinder.
   g. With the oil sampling cylinder held vertically over the bucket, open the drain or oil sampling valve.
   h. Open the bottom valve on the oil sampling cylinder.
   i. Open the top valve on the oil sampling cylinder.
   j. Fill the oil sampling cylinder with oil and allow four (4) extra liters to flush through it Tap the cylinder and make sure it is free of air.
   k. When the cylinder is flushed and completely filled, close the top valve of the oil sampling cylinder.
   l. Close the bottom valve of the oil sampling cylinder.
   m. Close the sampling or drain valve.
   n. Remove sampling hoses and drain.

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o. Check the oil sampling cylinder for the presence of air by shaking and listening for any oil movement. If air is detected then re-sample.

p. Record the pertinent data on the Insulating Oil-Lab Analysis data sheet. Note the presence of water, sludge, etc. in the comment section.

q. Pour the spent oil used for flushing into the waste oil container. The waste oil will be collected in bulk containers (55 gallon drums) and disposed at a later time.

r. Clean any spilled oil and return the site back to a clean condition.

s. Send sample and data sheet to lab for analysis.

7.3.2 Oil Dielectric Test

1. **Introduction**

   The oil dielectric breakdown voltage is the voltage at which oil fails to be an insulator. The test is a measure of the oil's ability to withstand electric stress without failure. Low test values may indicate the presence of water, dirt, carbon, conducting particles, etc.

2. **Equipment**

   a. Oil dielectric tester
   b. Thermometer
   c. Lint-free rags
   d. Clean and water-free solvent which has a high boiling point such as kerosene

3. **Procedure**

   There are two accepted methods for testing the dielectric strength of insulating oil. The first method uses electrodes, which are shaped like flat disks; and the second uses electrodes that are spherical in shape. The electrodes are called DE and VDE electrodes, respectively.

   a. Set the electrode spacing per Table 1.
   b. Clean the test cup using the solvent and lint-free rags if necessary.
   c. Thoroughly rinse (wash) the test cup with a portion of the oil sample. .
   d. Fill the test cup with the oil sample.
   e. Measure the temperature of the oil. If it is below 20°C (68°F), warming is required.
   f. Allow the oil sample to sit or be stirred for the time interval specified by Table 7-1.
      i) Apply the test voltage at the rate specified in Table 7-1 starting at 0 volts.
      ii) Record the breakdown voltage.
      iii) Wait the time specified in Table 7-1 before performing the next test.
      iv) Repeat the tests per Table 7-1.

Electrode	DE	VDE
Shape	Flat Disk	Spherical
Gap between electrodes	2.54 mm.	1.0 mm.
Set time	2 min.	0 min.
Stir time	0 min.	3 min.
Rate of voltage rise	3,000 volts/sec.	500 volts/sec.
Wait time between tests	1 min.	1 min.
Total number of tests per sample	5	5
Breakdown voltage	Average of last 5 tests	Average of last 5 tests results

Table 7-1: Test parameters for Oil Dielectric Test

4. Test Limits

Apparatus	138KV and below 877 Electrode	138KV and below 1816 Electrode	230KV and above 877 Electrode	230KV and above 1816 Electrode
New Transformers, Regulators and Reactors - main tank	30 KV	28 KV	35 KV	30 KV
In-Service Transformers, Regulators and Reactors -main tank	26 KV	26 KV	30 KV	25 KV
New Vacuum Tap Changers	30 KV	25 KV	35 KV	30 KV
In-Service Vacuum Tap Changers	26 KV	20 KV	30 KV	25 KV
New interrupting devices -Breakers and Load Tap Changers	30 KV	20 KV	35 KV	30 KV
In-Service interrupting devices - Breakers and Load Tap Changers	26 KV	12 KV	30 KV	25 KV

Table 7-2: Minimum Acceptable Limits for dielectric Breakdown Voltage of Various Types of Apparatus.

5. Example of calculating break-down voltage

Equipment:	**15 KV oil circuit breaker-in-service**
Electrode Type:	VDE (spherical)
Test 1	15 KV
Test 2	17 KV
Test 3	16.5 KV
Test 4	18 KV
Test 5	14.5 KV
Test 6	16 KV

Average of Tests 2 through 6 = 82 KV/5 = 16.4 KV

7.3.3 Leak Testing

1. Introduction

Most power transformers, voltage regulators and oil filled reactors are designed in a manner that seals the internals from the atmosphere. This sealing is intended to prevent oxygen and moisture from entering the device and causing premature loss of life or failure. This procedure describes various techniques for locating faulty seals. Each technique requires a great deal of attention and time in order to find all the various leaks.

2. Safety

Safe working distances from energized conductors must be observed and maintained.

3. Bubble Technique

a. Pressurize the transformer or regulator to within one (1) pound pressure of its indicated operating limit (generally 4 to 6 psig).
b. Spray a soap solution (children's bubble making solution works best) on each joint that is welded or has a gasket. The appearance of bubbles will indicate a leak.
c. Seal all leaky joints

4. **Ultra-Sonic Technique**
    a. Pressurize the transformer or regulator to within one (1) pound pressure of its indicated operating limit (generally 4 to 6 psig).
    b. Using a directional ultra-sonic detector, scan each welded or gasketed joint and "listen" for leaks.

    ***NOTE:** This technique requires a "quiet" environment*

    c. Seal all leaky joints.

5. **Vacuum Technique**
    This technique is effective in finding leaks in transformers or regulators under "full vacuum".

    ***NOTE:** Make sure the transformer or regulator is rated for full vacuum.*

    a. Connect a sensitive vacuum gauge to the transformer or regulator.
    b. Spray each welded or gasketed joint with a fast evaporating liquid such as alcohol. When the liquid is drawn in through the leak, it will expand immediately (boil) and cause the vacuum gauge to move quickly up scale.
    c. Seal all leaky joints.

7.3.4 Insulation Resistance Test

1. **Introduction**
    The electrical insulation of most transformers, regulators and oil filled reactors is made up of various materials such as porcelain, oil, paper, epoxy etc. These materials working alone or in combination make up insulation systems capable of withstanding thousands of volts. The materials, however, are not perfect insulators. This along with contaminants from the manufacturing process and the normal operating environment cause the insulation to be imperfect or "lossy".

    Figure 7-1 displays an electrical model of insulation test. In this model, the insulation is represented by a capacitor and resistor in parallel. The capacitor represents the perfect insulating qualities of the insulating system and the resistor represents the "lossy" or imperfect qualities.

    The Insulation Resistance Test measures the value of "R" or the "lossy" portion of the insulation. For insulations in good condition, "R" is of the order of hundreds to thousands of Megohms of resistance.

2. **Test Method**
    As previously discussed, insulation resistance is a measure of the lossy portion, "R", of the insulation. Its value is measured by placing a D.C. voltage across the insulation under test and either measuring the current, I, and computing "R" by Ohms Law (R =

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E/I) or by measuring "R" directly.

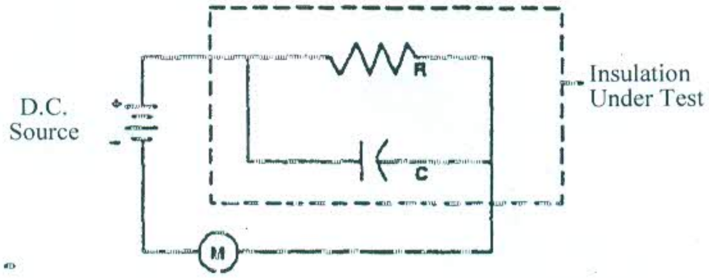

Figure 7-1. Schematic Diagram Showing the Circuit for Measuring Insulation Resistance

It should be noted that by using a D.C. source, the capacitor "C" will become charged and then current will flow through only the lossy portion "R".

The use of a "guard" circuit as shown in Figure 7-2 allows for the testing of individual component parts of .the insulation system. The guard circuit allows part of the current to return to the source without going through the meter.

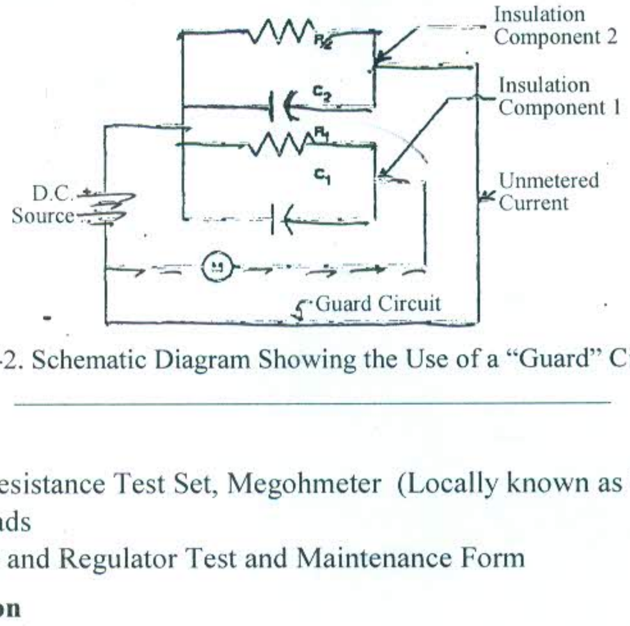

Figure 7-2. Schematic Diagram Showing the Use of a "Guard" Circuit

3. Equipment

a. Insulation Resistance Test Set, Megohmeter (Locally known as "Megger")
b. Shorting Leads
c. Transformer and Regulator Test and Maintenance Form

4. Test Preparation

a. De-energize the transformer, regulator, or reactor to be tested and obtain a

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clearance. Install fall arrest equipment

b. Copy Nameplate information on Transformer and Regulator Test Maintenance Form

c. Disconnect the transformer, regulator or reactor from any loads or sources. The transformer, or regulator must be de-energized and ***unloaded.***

d. Remove any wires used to ground or short circuit the windings.

e. Ground the test set to the station grid using the binding post provided.

f. Clean and dry all bushings.

g. Check the test instrument to make sure it is working properly; with no leads connected and the instrument turned on, a full ohmic scale reading should be obtained, with the high voltage lead connected to the return or ground lead a reading of zero (0) ohms should be obtained.

h. Find the appropriate connection diagram in sections 6 through 10 for the type of equipment being tested and make the necessary connections.

5. Test Procedure

a. With all personnel and equipment in the clear, energize the test set by either cranking the generator manually or electrically.

b. Slowly raise the test voltage to the desired level making sure that the amount of current being drawn does not exceed the rating of the test equipment NOTE: If the instrument has an ammeter, it will deflect to full scale as the capacitance charges and slowly return to near zero after the insulation capacitance becomes charged.

CAUTION: *Never apply voltage to equipment when it is under vacuum.*

c. After the desired test voltage has been obtained and held steady for one minute, read the meters and record on the Transformer and Regulator Test and Maintenance Form.

d. De-energize the test instrument and ground the equipment under test in order to discharge any capacitive charge.

e. Continue the test by making the next test connection indicated in sections 6 through 10.

6. Test Connections - Two Winding Transformers

NOTE: *On three phase transformers, Jumper H_1 to H_2 to H_3 and Jumper X_1 to X_2 to X_3.)*

a. Test connection for measuring the insulation resistance between the primary (high voltage) winding and ground, secondary (low voltage) winding guarded.

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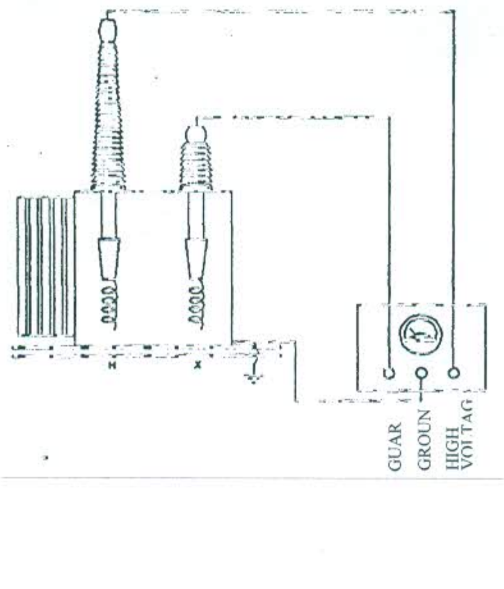
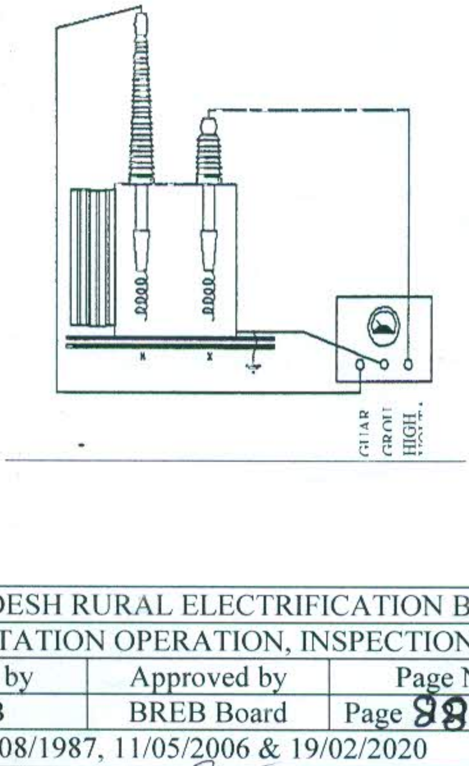


b. Test connection for measuring the insulation resistance between the secondary (low voltage) winding and ground, high voltage winding guarded.



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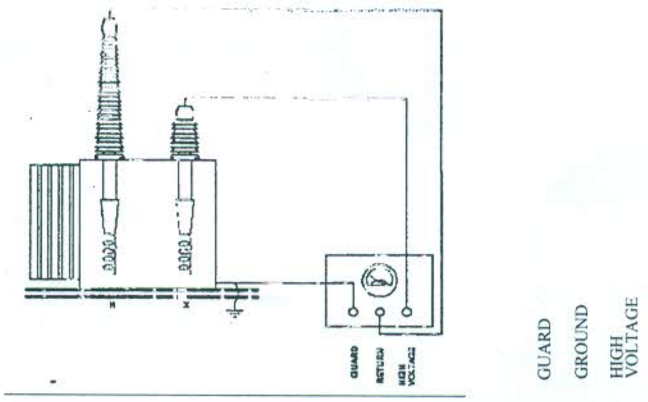
c. Test connection for measuring the insulation resistance between the low and high voltage winding insulations with ground being guarded.



d. Test connection for measuring the insulation resistance between the core iron and ground.

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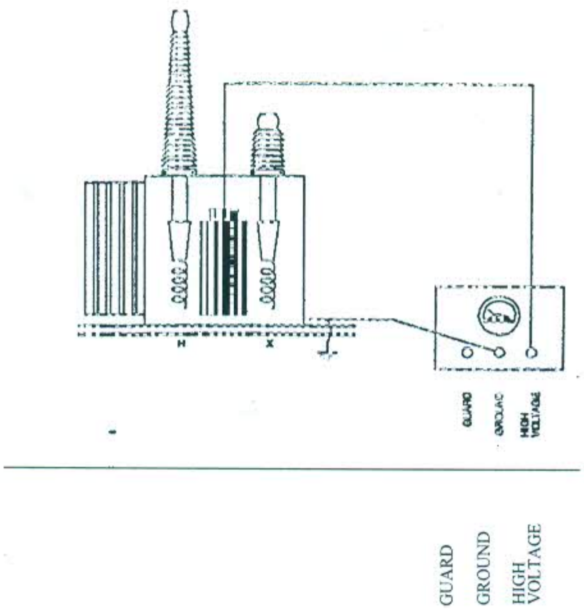
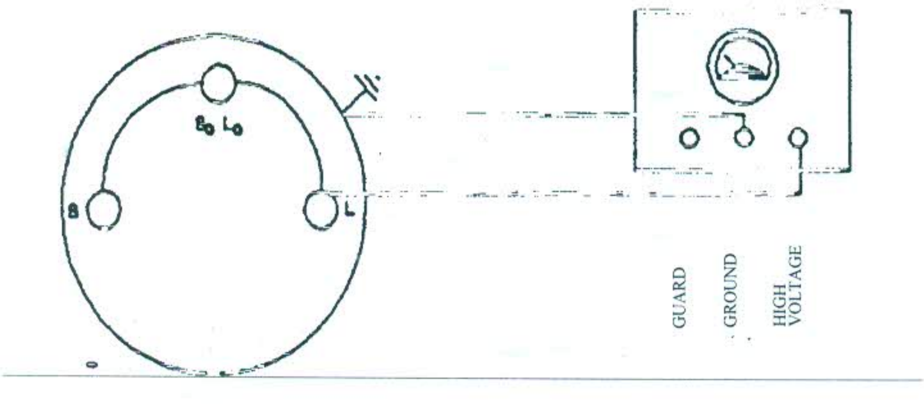
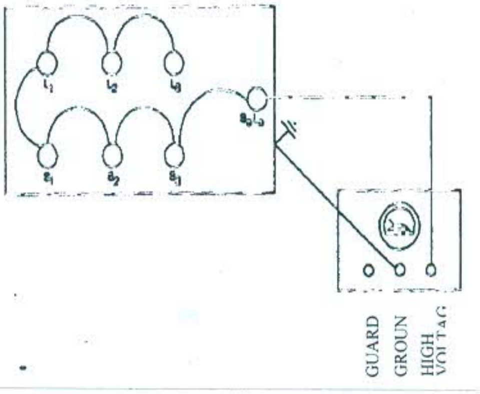


7. **Test Connections – Regulators**

   a. Test connection for measuring the insulation resistance between all windings and ground, single-phase regulator.



b. Test connection for measuring the insulation resistance between all windings and ground, three-phase regulator



8. Minimum Test Values

Table 7-3 Shows the Minimum Recommended Values of Insulation Resistance Expected For Windings in Good Condition

Nominal Voltage Class- Phase to Phase, KV	Minimum Insulation Resistance-Megohms	
	In Oil	In Air
1.2	32	640
6.35 P-G	500	2,700
11	500	4,600
15	550	8,200
19.1 P- G	670	13,400
33	930	18,600
69	1,860	37,200
115	3,100	62,000
135	3,720	74,400
230	6,200	124,400
345	9,300	186,000
Core to Ground	200	100

Table 7-3: Minimum Recommended Insulation Resistance at 20^0C measured by 1000 V Insulation Resistance Tester

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9. Insulation Resistance - Temperature Correction Factors

Insulation resistance measurements vary with temperature; the colder the temperature, the higher the reading. In order to determine the condition of the insulation all measured values are referenced to a standard temperature of 20°C (68°F). The measured values are corrected to 20°C by the multipliers listed in Table 7-4.

Transformer or Winding Temperature		Insulation Resistance Correction Multiplier
^{0}C	^{0}F	
-15	5	0.12
-10	14	0.16
-05	23	0.22
0	32	0.30
5	41	0.40
10	50	0.54
15	59	0.73
20	68	1.00
25	77	1.3
30	86	1.8
35	95	2.5
40	104	3.3
45	113	4.5
50	122	6.0
55	131	8.1
60	140	11.0
65	149	14.8
70	158	20.0
75	167	26.8
80	176	36.2
85	185	49.0
90	194	66.0
95	203	89.0

Table 7-4. Insulation Resistance Temperature Correction Factors

Example:

Winding Temperature	:	40^0C
Meter Reading @ 1000 volts	:	525 Megohms
Correction Multiplier	:	3.3 at 40^0C
Insulation Resistance at 20^0 C	:	525 Megohms x 3.3 = 1732.5 Megohms

7.4 ADDITIONAL INSPECTIONS AND MAINTENANCE WORK.

The following additional inspections and maintenance work may be deemed necessary to ensure good operating condition of transformers.

Receipt and Installation Inspection and Test of Transformers, Regulators

7.4.1 Introduction

Power transformers, regulators and reactors are relatively reliable devices, they can provide years and years of continual service if properly maintained. To a great degree the length and quality of service is determined by the condition of the apparatus at the time of receipt and installation. It is for this reason why the initial receipt, inspection and acceptance is so important

7.4.2 Initial Receipt

Transformers, regulators and reactors are shipped either by railroad, trucking company, ocean freight, etc. has control of the handling of the apparatus. The receipt inspection identifies any defects caused by the carrier or manufacturer and is the acceptance of the apparatus.

1. Coordinate the transformer, regulator, or reactor receipt inspection with the manufacturer and carrier. This should be completed within 72 hours of the arrival of the apparatus.
2. Make a thorough external inspection of the transformer, regulator or reactor prior to unloading. The inspection should include the following:
   a. Examine all blocking and tie downs for damage caused by movement of the apparatus. If Shock Detector (Impact Recorder) is installed by the manufacturer before shipment, its data should be down loaded to computer. Data analyses will detect when fault has been occurred.
   b. Check the tank and fittings for signs of external damage. Check the welds, seams, radiators, valves and accessory cabinets.
   c. Inspect the paint finish and measure its thickness in several places.

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d. Look for signs of oil leaks or spills.
e. Measure the nitrogen or gas pressure in the apparatus. If the pressure is positive or a vacuum exists, the tank is probably free from leaks. If no pressure exists, leaks may be present
f. Inventory the accessory boxes shipped with the apparatus, inspect for damage.
g. Inspect the bushings for porcelain damage.

3. Document any abnormalities or damages and file a concealed damage report with the carrier if necessary.

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7.4.3 Impact Recorder (Shock Detector)

1. The impact recorder is a mechanical device that records on paper tape any high impacts experienced by the transformer, regulator or reactor during shipment. These high impacts may cause damage to both the internal and external components of the apparatus. The impact recorder is typically the property of the manufacturer. If it is missing or damaged, if the seal is broken, or if it has been disturbed in any way, a Specific Carrier's Inspection Report must be issued by the carrier to relieve the purchaser (your company) of the responsibility for the recorder.
2. Prior to the removal of the impact recorder, arrange for a representative of the carrier and manufacturer to witness the inspection of the impact tape.
3. The impact tape records the following:
   a. Time
   b. Vertical impacts
   c. Horizontal impacts
4. Remove the recorder and the tape as per the instructions located inside the recorder cover. Mark the time and date of removal and obtain the following signatures:
   a. Purchaser's Representative
   b. Manufacturers Representative
   c. Carrier's Representative
5. Inspect the full length of the impact tape. Mark and photocopy any of the following:
   a. Horizontal impacts in zone 3 or higher (typically caused by railroad car humping).
   b. Vertical impacts having repeated peaks of 0.7 inches or more for 3 or more hours.
   c. Premature stopping of the tape.
6. File a hidden damage claim with the carrier if severe impacts are revealed.
7. Replace the tape and return the recorder to the manufacturer.

7.4.4 Dew Point Measurement

1. If the transformer, regulator or reactor has a vacuum or no pressure, pressurize to 3 PSIG with dry air nitrogen, wait at least 24 hours before measuring the dew point to allow for the gas to come to equilibrium with the surfaces of the insulation.
2. Thoroughly dry out the dew point tester and connecting hoses by purging (removing) with dry gas for several minutes.
3. Measure the dew point of all compartments.
4. If the transformer, regulator or reactor is found to be wet, it must be dried before

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being placed into service.

7.4.5 Internal Inspection - Safety & Preparation

1. Not all transformers, regulators or reactors are shipped filled with air. Before entering the transformer, regulator or reactor, make certain that the pressure is at zero and that the oxygen content is between 19.5% and 30% at all times personnel are inside the apparatus. If the apparatus is oil or nitrogen filled, it is necessary to remove the oil and/or nitrogen, and if possible, evacuate to a pressure of 1 millimeter of mercury and refill with breathing quality dry air. Ventilate Transformer and install fall arrest equipment.
2. Ground the transformer and all windings.
3. Provide CO_2 fire extinguishers for emergency use.
4. Use explosion proof lights with oil resistant cords.
5. Personnel must remove all metal and loose objects from pockets before entering the apparatus.
6. Before entering the apparatus put on clean coveralls and plastic shoe covers or overshoes. Check oxygen content and monitor for gases.
7. No smoking is allowed on or inside the apparatus.
8. Account for all tools and rags entering the apparatus to make sure they are removed.
9. Continually monitor the oxygen content of the apparatus and while open purge with breathing quality dry air.
10. Always have a safety watch stationed outside the manhole whenever anyone is in the tank.
11. Provide appropriate protection to prevent water and dirt from entering the tank.
12. Provide appropriate confined space breathing apparatus.

7.4.6 Internal Inspection

1. Record the total time the transformer, regulator or reactor windings are exposed to air.
2. Look at the internal parts and see if there are any loose or damaged parts.
3. Remove all debris (rubbishes).
4. Check the alignment of the coils and the tightness of the blocking.
5. Inspect the jacking bolts for misalignment and the core frame for welding cracks, distortion or excessive shifting.
6. Check all metallic electrical connections (bushings, CTs etc.) to make sure they are tight and that there are no missing washers or nuts.

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7. Remove any temporary shipping braces, these are usually painted a bright color.
8. Inspect the inside corners of the tank for possible cracks.
9. Look for any signs of free water or rusting.
10. Inspect the tap changer (If there was one shipped with the transformer).

7.4.7 Testing - Prior to Oil Fill

1. Temporarily disconnect the core ground and measure the insulation resistance from the core laminations to the tank wall. The resistance corrected to 20°C should be at least 100 megohms. Record the test data on the Transformer and Regulator Test and Maintenance form. Reconnect the core ground and verify continuity to ground.
2. Fully test all controls.
3. Perform a complete ratio test.
4. Make a final dew point measurement and determine if dry out is necessary.
5. Test all bushings and arresters.

7.4.8 Testing - After Final Oil Fill

After the transformer, regulator or reactor has been oil filled as per the manufacturer's instructions, perform the following tests:

1. OLTC (On Load Tap Changer) Reduced Voltage Test.
2. Insulation Power Factor Test.
3. Insulation Resistance Test.
4. Oil dielectric Test.
5. Winding Excitation Test.
6. Impedance Test.
7. Winding Resistance Test.

7.4.9 Claims

At the conclusion of the above items, an overall assessment of the condition of the power transformer, regulator or reactor can be made. Considerable judgment in filing a claim must be exercised. Damage claims should be filed in conjunction with the manufacture's representative's report with the full cooperation of the engineering and purchasing departments.

7.5 STORAGE OF POWER TRANSFORMERS AND REGULATORS

7.5.1 Introduction

Power transformers, regulators and reactors not put into immediate service must be stored

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in a manner that does not allow the degrading of the device, especially the insulation. The two suitable storage methods are:

1. Storage in dry air or nitrogen
2. Storage in oil

7.5.2 Storage - 0 to 3 Months

If the power transformer, regulator or reactor cannot be put into service for up to 3 months from the date of shipment, it may be stored in dry air or nitrogen.

1. Place apparatus on a solid level foundation of timbers.
2. Ground the tank and windings.
3. Measure and record the dew point of the apparatus (see Section 7.4.4).
4. Install gas regulating equipment and pressurize the main tank to 2 PSIG with dry air or nitrogen.
5. Read and record the gas bottle pressure daily for one week. If large pressure drops are indicated correct as soon as possible.
6. Inspect the gas regulating equipment and record the pressure on a weekly basis.

7.5.3 Storage - Beyond 3 Months

If the transformer, regulator or reactor cannot be put into service for beyond three months from the date of shipment, it must be stored in oil in order to prevent the dry-out of the cellulose insulation.

1. Place apparatus on a solid level foundation of concrete or timbers.
2. Ground the tank and windings.
3. Measure the dew point of the apparatus.
4. Test for and seal all leaks.
5. Fill the transformer, regulator or reactor with oil.
6. Install gas-regulating equipment and pressurize to 2 PSIG with dry nitrogen.
7. Inspect the gas regulating equipment and record the pressure on a monthly basis.

7.5.4 Control Cabinets

Energize the control cabinet heater and put heater into operation in order to prevent condensation on all stored equipment.

7.5.5 Radiators

Store with top and bottom openings sealed and in a manner that prevents standing water to accumulate at these points. Consideration should be given to installing the radiators on the apparatus in order to prevent loss or damage.

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7.5.6 Fans

Fans should be stored in waterproof containers indoors or on the installed radiators outdoors. If stored outdoors, check the manufacturer's specific storage instructions.

7.5.7 Pumps

The pump openings should be sealed with blind flanges and stored in waterproof containers preferably indoors. If stored outdoors, they must be stored up off the ground. Consideration should be given to installing the pumps on the apparatus in order to prevent loss or damage.

7.5.8 Bushings

Bushings are fragile and highly susceptible to damage from moisture. Bushings are to be stored either in the apparatus or indoors in waterproof bags and crates. Oil filled bushings must not be stored at an angle of less than 20° from the horizontal.

7.5.9 Arresters

Arresters are fragile and highly susceptible to damage from moisture. They are to be stored in waterproof containers preferably indoors and upright.

7.5.10 Accessories

Spare gaskets, paint, bushing connectors, sudden pressure relays, tape, gasket cement, etc. are to be stored indoors in a dry place and clearly marked FRAGILE. The device which they are for shall be marked on the accessory item.

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7.6 TEST AND MAINTENANCE SCHEDULE FOR POWER TRANSFORMER AND VOLTAGE REGULATOR

ACTION	SCHEDULE					
	INITIAL			ROUTINE		
	Upon Receipt or Installation	After Energization				
		24 hours	1 month	Monthly	Yearly	3 Years
Dissolved Gas Analysis(DGA)		X	X		X	X
Oil Water	X				X	X
Oil-Acid		X				X
Oil-IFT		X				X
Oil-Color		X				X
Dew Point	X		X			X
Inspection	X			X	X	X
Minor Maintenance					X	X
Major Maintenance	X					X

Table 7-5

* The first major maintenance should be performed at three (3) years or 36,000 operations whichever occurs first for LTC transformer. If minor test and maintenance indicates the transformer to be in normal condition, routine major test and maintenance can be delayed an additional year or follow manufacturer's recommendations.

7.7 TRANSFORMER AND REGULATOR MINOR MAINTENANCE

7.7.1 Introduction

Minor maintenance and testing of transformers, regulators and reactors is a yearly practice designed to identify and correct problems before they become major. The practice does not require an outage and is summarized on the Transformer and Regulator Test and Maintenance Form.

7.7.2 Safety

During minor maintenance, the transformer, regulator or reactor is energized and a legal/safe working clearance must be kept from all energized parts. This work is to be performed by qualified personnel only.

7.7.3 Main Tank

1. Check the oil level and temperature. The oil level indicator will change with temperature due to the expansion and contraction of the oil. The 25°C mark indicates the correct oil level for the transformer and oil at a 25°C temperature. With the oil at -20°C, the level indicator should read "low" and with the oil at 85°C the indicator should read "high" for properly filled transformers. If maintenance is required on the liquid level gauge be aware of the oil temperature and fill to that temperature level.
2. Check for any oil leaks and note on test and maintenance form.
3. Sample the oil and perform a dielectric strength test.
4. Sample the oil for dissolved gas analysis test if due at this time.
5. Check the nitrogen blanket regulating equipment The nitrogen blanket should be held at +1 to +3 P.S.I.
6. Using clamp on ground tester or a ground test set, test the ground connections, ideally the resistance should be less than 0.1 to 0.5 ohms.
7. Inspect the pressure relief devices for proper seal.

   NOTE: *Keep legal safe working distances from the energized bus and conductors when inspecting. Use binoculars if necessary.*

8. Wire brush all rust spots and spray with zinc rich primer. Finish coat all premiered surfaces.

7.7.4 No Load Tap Changer and On Load Tap Changer (if equipped)

1. Make sure the no load tap changer is locked or bolted into position.

   NOTE: *The no load tap changer position cannot be changed when the transformer is energized without damage or failure.)*

2. Check the oil levels in the selector and/or transfer switch compartments of the load tap changer.
3. Clean and dry breather vents, replace desiccant filters if appropriate.
4. Perform infrared inspection of the OLTC (On Load Tap Changer) mechanism. If the

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OLTC temperature is higher than that of the main tank, major maintenance is necessary.

5. Inspect the LTC drive mechanism and lubricate if necessary.
6. If excessively high or low BUS voltages do not result, operate the OLTC through the neutral position in order to operate the OLTC reversing switch.
7. Using a small variable transformer (variac), operate the OLTC motor at 75% to 80% of normal voltage. If the motor stalls when driving the reversing switch, investigate for possible mechanical binding. Before performing this test, verify that vacuum interrupter protective circuits will not fail under reduced voltage.
8. Verify that the OLTC position indicator and operations counter work properly.
9. Take oil samples from the selector and/or transfer switch compartments and perform oil dielectric tests.

10. Wire brush all rust spots removing the large particles and any oil. Spray with a rust converter primer or a zinc rich primer, finish coat all premiered surfaces.

7.7.5 Cooling Equipment

1. Check all electrical connections to the cooling fans.
2. Lubricate all fan motors, if applicable.
3. Operate all cooling fans.
4. Remove/Replace non-working fan motors.

7.7.6 Bushing

1. Using binoculars, inspect the bushings for cracks.

   ***NOTE:** Keep a legal safe working clearance from all energized parts.*

2. Check bushing oil levels.

7.7.7 Controls

1. Test the control/indicating contacts on all oil level and temperature gages.
2. Inspect and tighten all electrical connections.
3. Operate and test the control cabinet heaters.
4. If the transformer is equipped with a on load tap changer. Manually operate the tap changer controls and run the tap changer two to three steps higher, place the controls back to the automatic mode and allow the tap changer to return to its normal position checking the timing and bandwidth controls. Repeat by running the tap changer down two to three steps.

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5. Check all annunciator, alarm and control circuits.

7.8 MAJOR MAINTENANCE OF TRANSFORMERS AND REGULATORS

7.8.1 Introduction

Major maintenance of power transformers and regulators involves the de-energization and removal from service of the apparatus. This type of maintenance should occur at a maximum frequency of once every three years or more preferably when diagnostic tests indicate it to be necessary. A higher frequency of major maintenance is generally the result of.

1. Improper application of the apparatus
2. Poor quality of design and/or workmanship
3. Imminent failure

The major maintenance items are summarized on Table 7-5, Test and Maintenance Schedule For Power Transformer and Voltage Regulator .

7.8.2 Safety

De-energize the apparatus to be maintained, tag and obtain a clearance. After a clearance has been obtained, test for de-energization and apply personal safety grounds. Make sure the device is de-energized and no back feeds exist.

7.8.3 Minor Test And Maintenance

Perform all the test and maintenance items listed under minor test and maintenance.

7.8.4 Main Tank, Bushings and Arresters

Clean and dry all bushing and arrester porcelain and isolate from the bus.

1. Perform insulation power factor tests on:
   - All windings
   - All bushings
2. Perform winding exciting current tests.
3. Perform leakage current tests on all arresters.
4. Clean all bushing and arrester connections.
5. Perform a dew point test on the gas blanket of the main tank. A conservator tank unit does not require this test. If the dew point measurement is above the accepted value and the insulation power factor is above 1.0%, drying out of the apparatus is

necessary.

6. Check all bushing, manhole, and flange gaskets for leaks.
7. Test and adjust all thermal indicators and their switches by removing the temperature sensing bulb from its well. Compare the instrument with the test thermometer and adjust if necessary. Make sure that each cooling stage is activated at the appropriate temperatures
8. Completely repaint the apparatus, if necessary.

7.8.5 Tap Changers

1. Manually operate the no load tap changer through all positions in order to "wipe" all contacts. Return to its normal position. Perform TTR (Transformer Turn Ration) test at the position the No Load tap is set on to verify that it is indeed on that tap.
2. If equipped with a On Load Tap Changer do the following maintenance.
   a. Drain and filter the oil from the tap and/or selector switch compartments of the On Load Tap Changer (OLTC) Section.
   b. Flush each compartment with filtered oil in order to remove all carbon.
   c. Inspect the on load tap changer mechanism and drive trains. Maintain, replace or exchange the position of worn contacts; Note the percent of contact wear.
   d. If the tap changer uses vacuum bottles for arc interruption, test the bottles and control circuitry.
   e. Check the spring tension for each contact.
   f. Check the timing of the on load tap changer mechanism through the full operating range.
   g. Fill the tap and/or selector switch compartments with clean, filtered oil.

7.8.6 Final Test

1. Perform a partial turns ratio test to verify proper operation of the on load and no load tap changers.
2. Reset the no load and on load tap changers (OLTC) to their proper positions.

7.8.7 Oil Filtering

1. Perform only when transformer is initially installed and subsequently only when tests on oil or gas sample show conditions and characteristics to be less than acceptable.
2. Perform only with transformer de-energized.

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3. Use vacuum process and heated oil.
4. Follow transformer manufacturer's recommendations and oil filter equipment manufacturer's recommendations and instructions (Section 23 REFERENCE MATERIAL)
5. Ground all winding terminals (line and neutral), oil filtering equipment, oil containers, etc., solidly to a common ground and to the substation ground. This procedure will eliminate development of hazardous static voltage charge. Leave all winding terminals grounded as long as possible after oil filtering is completed to ensure drainage of static charge on the windings to a safe value.
6. Perform an insulation power factor test. Doble test or other established methods may be used. This test will determine bushing and winding insulation condition.
7. If power factor test equipment is not available, an insulation resistance test should be performed. This will reveal insulation condition in terms of insulation resistance. (Note: Terminal grounds must be removed for insulation power factor and insulation resistance tests, thus requiring appropriate safety precautions to be observed).
8. Moisture content of insulation and oil may remain too high through filtering process. This will require continued filtering with heated oil and may require application of external heat, circulation of heated air through gas space or by other approved methods. In severe cases of wetness or free, suspended water, reconditioning of the transformer at a service and repair facility may be necessary.

7.9 RATIO TESTING

7.9.1 Introduction

The Transformer/Regulator Ratio Test is used to determine the condition of transformer or regulator windings. It is helpful in finding open or shorted coils and tap changer problems. The test is normally performed prior to energization, after a fault situation or at the completion of tap changer maintenance.

By definition, the voltage ratio or turns ratio is the ratio of the higher voltage to the lower voltage winding. The Calculated Voltage Ratio is found by dividing the appropriate voltage values and the Measured Voltage Ratio is found by testing. For well-designed and problem-free transformers, the Measured Voltage Ratio should agree within 0.5% of the Calculated Voltage Ratio.

7.9.2 Equipment

1. Transformer Voltage (Turn) Ratio Test Set (Biddle TTR) with instruction manual
2. H winding and X winding test leads

7.9.3 Test Preparation

1. De-energize the transformer or regulator to be tested and obtain a clearance. After a clearance has been obtained, test for de-energization and install personal safety grounds
2. Copy nameplate information and phasor diagram on Transformer/Regulator Test and Maintenance Form.
3. Disconnect the transformer or regulator bushing terminals from any loads or sources. The transformer must be de-energized and unloaded.
4. Remove any wires used to ground or short circuit the transformer windings.
5. Ground the ratio test set to the station ground grid using the binding post on the instrument

(NOTE: If there are energized high voltage conductors near the transformer, it may be necessary to also ground one terminal of the transformer or regulator to the station ground grid in order to minimize the "noise" picked up by the test instrument.)

6. In order to check the test instrument, follow the Instruction Manual.
7. For connection and color coding of the leads, follow the Instruction Manual.
8. Find the connection diagram in Figure 7-4 that agrees with nameplate phasor diagram of the transformer or regulator being tested.
9. Connect the exciting leads, the H test leads, to the higher voltage winding of the two windings being tested.
10. For Subtractive Polarity transformers, connect the X_{red} lead to the lower voltage terminal which corresponds to the H_1, connection as instructed by Figure 7-4. Connect the X_{yellow} lead to the other lower voltage terminal. NOTE: For additive polarity transformers, the X_{red} and X_{yellow}, leads must be interchanged and in the opposite position of the $\mathbf{H}_{red}$ and $\mathbf{H}_{yellow}$ leads.

7.9.4 Measuring The Ratio

1. Set the dials to 0.000
2. While cranking the instrument so that the exciting voltage is approximately eight (8) volts, turn the first dial clockwise until the galvanometer deflects right
3. Reverse the dial (counter-clockwise) one (1) digit
4. Repeat steps 2 and 3 for dial two (2) and then dial three (3).
5. While cranking, adjust dial four (4) so that the galvanometer reads zero (0) or Null.
6. Read the Measured Voltage Ratio from left to right
7. Record the Measured Voltage Ratio.
8. Compare the Measured Voltage Ratio with the Computed Voltage Ratio.

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9. Repeat for the remaining tap positions, phases and winding combinations

7.9.5 Example of Test Results for 3-phase Transformers

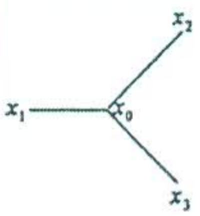
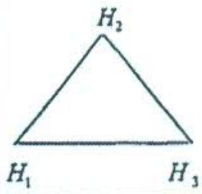
H WGD.		X WGD.		COMPUTED VOLTAGE RATIO	MEASURED VOLTAGE RATIO			
T	VOLTS	T	VOLTS		A0	B0	C0	WINDING DIAGRAMS
A/1	36200	N	12470	5.027	5.010	5.021	5.021	
B/2	35300	N		4.903	4.888	4.895	4.890	Y - WINDING
C/3	34400	N		4.779	4.768	4.777	4.772	CONFIGURATION
D/4	32600	N		4.652	4.645	4.649	4.650	
E/5	34400	N		4.528				
		16R	13717	4.344				NONE
		15	13639	4.368				
		14	13561	4.394				X - WINDING
		13	13483	4.419				CONFIGURATION
		12	13405	4.445				
		11	13327	4.471				
		10	13249	4.497				
		9	13171	4.524				
		8	13094	4.550				
		7	13016	4.578				
		1R	12548	4.748				
		N	12470	4.779				
		1L	12392	4.808				H-WINDING
								CONFIGURATION
H WDG.		Y WDG.		COMPUTED VOLTAGE RATIO	A0	B0	C0	
T	VOLT S	T	VOLT S					
C/3								

Figure 7-3

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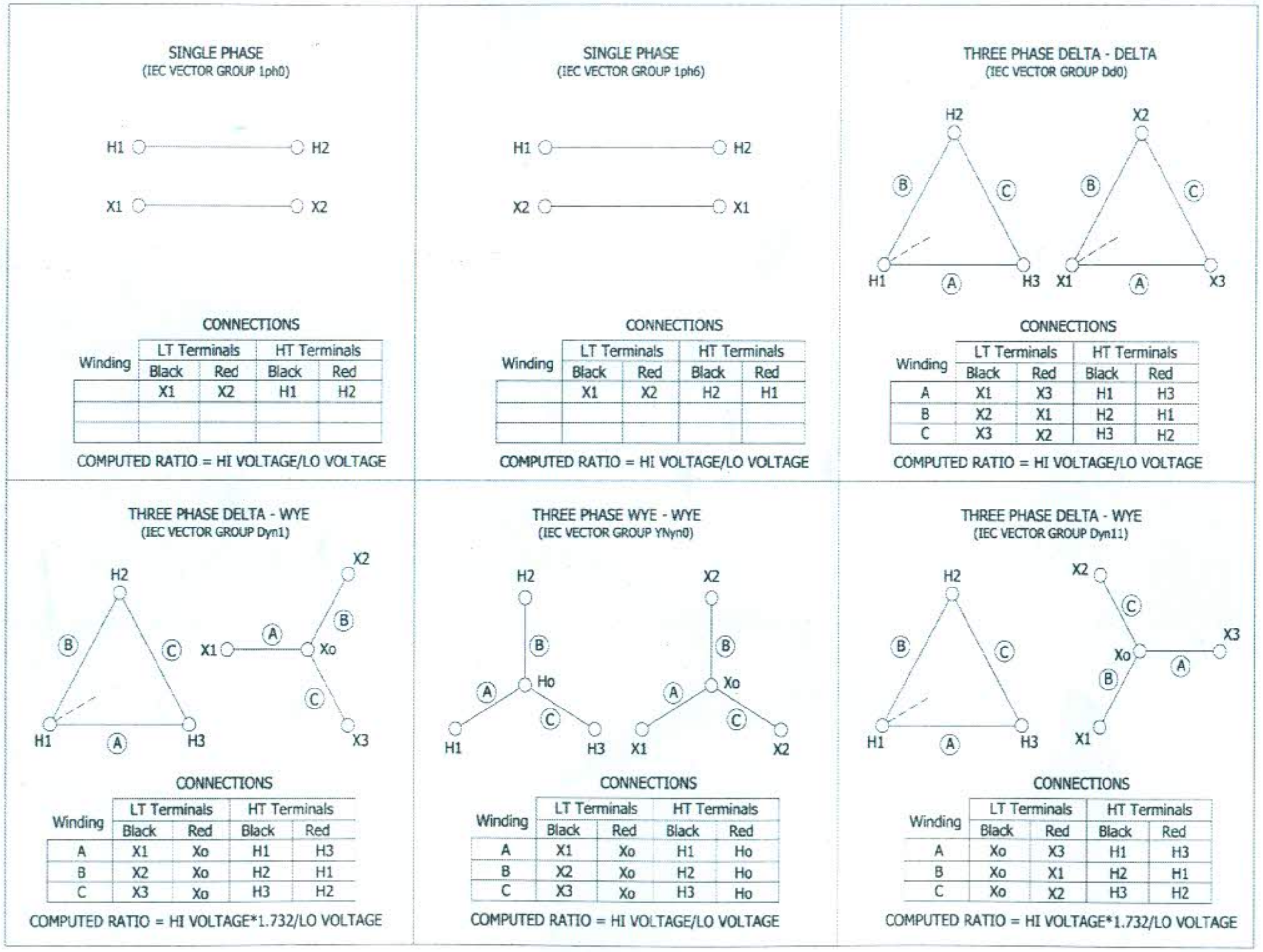
7.9.6 Single and Three Phase Voltage Ratio Measurement Connections



SINGLE PHASE (IEC VECTOR GROUP 1ph0) — CONNECTIONS

Winding	LT Terminals		HT Terminals	
	Black	Red	Black	Red
	X1	X2	H1	H2

COMPUTED RATIO = HI VOLTAGE/LO VOLTAGE

SINGLE PHASE (IEC VECTOR GROUP 1ph6) — CONNECTIONS

Winding	LT Terminals		HT Terminals	
	Black	Red	Black	Red
	X1	X2	H2	H1

COMPUTED RATIO = HI VOLTAGE/LO VOLTAGE

THREE PHASE DELTA - DELTA (IEC VECTOR GROUP Dd0) — CONNECTIONS

Winding	LT Terminals		HT Terminals	
	Black	Red	Black	Red
A	X1	X3	H1	H3
B	X2	X1	H2	H1
C	X3	X2	H3	H2

COMPUTED RATIO = HI VOLTAGE/LO VOLTAGE

THREE PHASE DELTA - WYE (IEC VECTOR GROUP Dyn1) — CONNECTIONS

Winding	LT Terminals		HT Terminals	
	Black	Red	Black	Red
A	X1	Xo	H1	H3
B	X2	Xo	H2	H1
C	X3	Xo	H3	H2

COMPUTED RATIO = HI VOLTAGE*1.732/LO VOLTAGE

THREE PHASE WYE - WYE (IEC VECTOR GROUP YNyn0) — CONNECTIONS

Winding	LT Terminals		HT Terminals	
	Black	Red	Black	Red
A	X1	Xo	H1	Ho
B	X2	Xo	H2	Ho
C	X3	Xo	H3	Ho

COMPUTED RATIO = HI VOLTAGE/LO VOLTAGE

THREE PHASE DELTA - WYE (IEC VECTOR GROUP Dyn11) — CONNECTIONS

Winding	LT Terminals		HT Terminals	
	Black	Red	Black	Red
A	Xo	X3	H1	H3
B	Xo	X1	H2	H1
C	Xo	X2	H3	H2

COMPUTED RATIO = HI VOLTAGE*1.732/LO VOLTAGE

Figure 7-4

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7.9.7 Computed Voltage Ratio

The formulas for computing the voltage ratio are given on the Transformer and Regulator Test and Maintenance Form. The Measured Voltage Ratio should agree within± 0.5% of the Computed Voltage Ratio.

Example:

H-3ph voltage = 33 KV DELTA
Y-3ph voltage = 11 KV WYE

$$\text{Computed Voltage Ratio} = \frac{\text{H-3ph voltage}}{\text{Y-3ph voltage}} \times 1.732$$

$$= \frac{33\ KV}{11\ KV} \times 1.732$$

$$= 5.196$$

For windings in good condition:

Maximum Measured Voltage Ratio = Computed Voltage Ration x 1.005
= 5.196 x 1.005
= 5.222

Minimum Measure Voltage Ratio = Computed Voltage Ration x 0.995
= 5.196 x 0.995
= 5.170

7.9.8 Exciting Current

The exciting current is the current required to magnetize the iron core of the transformer. An estimate of the amount of exciting current required to magnetize the core is indicated by the ammeter on the test set.

For most transformers the value of the exciting current is very low and results in an ammeter deflection of 1/4 scale or less.

7.9.9 Analysis of Results

The following table may be used to interpret the test results.

EXCITING CURRENT	MEASURED VOLTAGE RATIO		
	Greater Than Computed Ratio	Lower Than Computed Ratio	Agrees With Computed Ratio
High	Shorted "X" (excited) winding	Shorted "H" winding	Shorted third winding-not in test circuit
Low or Zero	Open "X" (excited) winding	Open "X" (excited) winding	Faulty ammeter or normal winding with low exciting current
Normal	Open "H" winding	Open "H" winding	No problems detected

Table 7-6

7.9.10 Zero Error Check

The Zero Error test checks the zero off-set accuracy of the test instrument. For instruments in good condition, a reading of 0.000 to 0.005 should be obtained.

1. Screw the exciting, "X" leads tightly against the anvils.
2. Short the "H" leads together.
3. Turn the dials on the test set to 0.000.
4. Crank the test set so that 8 volts is indicated by the voltmeter.
5. While cranking, adjust the fourth dial so that the galvanometer reads zero (null).
6. The value indicated by the forth dial is the zero off-set error.

7.9.11 Unity Ratio Check

The Unity Ratio test determines the percent accuracy of the test instrument. For accurate instruments, a reading between 1.002 and 0.998 should be obtained.

1. Screw the clamps of the exciting, "X" leads tightly against the anvils.
2. Connect the black "H_1" lead to the black exciting "X1," anvil and connect the red "H_2" lead to the red exciting "X_2" anvil.

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3. Set the dials to read 1.000.
4. Crank the generator so that 8 volts is indicated by the voltmeter.
5. While cranking, adjust the fourth dial so that the galvanometer reads zero or null.
6. If the test set does not read between 1.005 and 0.995, the instrument is either out of calibration or damaged, consult the manufacturer's instruction book

7.10 POWER TRANSFORMER AND REGULATOR INSULATION DISSIPATION POWER FACTOR TEST

7.10.1 Introduction

The electrical insulation of transformers and regulators are made up of various dielectric (insulating and non-conductive) materials such as paper, oil, porcelain, epoxy, etc. These materials working alone and in combination are sized to withstand, without failure, very high voltages. In general, the higher the designed withstand voltage, the more insulation required.

Figure 7-5 illustrates a simple model or equivalent circuit of electrical insulation. In this model, the electrical insulation is represented by two quantities, resistance (R) and Capacitance (C). The Resistance (R) represents the imperfect portion of the insulation or path for "leakage" current The lower the value of Resistance (R), the more imperfect the insulation. The capacitance (C) represents the perfect insulating (dielectric) qualities of the insulation. The thicker the insulation the lower the value of capacitance.

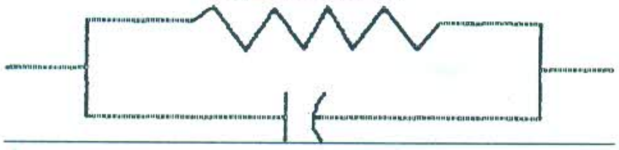

Figure 7-5. Simple Model of Electrical Insulation

7.10.2 Comparison to Insulation Resistance Test

As the withstand voltage of the insulation increases so does the value of Resistance (R) thus providing more resistance to leakage currents. This is noticed when performing the Insulation Resistance (Megger) Test. For example, the Insulation Resistance of 15 KV circuit breaker insulation may be measured and found to be 250 megohms and a 138 KV insulation measured and found to be 3000 megohms. Both insulations are good but due to their different voltage ratings they have significantly different insulation resistances. Unfortunately, the Insulation Resistance test only measures the value of R and indicates how poor the insulation is and changes dramatically with the voltage rating of the insulation.

Power Factor testing measures both the Resistive (R) or imperfect qualities and the Capacitance (C) or perfect insulating (dielectric) qualities of the insulation and thus gives a total indication of the quality of the insulation. The Insulation Dissipation Factor is the inverse (reciprocal) of the product of the resistive portion of the insulation (R) times the capacitive portion (C). The Insulation Power Factor is the ratio of energy loss (Watts) in the insulation (Dielectric loss) to the charging volt amperes. Both the Insulation Dissipation Factor and Insulation Power Factor are independent of the amount of insulation under test. For good insulation, the Insulation Dissipation or Power Factors are generally always constant (less than 1.0 percent) no matter what the voltage rating of the insulation is. **FOR GOOD INSULATION, THE INSULATION DISSIPATION FACTOR IS THE SAME AS THE INSULATION POWER FACTOR AND LESS THAN 1.0%.**

7.10.3 Test Method

The Insulation Dissipation Power Factor test measures both the value of R and C by utilizing an A.C. voltage rather than a D.C. voltage used in the Insulation Resistance Test (see Figure 7-6). Typically, the Insulation Dissipation Factor test measures the ratio of the current through the Resistive portion (R) to the current through the Capacitive portion (C) while the Power Factor Test measures the ratio of the power dissipated by the Resistive portion (R) of the insulation (Dielectric loss) to the apparent power (charging volt amperes) consumed by both Resistive (R) and Capacitive (C) portions of the insulation. The units of Power Factor are percent Power Factor (% P.F.) and Dissipation Factor (% D.F.).

For 50 Hertz equipment, the Dissipation Factor is:

$$\%D.F. = \frac{1}{(377)(R)(C)} \times 100$$

$$= \frac{I_R}{I_C}$$

where: R is the Resistance of the insulation in ohms

C is the Capacitance of the insulation in Farads

% D.F. is the percent Dissipation Factor

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I_R is the current through the Resistive portion (R)

I_c is the current through the Capacitive portion (C)

For 50 Hertz equipment, the Power Factor is:

$$\%P.F = \frac{Real\ Power}{Apparent\ Power} \times 100$$

$$= \frac{Dielectric\ Loss}{Charging\ Volt\ Amperes} \times 100$$

where: Real Power is the power consumed by the Resistive portion of the insulation (Dielectric loss).

P.F. is the percent Power Factor.

Apparent Power (Charging Volt Amperes) is the value obtained by multiplying the voltage applied across the insulation with the test set times the current flow through the insulation; (V)(I).

For new insulation in good condition, the Insulation Dissipation or Power Factor is generally less than one half percent (0.5%) and almost always less than one percent (1.0%). As insulations begin to deteriorate or absorb water, increases in the Insulation Dissipation/ Power Factor can be easily observed.

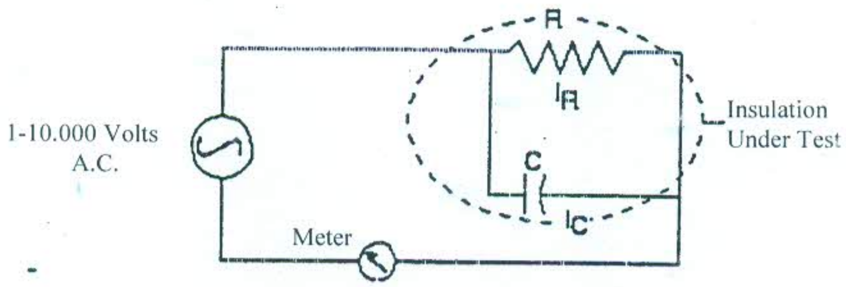

Figure 7-6. Schematic Diagram showing the Test Circuit for measuring Insulation Power Factor

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The use of a "guard" circuit as shown in Figure 7-5 allows for the testing of individual

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component parts of the insulation system. The guard circuit allows part of the current to return to the source without flow in, through the Dissipation/Power Factor meter.

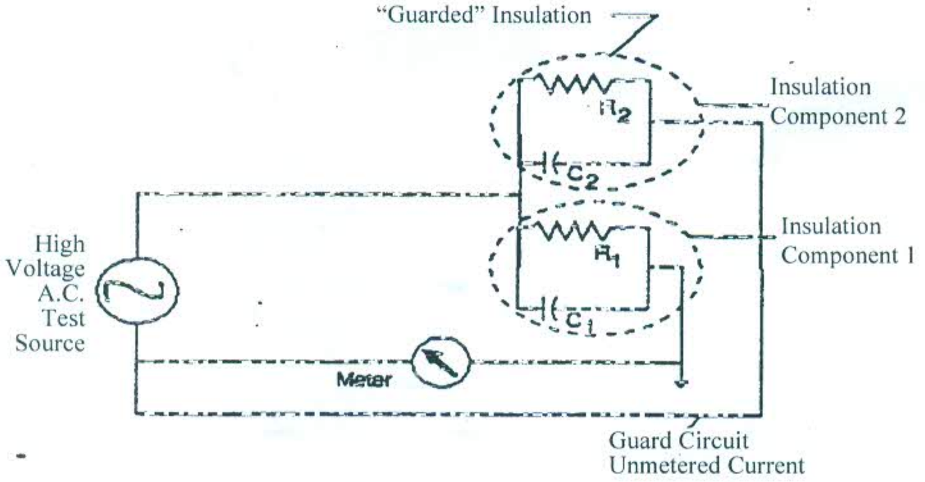

Figure 7-7. Schematic Diagram showing the use of a "Guard" Circuit

By making the guard circuit and ground the same point on the test circuit, tests can be performed on ungrounded insulations and yet still leave the test set solidly grounded for reasons of safety. The use of the ungrounded specimen test ("UST') is shown in Figure 7-8.

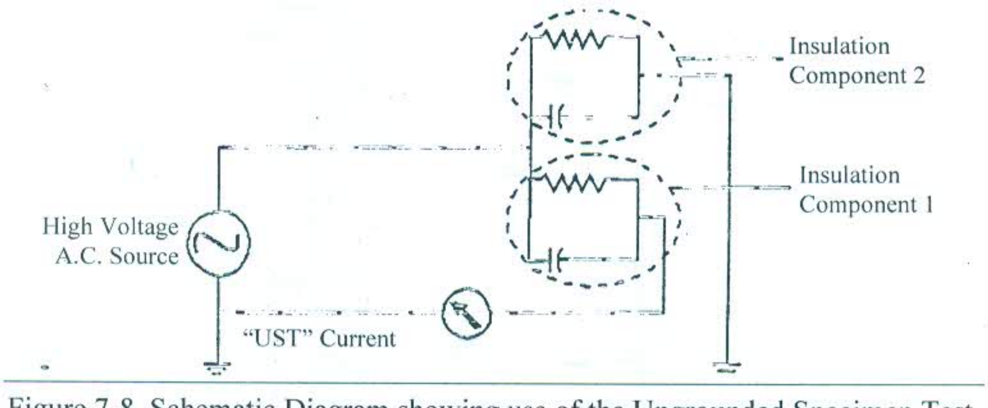

Figure 7-8. Schematic Diagram showing use of the Ungrounded Specimen Test.

7.10.4 Equipment

1. Doble Power Factor Test Set
2. Shorting Leads
3. Transformer and Regulator Test Data on Floppy Disk/CD.

7.10.5 Test Procedure

CAUTION: *There is always the possibility of voltage being induced at the terminals of The transformer due to overhead lines or the existence of residual static charge.*

1. De-energize the transformer or regulator to be tested and obtain a clearance.
2. Ground all transformer windings to insure that it is fully de-energized and no back feeds exist. Disconnect the transformer or regulator from any loads or sources. The device under test must be de-energized and unloaded. Isolate from long bus runs and arresters.
3. For three phase transformers, install the shorting leads and short circuit the primary windings. Using additional shorting leads, repeat for the secondary and tertiary windings.
4. Ground the M4000/Power Factor Test Set to the station ground grid. Connect the leads to the test set and obtain power from a grounded 120 volt outlet. The ground of the 120 volt outlet and the station ground grid must be electrically tied together.
5. Clean and dry all bushings. Wet or contaminated bushings will result in a high Dissipation/ Power Factor.
6. Find the appropriate connection diagram for the type of equipment being tested and make the necessary connections.
7. Temporarily isolate the transformer from the previously installed safety grounds for test purposes. Make sure the neutrals are disconnected from ground.
8. Program M4000 to run tests (refer to Doble Automated Insulation Analyzer).

7.10.6 Interference Suppression

The Doble M4000 Tester is equipped with automated line sync reversal and line frequency modulation at 50 or 60 Hz with either reference to 10KV or actual values. The techniques of averaging the results of two tests performed at different frequencies reduces the effect of interference automatically.

7.10.7 Test Connections - Two Winding Transformers

*(**NOTE:** On three phase transformers, Jumper H_1, to H_2 to H_3 and Jumper X_1, to X_2* to X_3.)

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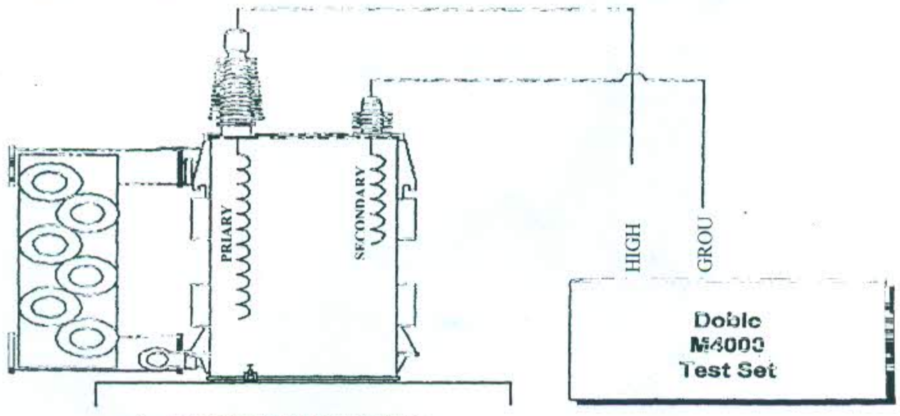
1. Test connection for measuring the insulation Dissipation or Power Factor of the insulation between the primary (high voltage) winding and the secondary (low voltage) winding and ground. Insulation Tested: P-G and P-S.



2 – WINDING TRANSFORMER

Test Lead Connections		
High Voltage	**Blue**	**Red**
$H_1\ H_2\ H_3$	$X_1\ X_2\ X_3$	-
or		
$H_1\ H_2\ H_3$	-	$X_1\ X_2\ X_3$

2. Test connection for measuring the Insulation Dissipation or Power Factor of the insulation between the primary (high voltage) winding and ground; secondary (low voltage) windings guarded. This typically measures the insulating qualities of the oil and primary winding. Insulation Tested: P-G.

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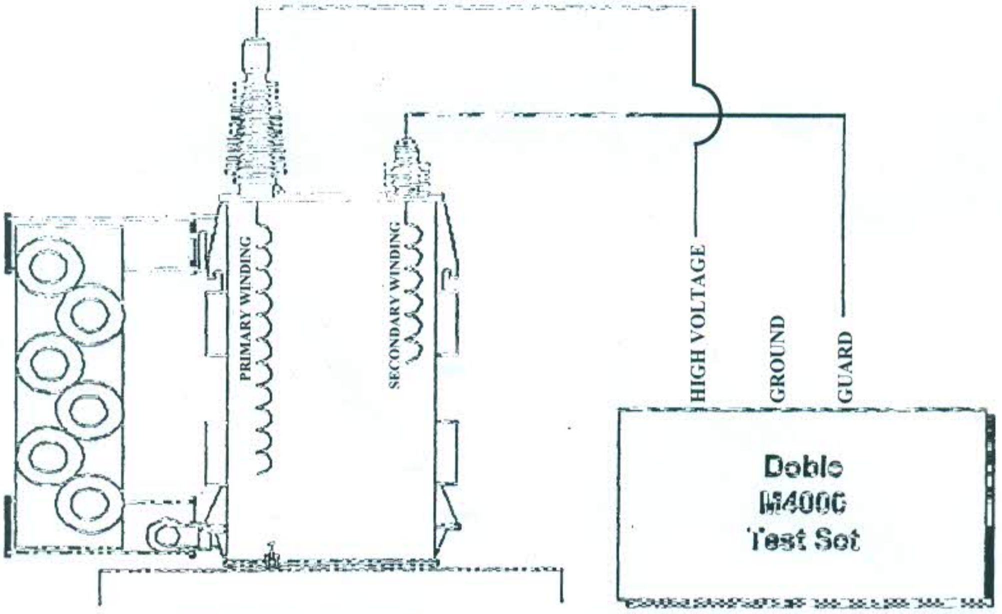

2 – WINDING TRANSFORMER

Test Lead Connections		
High Voltage	**Blue**	**Red**
H_1 H_2 H_3	X_1 X_2 X_3	-
or		
H_1 H_2 H_3	-	X_1 X_2 X_3

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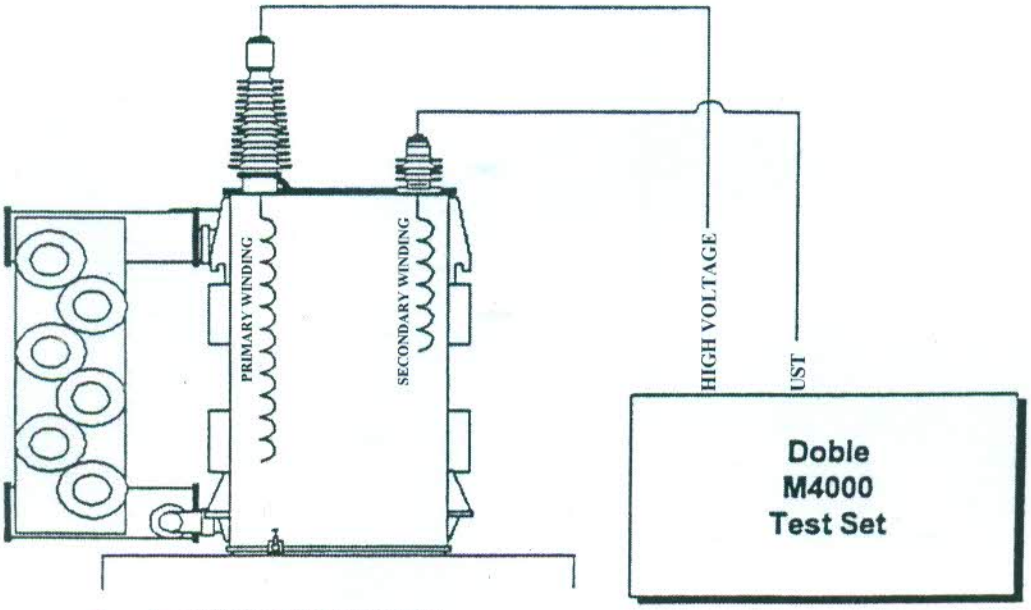
3. Test connection for measuring the Insulation Dissipation or Power Factor of the insulation between the primary (high voltage) and secondary (low voltage windings; Ungrounded Specimen Test (UST). High Insulation Dissipation/Power Factors indicate that one or both of the windings are contaminated. Insulation Tested: P-S.



- 2 – WINDING TRANSFORMER

Test Lead Connections		
High Voltage	**Blue**	**Red**
X_1 X_2 X_3	H_1 H_2 H_3	-
or		
H_1 H_2 H_3	X_1 X_2 X_3	-

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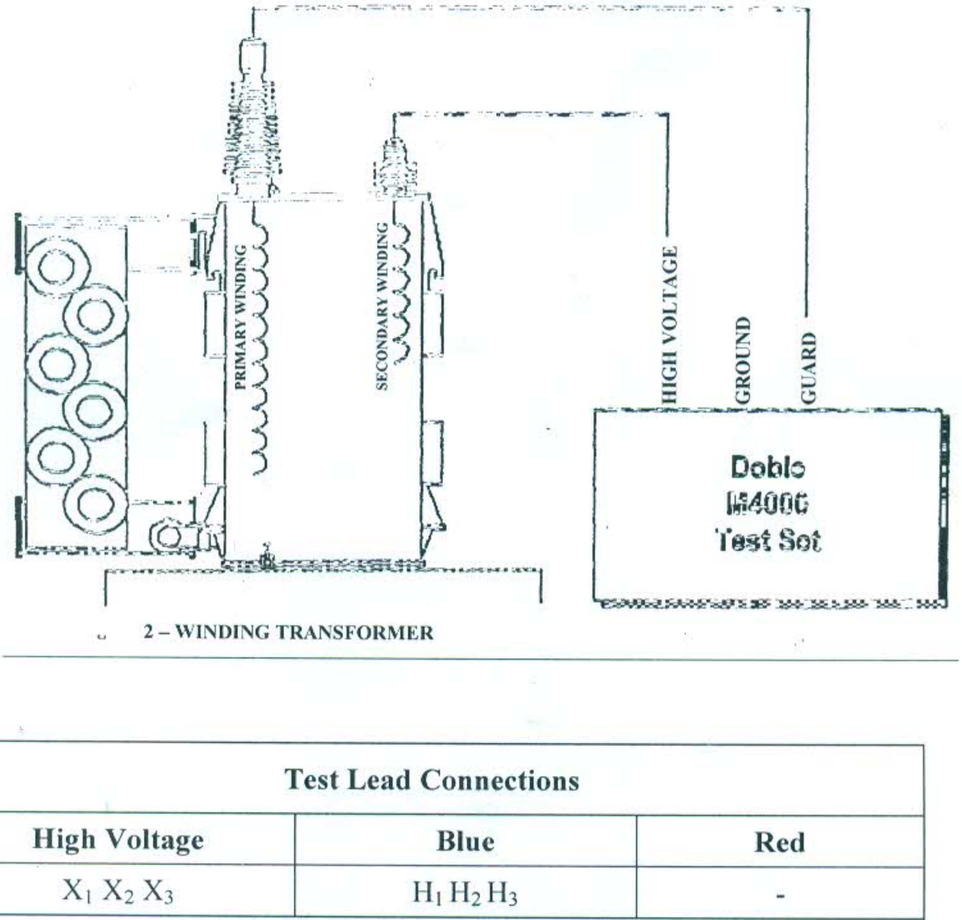
4. Test connection for measuring the Insulation Dissipation or Power Factor of the insulation between the secondary (low voltage) winding and ground; primary (high voltage) winding guarded. High Insulation Dissipation/Power Factors indicate that the secondary (low voltage) winding insulation is contaminated. Insulation Tested: S-G.



2 – WINDING TRANSFORMER

Test Lead Connections		
High Voltage	**Blue**	**Red**
X_1 X_2 X_3	H_1 H_2 H_3	-
or		
X_1 X_2 X_3	-	H_1 H_2 H_3

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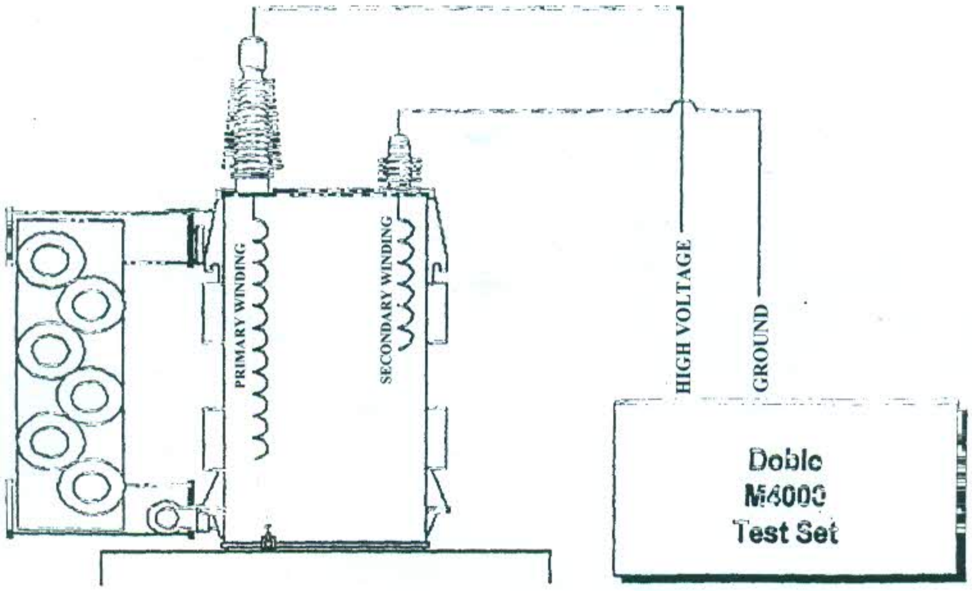
5. Test connection for measuring the Insulation Dissipation or Power Factor of the insulation between the secondary (low voltage winding) and primary winding and ground. High Insulation Dissipation/Power Factor values generally indicate contaminate (water) deep inside the windings. Insulation Tested: S-G and P-S.



2 – WINDING TRANSFORMER

Test Lead Connections		
High Voltage	**Blue**	**Red**
$X_1 X_2 X_3$	$H_1 H_2 H_3$	-
or		
$X_1 X_2 X_3$	-	$H_1 H_2 H_3$

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7.10.8 Maximum Test Values

The maximum recommended values of Insulation Dissipation/Power Factor expected for insulation in good condition at 20°C is one percent (1.0%). Insulation Dissipation/Power Factors above one percent (1.0%) at 20°C should be investigated further and the cause for these high values determined. Temperature correction factors are listed in Table 7-7.

Insulation Dissipation/Power Factor values that exceed one percent (1.0%) should be examined carefully. High values can indicate failure or significant aging of the insulation system under test Common causes are:

1. Water absorption
2. Carbon tracking
3. The presence of metallic particles in the oil or solid insulation
4. Insulation failure
5. Instrumentation failure
6. Contaminated oil
7. Severe leakage over the bushing because of water, high humidity or conducting contamination

7.10.9 Insulation Dissipation/Power Factor – Temperature Correction Factors

Insulation Dissipation/Power Factor measurements vary with temperature. In order to determine the condition of the insulation, all measured values are referenced to a standard temperature of 20°C (68°F). The measured values are corrected to 20°C by the multipliers listed in Table 7-7. The correction multipliers are for two types of equipment, older low voltage apparatus and modern high voltage apparatus.

7.10.10 Tip-Up/Tip Down Test

Additional information as to the condition of the insulation can be obtained by determining the Insulation Dissipation/Power Factor at higher (tip-up) or lower (tip-down) test voltages. If the Insulation *Dissipation/Power Factor increases with increased voltage, say 2.0 KV, 4.0 KV, or 6.0 KV, then the* change is usually due to ionization of gas in the voids of the insulation or the presence of carbon. If the Insulation Dissipation/Power Factor remains constant, then the cause of any excessively high Dissipation/Power Factor values is generally the presence of moisture in the insulation.

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Transformer or Winding Temperature		Insulation Dissipation/Power Factor Correction Multiplier		
		Older Apparatus Up to 161 KV	Modern Apparatus (1975 & newer) 230 KV and Above	Instrument Transformers C.T.'s and P.T.'s
C'	F'			
-10	14	1.98	.89	1.94
- 5	28	1.76	.92	1.81
0	32	1.57	.95	1.67
5	41	1.41	.98	1.52
10	50	1.25	.99	1.36
15	59	1.11	1.01	1.19
20	68	1.00	1.00	1.00
25	77	0.90	0.98	0.83
30	86	0.80	0.95	0.69
35	95	0.71	0.92	0.58
40	104	0.65	0.89	0.48
45	113	.0.57	0.85	0.41
50	122	0.51	0.81	0.36
55	131	0.47	0.77	-
60	140	0.41	0.70	-
65	149	0.38	0.65	-
70	158	0.33	0.55	-

Table 7-7: Insulation Dissipation or Power Factor Temperature Correction Factor

Example:

High Voltage Rating : 115 KV
Year : 1972
Winding Temperature : 40°C
Meter Reading : 0.76% P.F.
Temperature Correction : 0.65

(NOTE M4000 Test Controller with built in DTA program will assign the monitored temperature probe reading directly onto the test form.)

Insulation Dissipation/ : 0.76% X 0.65
Power Factor at 20°C : 0.491%

7.10.11 Abnormal Readings

Insulation Dissipation Factor values that exceed one percent (1.00%) should be examined carefully. High values can indicate failure or significant aging of the insulation system under test. Common causes are:

1. Water absorption
2. Carbon tracking
3. The presence of metallic particles in the oil or solid insulation system.
4. Insulation failure
5. Instrumentation failure.
6. Contaminated oil
7. Severe leakage over the bushing because of water, high humidity or conducting contamination.

   * Some equipment such as certain bushings may exhibit the exception to the above statement, i.e. McGraw ACR 25KV bushing may exhibit Power Factor Readings up to 3% and still be within their service life. Please refer to DTA analysis or manufacturer recommendations.

7.11 OPENING TANK

Transformer tank should only be opened for a definite or specific purpose, such as, bushing replacement, abnormal operation, malfunction, failure, etc. Whenever the tank is to be opened, external electrical clearances must be verified for safety. Any pressure or vacuum should be relieved and the gas space above the oil should be purged with air to remove nitrogen, oil vapor and any other gases thus minimizing the possibility of asphyxiation (suffocation) of personnel working inside the tank or near tank openings. All hand tools should be attached to workman or firm object on transformer cover by a rope or cord to prevent falling or being dropped into transformer. Workman should also remove all pencils, coins, and other loose objects from their clothing before opening the tank. Hand-hole, manhole or other covers should be removed carefully and in accordance with manufacturer's recommendations. All terminals must be grounded. The gaskets should be inspected for compression or seating and whether to reuse or replace the gasket. Lower the oil level a sufficient distance to permit access to bottom bushing connections, tap-changer, core ground connections, etc. Protection should be provided to prevent entrance of rain and other contaminants into transformer tank. The transformer tank should not be left open for more than two hours unless complete filtering of the oil is planned.

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With tank open and properly prepared for safe work conditions, the following work items may be performed and certain observations made

1. Bushings found broken or leaking of oil can be repaired. All bushing connections can be checked for tightness and evidence of heating.
2. Tap changer conditions and correct operation can be observed. Contact resistance can and should be measured if evidence of heating, wear, erosion or misalignment is observed.
3. Core ground connection can be checked for tightness or disconnected for meggering of core resistance to ground.
4. Pressure relief device operation, high oil level and high gas pressure can be investigated. Smoke or bubbles rising through the oil indicate an internal disturbance, such as, winding deformation during a through fault, internal arc, insulation deterioration, etc. In most cases, smoke indicates definite damage whereas bubbles may indicate a non-damaging disturbance. Further verification of transformer condition can be made by performing ratio, resistance and power factor tests and analyzing oil and gas samples.
5. Causes for unusual noises and vibration can be investigated by checking for loose core iron and clamps, winding clamps, missing wedges and bracing, etc.
6. General condition of winding and lead insulation and CT wiring can be observed.
7. Corrosion of tank walls and other metal parts may be investigated.
8. Deposition of sludge in the ducts or other location may be observed. Such deposits may impede the circulation of oil which will require that the oil be filtered through *Fullers earth* to remove the sludge and return the oil to a serviceable condition. The oil will also need to be dried at this time. Vacuum refilling will be done.

After all internal inspection, adjustments and repairs have been completed, hand holes and any other openings should be closed. Gasket seats must be clean, smooth and either dry or painted with manufacturer's recommended sealant or cement where applicable.

7.12 FINISHING WORK AND INSPECTION

1. Repair any paint damage or rust found on top, sides and auxiliary equipment with rust conversion primer, galvanizing primer and finish coats.
2. Wipe clean all bushings.
3. Wipe clean any oil residue, dust or other debris (rubbish).

4. Check all bolted items for tightness, such as, bushing flanges and connections, junction box covers etc.
5. Replace any control cabinet gaskets that are bad and plug any holes in the cabinet.
6. Check tap changer for correct tap position and padlocking.
7. Review electrical clearance, tagging and grounding jumper instructions. In accordance with these instructions, remove grounding jumpers in preparation for returning transformer to energized service.

8.0 VOLTAGE REGULATORS

8.1 GENERAL

Voltage regulators require inspection and maintenance on a regular schedule since they have numerous moving parts, perform tap-change switching in oil and have a complex electronic control system with settings and adjustments that may change (drift) with age.

8.2 MONTHLY INSPECTION

Both visual and functional monthly inspections should cover the following items as a minimum. Manufacturer's recommendations should also be reviewed in conjunction with inspections. See Reference 3.A (Keep in mind that most voltage regulators will be energized and dangerous during inspections. Also treat all neutral and ground conductors as if they are energized).

1. Look for loose, broken or contaminated bushings, oil leakage from bushings and evidence of heating at terminals.
2. Record oil level indicated by oil gauge.
3. Record oil temperature (if regulator has a thermometer).
4. Inspect general condition including tightness of connections, tightness of cover fasteners, oil leaks at gaskets, valves and welds, tank and accessory paint finish, rust formation, and breakage of glass covers in position indicator and instruments, dryness of control cabinet and controls, proper operation of heaters, wiring condition, etc.

   CAUTION: *No inspection above edge of top cover should be performed while regulator is energized.*

5. Check against previous record of settings to verify proper settings of voltage sensor, line-drop compensator, band width, position indicator travel stops and time delay.
6. Record tap-changer operation counter reading.
7. Check regulator operation (energized).

a. Record voltages (regulated) and drag-hand positions.
b. Switch to "manual" position.
c. Run to neutral position.
d. Record voltages again (unregulated).
e. Run the regulator two taps beyond neutral. (This checks for proper operation and wipes the reversing switch)
f. Switch back to "automatic" position. Verify that after time delay setting of control has expired, regulator will return to normal raise or lower top position.

8. Reset drag-hands.
9. Check regulator operation (de-energized or bypassed).
   a. Switch to "manual" position.
   b. Run to neutral position.
   c. Perform by pass switching operation (by authorized personnel only). See Reference 3.A.
   d. Connect an external power supply to the external supply terminal.(Check the voltage rating of the control before energizing)
   e. Switch to "external" control power supply.
   f. Run successively to maximum of raise and lower positions (this checks the stops as well as correct operation over total top range).
   g. Run to "neutral" position.
   h. Return control power to "internal"
   i. Perform switching to remove by pass and return regulator to service.
   j. Switch to "automatic" position.
   k. Reset drag-hands.

   Note: After a few successful monthly checks, this operation check can normally be assigned to only annual performance.
10. Static Control
   a. Check all indicating lamps using test switch procedures given in manufacturer's instruction book.
   b. Overall test of controls is not considered necessary on monthly schedule unless utilized for training purposes. Otherwise it should be performed on annual

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schedule.

8.3 ANNUAL INSPECTIONS

Annual inspections should be performed to cover important items not included in the monthly inspections, but they could be performed to coincide with one of the monthly inspections. Reference can be made to REB Bulletins, and manufacturer's recommendations should be reviewed before each inspection.

1. Collect an oil sample from the bottom drain valve. Use a clean, dry standard oil sampling bottle.
2. Test oil sample per ASTM D877 for the following:

8.4 TEST LIMITS

Apparatus	138KV and below ASTM D877	138KV and below ASTM D1816	230KV and above ASTM D877	230KV and above ASTM D1816
New Transformers, Regulators and Reactors - main tank	30 KV	25 KV	35 KV	30 KV
In-Service Transformers, Regulators and Reactors - main tank	26KV	20 KV	30 KV	25 KV
New Vacuum Tap Changers	30 KV	25 KV	35 KV	30 KV
In-Service Vacuum Tap Changers	26 KV	20 KV	30 KV	25 KV
New interrupting devices - Breakers and Load Tap Changers	30 KV	25 KV	35 KV	30 KV
In-Service interrupting devices -Breakers and Load Tap Changers	26 KV	20 KV	30 KV	25 KV

Table 8-1: Minimum Acceptable Limits for dielectric Breakdown Voltage of Various Types of Apparatus.

NOTE:

1. Dielectric strength using standard test cup (minimum acceptable strength is 26 KV for 2.54 mm gap)
2. Moisture content (maximum acceptable content is 25 ppm with no free water)
3. Acidity (maximum acceptable is 0.025 mg KOH/g for new oil and 0.25 KOH /g for severely aged oil).

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4. Absorbed gas content (in the order of 0.25 % is acceptable).
5. Viscosity 11 Centestokes @ 40 C
6. Color – 0.5 max. (New oil is 0.0 and black oil is 8.0)
7. Arc products (principally carbon particles formed during tap-changer operation).
8. Perform additional tests, if any of above test results show unsatisfactory oil condition, according to appropriate standards and manufacturer's recommendations.

Collect an oil sample for DGA (Dissolve Gas Analysis).

The DGA (Dissolve Gas Analysis) should check for the following gases: Methane, Ethane, Ethylene, and CO_2.

Check accumulated tap-changer operations against manufacturer's recommendation for contact replacement.

Perform all tests required in the monthly inspections.

Check all controls and control components for proper settings, calibration, operation and condition. Follow procedures given in manufacturer's instruction book.

8.5 ADDITIONAL INSPECTIONS AND MAINTENANCE WORK

The following additional inspections and maintenance work may be determined necessary to ensure good operating condition of voltage regulators.

8.5.1 Oil Filtering

1. Perform only when voltage regulator is initially installed and subsequently only when tests on oil or gas samples show conditions and characteristics to be less than acceptable.
2. Perform only with voltage regulator de-energized.
3. Use vacuum process and heated oil.
4. Follow voltage regulator manufacturer's recommendations and oil filter equipment manufacturer's recommendations and instructions.
5. Ground all winding line and neutral terminals, oil filtering equipment, oil containers, etc., solidly to a common ground and to the substation ground. This procedure will eliminate development of hazardous static voltage charge, Leave all winding terminals grounded as long as possible after oil filtering is completed to ensure drainage of static charge on the windings to a safe value.
6. Perform an insulation power factor test. Doble test or other established methods may be used. This test will determine bushing and winding insulation condition.

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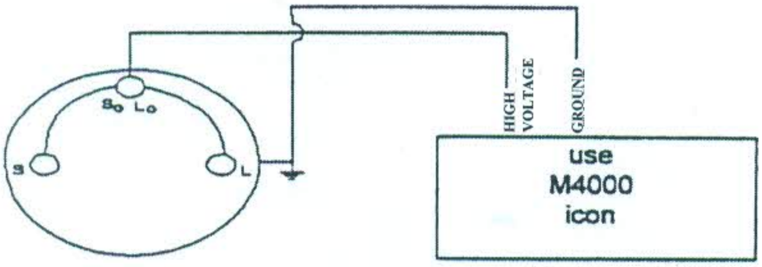
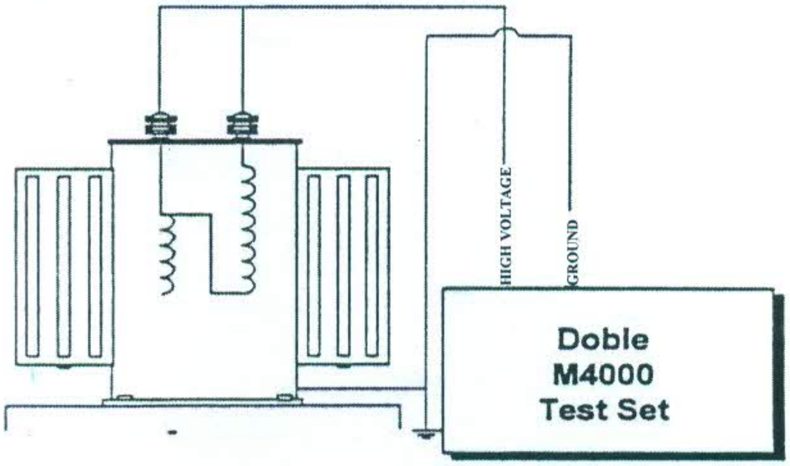
8.5.2 Test Connections - Regulators

1. Test connection for measuring the Insulation Dissipation/Power Factor of the insulation between all windings and ground, single-phase regulator.



2. Test connection for measuring the Insulation Dissipation/Power Factor of the insulation between all windings and ground, three-phase regulator.



Test Lead Connections		
High Voltage	**Blue**	**Red**
All	-	-

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3. If power factor test equipment is not available a megger test to measure insulation resistance can be substituted. This will reveal insulation condition in terms of insulation resistance. (Note: Terminal grounds must be removed for insulation power factor and megger tests, thus requiring appropriate safety precautions to be observed).

4. Moisture content of insulation and oil may remain too high through filtering process. This will require continued filtering with heated oil and may require application of external heat, circulation of heated air through gas space or by other approved methods. In severe cases of wetness or free, suspended water, reconditioning of the voltage regulator at a service and repair facility may be necessary.

8.6 OPENING TANK

Voltage regulator tank should only be opened for a definite or specific purpose, such as, bushing replacement, abnormal operation, malfunction, failure, etc. Whenever the tank is to be opened, external electric clearances must be verified for safety. Any pressure or vacuum should be relieved and the gas space above the oil should be purged with air to remove nitrogen, oil vapor and any other gases thus minimizing the possibility of asphyxiation (suffocation) of personnel working inside tank or near tank openings. All hand tools should be attached to workmen or firm object on voltage regulator cover by a rope or cord to prevent falling or being dropped into tank. Workman should also remove all pencils, coins and other loose objects from their clothing before opening the tank. Hand hole, manhole or other covers should be removed carefully and in accordance with manufacturer's recommendations. The gaskets should be inspected for compression or seating and whether to reuse or replace the gaskets. Lower the oil level a sufficient distance to permit access to bottom bushing connections, tap-changer, core ground connection, etc. Protection should be provided to prevent entrance of rain and other contaminants into voltage regulator tank. The tank should not be left open for more than two hours unless complete filtering of the oil is planned.

With the tank open and properly prepared for safe work conditions, the following work items may be performed and certain observations made. :

1. Bushings found broken or leaking of oil can be repaired or replaced as determined appropriate. All bushing connections can be checked for tightness and evidence of over heating.

2. Tap changer condition and correct operation can be observed. Connections can be checked and tightened. Contact resistance can and should be measured if evidence of over heating, wear, erosion or misalignment is observed.

3. Core ground connection can be checked for tightness or disconnected for meggering of the core resistance to ground.
4. Causes for high oil level and high gas pressure can be investigated. Smoke or bubbles rising through the oil indicate an internal disturbance, such as, winding deformation during a through fault, internal arc, insulation deterioration, etc. In most cases, smoke indicates definite damage, whereas bubbles may indicate a non-damaging disturbance. Further verification of voltage regulator condition can be made by performing ratio, resistance and power factor tests and analyzing oil and DGA (Dissolve Gas Analysis) samples.
5. Causes for unusual noises and/or vibration can be investigated by checking for loose core iron and clamps, winding clamps, missing wedges and bracing, tap changer gear and contact alignment, etc.
6. General condition of winding and lead insulation and CT and PT wiring can be observed.
7. Corrosion of tank walls and other metal parts may be investigated.
8. Deposition of sludge in the ducts or other location may be observed. Such deposits may impede the circulation of oil.

After all internal inspection, adjustments and repairs have been completed, hand holes and any other openings should be closed. Gasket seats must be clean, smooth and either dry or painted with manufacturer's recommended sealant or cement where applicable.

8.7 FINISHING WORK AND INSPECTION

1. Repair any paint damage or rust found on top, sides, and auxiliary equipment with a rust converter primer, a galvanizing primer, and a finish coat.
2. Wipe clean all bushings.
3. Wipe clean any oil residue, dust or other debris.
4. Check all bolted items for tightness, such as, bushing flanges and connections, junction box cover, etc.
5. Replace any control cabinet gaskets that are bad and plug any holes in the cabinet.
6. Set tap changer on neutral tap position and give all controls a final check for proper settings and adjustments.
7. Review electrical clearance, tagging and grounding jumper instructions. In accordance with these instructions, remove grounding jumpers in preparation for returning voltage regulator to energized service.

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8.8 PERIODIC MAINTENANCE

Every regulator should be removed from service and the contacts maintained according to the schedule listed below.

VOLTAGE REGULATOR MAINTENANCE SCHEDULE
CONTACT INSPECTION

TYPE	MAINTENANCE PROCEDURE # 1		MAINTENANCE PROCEDURE # 2	
	No. of Operations	No. of Months	No. of Operations	No. of Months
ML32 (624 A.) VR32 (700 A)	Initial 400000	48	Additional 100000	24
VR32 (263 A.) JFR (263A.)	Initial 200000	36	Additional 100000	24
ML32 (100 A.) VR32 (100 A.) JFR (100 A.)	Initial 600000	72	Additional 200000	48
TOSHIBA	125,000	800 micro ohms*	every 250,000 to 1,000,000	

* For Toshiba voltage regulator, this is in terms of contact resistance instead of months

Table 8-2

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Maintenance Procedure # 1.
Clean the operating mechanism
Inspect and clean the moving contacts
Filter the oil

Maintenance Procedure # 2
Include Maintenance Procedure # 1
Replace worn contacts and parts if required
Doble and Insulation Resistance Test (See Transformers Section 7 for limits)

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9.0 ACR / OCR/ BREAKER

9.1 GENERAL

Three-phase and single-phase Automatic Circuit Re-closers / Oil Circuit Re-closers/ Breakers are installed in the RE (Rural Electric) system to protect equipment. To ensure efficient and trouble-free service, it is essential to carry out inspection and maintenance on a regular schedule as described below:

CAUTION: *Proper safety precautions must be taken during visual inspection of energized Re-closer/ Breaker.*

9.2 MONTHLY INSPECTIONS

Monthly inspections must cover the following items in addition to manufacturer's recommendations.

1. Look for loose, broken or contaminated bushings. If they are removed for any reason, new gaskets are to be installed.
2. Check for loose or corroded connections.
3. Check tank for damage or oil leaks.
4. Record the reading of operations counter.
5. De-energize the re-closer/ breaker, if possible, with the by-pass and disconnect switches. Test operate with the electronic controls or with the hook switch to check operating mechanism and proper functioning of the counter and mechanism.
6. Inspect general condition including tightness of connections, tightness of cover fasteners, oil/ gas leaks (if any) at gaskets, valves and welds, tank and accessory paint finish, rust formation, breakage of glass covers in (if any), dryness of control cabinet and controls, proper operation of heaters, wiring condition, etc.
7. Test the battery and battery voltage in electronic control by using the front panel controls. The display will indicate whether it needs to be changed out.

9.3 PERIODIC INSPECTIONS

Perform periodic inspection in accordance with the ACR/ OCR/ Breaker Maintenance Schedule in section 9.9. However, operating experience with different types of reclosers is the best basis for establishment of schedules.

1. Remove the re-closer/ breaker from service by replacing it with a spare recloser/ breaker or a by-pass fuse cutout with the proper coordinating fuses they can be used as a temporary replacement. Dismantle the re-closer/ breaker in a workshop free of moisture and dust, according to the manufacturer's recommendations. Perform detailed inspection to check the following items as a minimum :
   a. Proper operation of re-closer/ breaker and operation counter.
   b. Moisture present in oil or indicated by soft spots on tank liner. In such case liner should be replaced with new one.
   c. Warping or blistering of tank liner. In such case liner should be replaced with new

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d. Alignment of arcing contacts.
e. Oil level in tank.

f. Dielectric strength of oil (minimum acceptable strength is 26 KV for 2.54 mm gap).
g. Condition of gaskets.
h. Smooth or sticky operation of re-closer/ breaker.
i. Any other item or abnormal condition requiring attention.

9.4 LIMIT – TEST LIMITS FOR OIL DIELECTRIC TESTS (See Table 8-1)

9.5 INSTRUCTIONS AND RECORDS

Manufacturer's instructions outlining inspection and maintenance procedures must always be followed. Monthly and annual inspection records should be maintained for each recloser/ breaker. (See Section 22 - SUBSTATION INSPECTION AND MAINTENANCE FORMS).

9.6 ROUTINE MAINTENANCE

Monthly inspections may determine minor maintenance work needed, such as cleaning the bushings, tightening connections, counter repair, etc. The re-closer MUST BE DE-ENERGIZED before performing any maintenance work. The maintenance must be performed in accordance with the procedures prescribed by the manufacturer.

9.7 PERIODIC MAINTENANCE OF ACR/ OCR/ BREAKER

The re-closers/ breaker that interrupt in oil should be removed from service at least every three years or after 100 operations for inspection and maintained in a repair shop. However, such inspection and maintenance may also be necessary if a malfunction is reported in operation or if an excessive number of fault interruptions occur. Manufacturer's instructions should be strictly followed to perform shop inspection and maintenance which includes the following as a minimum: The re-closers/ breakers with the FXB electronic control and/ or contact monitor that indicates how much contact life is left in them. For example when a Nulec ACR contact life reach's 20% on any one of the contacts the breaker has to be removed from service and returned to the factory for replacement and The ACR of Cooper Power service life monitor with the FXB control shows 0%, its life has been used up and the ACR has to be returned to the work shop for inspection/replacement of the vacuum bottles/contacts and overhaul on the mechanism.

1. Dismantle recloser mechanism.

2. Inspect and clean all parts. Solvent, detergents or water-soluble cleaners can not be used for cleaning the internal parts of recloser. Clean, dry transformer oil is recommended as the best cleaning agent.
3. Replace worn out contacts and deteriorated parts.
4. Check the proper functioning of recloser after re-assembly as follows :
   a. If the mechanism does not operate smoothly, check for burrs & flush with clean oil to remove particles which prevent the trip piston from moving freely along the full length of the cylinder.
   b. Determine if the re-closer trips at the proper current value by conducting minimum tripping current test according to manufacturer's instructions.
   c. Verify time- current characteristics as required by manufacturer.
   d. Check by operating through the proper sequence of operation to lockout.
   e. Check resetting time during sequence test.
5. Corrosion of tank walls and other metal parts are to be investigated and repaired as necessary.
6. Clean stationary and moving contact with a Scotch Brite pad and lint free cloth. If the contacts are badly pitted or burned, replace the contact. When it is necessary to replace one contact, replace both sets i.e. moving & stationary at the same time.
7. Test tank oil and replace if results are not satisfactory.

9.8 OIL CHANGE

Replace tank oil as follows:

1. When test results indicate the need for replacement.
2. Following 100 fault operations (or according to manufacturer's recommendation).
3. If dielectric strength falls below 26 KV for 2.54 mm gap.
4. If excessive, carbon or moisture contamination is detected.
5. If deposits of sludge are detected.
6. The parts and the inside of the tank should be free from sludge, dirt, carbon deposits and moisture before the new oil is added.
7. Oil level is to be maintained as recommended by manufacturer.

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9.9 ACR/OCR/Breaker MAINTENANCE SCHEDULE

TYPE	MAINTENANCE PROCEDURE # 1		MAINTENANCE PROCEDURE # 2	
	No. of Operations	No. of Months	No. of Operations	No. of Months
4H HR Model B	00	24	68 Fault Ops. or 600 Normal Ops.	60
L Model K	100	12	68 Fault Ops. or 300 Normal Ops.	36
RX OYT	100	36	68 Fault Ops. or 300 Normal Ops.	60
VWE VW VRV	400	48	232 Fault Ops. or 1000 Normal Ops.	120
KFE			248 Fault Ops	

Note: For other type ACR/ OCR/ Breakers, refer to manufacturer's instructions.

Table 9-1

Further ACR/ OCR/ Breaker Maintenance Schedule Guidelines

When the FXB electronic control indicates 0% contact wear the OCR that it is monitoring must be taken out of service for Maintenance Procedure # 2

N12	6 kA fault 1,000	12.5 kA fault 100	
N36	6 kA fault 1,000	12.5 kA fault 520	l6kA fault 500

When the Nulec electronic control indicates 20 % contact wear the N12 or N36 that it is monitoring must be taken out of service for Maintenance Procedure # 2

No maintenance can be done with the Nulec breakers except recharging SF6 gas. When the contact monitor shows 20% of the contact life left for the breaker contacts it must be returned to the factory

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Maintenance Procedure # 1.
Clean the operating mechanism
Inspect and clean the moving contacts
Inspect the liner
Replace the oil

Maintenance Procedure # 2
Include Maintenance Procedure # 1
Replace worn contacts and parts if required
Insulation Test
Operations Test
a. Minimum pick-up current
b. Time-current characteristics
c. Sequence of operation
d. Operation to lockout

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10.0 SWITCHES

10.1 GENERAL

Switches in the electric system are categorized as air break, disconnect and by-pass switches. Switches are generally designed to require minimum maintenance. MANUFACTURER'S INSTRUCTIONS SHOULD BE FOLLOWED FOR INSPECTION AND MAINTENANCE PROCEDURES. See section 23 - REFERENCE MATERIAL

10.2 INSPECTION

Visual inspection should be carried out monthly. Use of binoculars is recommended to detect a need for repair or maintenance, while maintaining a safe distance. An infra-red heat detector can be used to detect hot spots caused by loose connections, deteriorated contacts, corrosion, bushing leakage current, etc. However, twice a year switches should be opened and closed a number of times to observe the alignment of operating mechanism, mountings and blades to verify proper operation and performing corrections, if necessary.

CAUTION: *Before performing any work, de-energize and properly ground the switch. Approval of operations staff must be obtained for scheduling work on switches.*

Inspect the following:

1. **Operating Mechanism is checked for:**
   a. Smooth operation
   b. Rust or corrosion on metallic parts
   c. Loose or broken connectors
   d. Proper ground connection to operating handle.

2. **Insulator should be checked for:**
   a. Cracks, chips or breaks
   b. Evidence of flashover
   c. Contamination

3. **Mountings are checked for:**
   a. Rust or corrosion
   b. Proper alignment
   c. Tight ground connection

4. **Blades are checked for:**
   a. Evidence of overheating
   b. Proper alignment
   c. Sufficient pressure on blade at contact points

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5. **Contacts, terminals and connections are checked for:**
    a. Oxidation, wear or pitting
    b. Contamination
    c. Secure connections
    d. Evidence of heating

10.3 MAINTENANCE

Maintenance may be required as a result of monthly inspections. However, maintenance of switches should be carried out at the same time as the scheduled maintenance of associated equipment. In addition to the instructions given by the manufacturer, maintenance should include the following as a minimum:

1. Remove contamination with soap, water and Scotch Brite Pads. (DO NOT use sand paper)
2. Tighten loose bolts and nuts and secure connections
3. Replace corroded and damaged parts
4. Realign switch blade contacts, if necessary
5. Redress contacts if necessary with a very fine bastard file & a high voltage rated electrical lubricant (silvering is recommended). **PENETROX SHOULD NEVER BE USED** on the contact blades.
6. Lubricate hinges with a long lasting grease.

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11.0 FUSES

11.1 GENERAL

Routine inspection and maintenance of fuses is required for trouble-free operation. The procedure to be followed is described below. See Section 23- REFERENCE MATERIAL

11.2 LINK REPLACEMENT

When the fuse link is blown, damaged or deteriorated, the only maintenance possible is replacement.

Some of the definite requirements of fuse replacement are:

1. Always replace a fuse line with the same type and ampere rating unless a change is authorized.
2. Never install a fuse link with a higher rating than the fuse holder.
3. Replace all fuses of a group when one or more have blown, such as all three fuses on a three-phase transformer bank.
4. Never install more than one link in a fuse holder even if the combined rating is less than that of the holder.
5. Take care to not over strain or stretch a fuse link when installing.
6. Be sure that the electrical contacts are clean and the connections are tight.
7. Use a high voltage rated electrical lubricant at the tips of the fuse holder for better electrical contact. **NEVER USE PENETROX.**
8. Never hang the fuses upside down as they will collect moisture in the tubes. The fuse element will corrode and fail giving a false indication that a fault is still on the line when there is none. Store them inside or hang them right side up.

11.3 TUBES

Fuse tubes deteriorate at each operation and by weathering:

1. Replace tubes that are severely eroded, warped, broken or burned on either the inside or outside.
2. Bakelite tubes which are worn and rough from weathering may be resurfaced on the outside with non-conducting weather-resistant finish recommended by the manufacturer.

11.4 CONTACTS

Good electrical contacts on the fuse link and holder are essential to minimize heating

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which would interfere with the proper operation of the fuse. Check and correct as follows:

1. The fuse link shall be installed with clean, tight connections.
2. Contact surfaces on the fuse tube and the clips shall be in alignment with adequate pressure.
3. If the contacts have become annealed due to excessive heat, or are badly pitted, replace completely.
4. If contacts are rough or slightly pitted, smooth with a fine bastard file.
5. A non-oxidizing high voltage electrical lubricating grease spread over the contact surfaces after cleaning will help prevent corrosion.

11.5 MOUNTINGS

1. Clean and paint metal bases to prevent rusting. Use a rust converter primer, then a coat of galvanizing primer and then a finish coat of paint.
2. Inspect insulators for cracks, chips, breaks and burns. Replace if damage is more than superficial. Any small chip or piece missing will be painted with red Gylptal paint to seal the porcelain and show that it has been maintained.
3. Porcelain insulators and housings should be cleaned of accumulated contamination by washing, scrubbing or chemical treatment as required.
4. Check for alignment and secure fastening.
5. Check drop-out feature for alignment and freedom of operation. Lubricate if and as recommended by the manufacturer.
6. Check latches and guards, if any, for proper functioning.

12.0 SURGE ARRESTERS

12.1 GENERAL

System equipment is protected against lightning phenomena by surge arresters (see Section 23-Reference Material). To ensure safety, surge arresters should be inspected monthly to determine that:

1. Porcelain is not cracked or contaminated
2. Line lead is securely fastened to line conductor and arrester
3. Ground lead is securely fastened to line ground and arrester terminals
4. Arrester is not located in such a manner as to be subject to:
   a. Damaging fumes or vapors, excessive contamination, or excessive humidity, moisture, dripping water, steam or salt spray.
   b. Abnormal shocks or vibrations.

12.2 SURGE ARRESTER LOSS TEST

12.2.1 Introduction

Surge arresters are used to protect electrical lines and equipment from high voltage surges resulting from lightning, switching, etc. During normal operation they act as an insulator between energized equipment and ground or other conductors. During high voltage surges, they act similar to a short circuit and discharge the surge to ground or other conductors and then "reseal" themselves after the surge has been dissipated. To continually provide the necessary high voltage insulating characteristics under normal conditions and discharge surges under over-voltage conditions, good dielectric (electrical insulating) properties and surge conducting properties must exist.

Loss testing of surge arresters with Dissipation/Power Factor Test equipment can identify deteriorated or faulty surge arresters. Surge arresters with low losses can be considered to be in acceptable operating condition. Surge arresters with high losses are generally nearing the end of their operating life.

12.2.2 Equipment

1. Insulation Dissipation or Power Factor Test Set (M4000).
2. Shorting Leads and Jumpers.
3. Doble Test Assistant (DTA) Test Data.

12.2.3 Test Procedure

There is always the possibility of voltage being induced at the terminals of the device being tested due to overhead lines or the existence of residual static charge voltage.

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1. De-energize the surge arrester to be tested and obtain a work clearance.
2. Properly ground the surge arrester to insure that it is fully de-energized and no back feeds exist. Disconnect the surge arrester from any loads or sources. The surge arrester under test must be de-energized. Isolate from long bus runs and other devices.
3. Copy nameplate information on the test form.
4. Clean and dry the surge arrester. Wet or contaminated porcelain surfaces will result in high losses and abnormal results.
5. Ground the Dissipation/Power Factor Test set to the station ground grid. Connect the leads to the test set and obtain power from a grounded 240 volt outlet.
6. Connect the high voltage test lead to the terminal of the surge arrester and the ground lead to its base.
7. Temporarily isolate the surge arrester from the previously installed safety grounds for test purposes.
8. Accept test results shown by M4000 for:

   Test Voltage, Test Current,
   Capacitance, Milliwatt Loss

9. Compare the measured milliwatt loss values with the values obtained by testing other arrestors identical in type and voltage, similar values should be obtained.
10. Continue by making tests on the remaining surge arresters.

12.2.4 Example

Test Voltage	= 10 KV
Test Current	= 0.392 mA
Milliwatt Loss	= 0.213 mW

12.2.5 Abnormal Loss Values

Surge arresters of the same type and voltage should have nearly identical losses. Test measurements that do not agree with other identical surge arresters should be investigated further. High losses may indicate:

1. Water absorption or foreign deposits
2. Punctures in disks
3. Carbon traces
4. Broken resistors
5. Excessive surface leakage across the outside of the porcelain skirts
6. General deterioration.
7. Instrumentation error

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12.3 REPLACEMENT

Damaged or defective arresters must be replaced immediately. Damaged arresters may be indicated by the following:

1. Station Class: Black exhaust ports or broken porcelain
2. Distribution Class: Blown out ground lead disconnector or broken porcelain

CAUTION: *Proper distances must be maintained for safety during visual inspections described above.*

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13.0 BUSHINGS AND BUS INSULATORS

13.1 GENERAL

Maintenance of insulators is very important to ensure equipment safety and continuity of power supply. The following procedures should be followed for monthly inspection and repair of insulators.

CAUTION: *Equipment must be de-energized before any maintenance work is performed.*

1. Porcelain
   a. Look for fractures, chips, deposits of dirt, salt, cement dust or foreign matter that may cause a flashover.
   b. Check for suspected cracks/ hair cracks in porcelain insulators by closely visually inspecting each shell or petticoat
   c. If the main porcelain body of either a pin type or post insulator is cracked/ hair cracks, replace it immediately.
   d. Hone smooth any small chipped areas on porcelain shells or petticoats and paint with an approved Electrical sealant or **Glyptal** Varnish or equivalent to provide a glossy finish and lessen dirt accumulation, if replacement is not justified.
   e. The loss of a porcelain skirt on a pin cap insulator reduces the insulation value of the insulators. Replace any units that are broken.
   f. The loss of petticoats on post insulators is not as critical as on pin types. Therefore, even if one or more petticoats are broken away the post insulator may remain serviceable. Hone and paint the chipped or broken unit if replacement for other reasons is not justified.
   g. Replace the insulator if loose cement permits movement of porcelain or metal parts.
2. Metal Parts
   a. Look for fractures and places that need painting
   b. Replace insulators having defective hardware
   c. Wire-brush rusty spots to remove large particles
   d. Apply rust converter primer coat and a coat of galvanizing primer
   e. Apply finish coat of paint to spots covered with primer

13.2 MAINTENANCE TESTS

Maintenance tests on insulators should normally be limited to occasional power factor measurements at the more important installations. Bus and switch insulators can be power factor tested in conjunction with similar testing of other apparatus within the installation.

13.3 BUSHING STORAGE

1. **Introduction**

   High voltage bushings are generally insulated by one or more of the following materials.
   Porcelain
   Epoxy
   Oil
   Kraft paper
   Organic compounds
   SF6
   In order to achieve and keep their high voltage insulating characteristics, bushings made of these materials must be stored and handled appropriately.

2. **Compound-Filled Bushings**

   Compound-filled bushings are of a very early design, they utilize a thick organic compound poured into the bushing for obtaining the necessary dielectric strength. The portion of these bushings below the flange is typically made of oil impregnated kraft paper. These bushings must be stored indoors, upright and in a clean, dry, warm environment to prevent the formation of voids in the compound and to keep the kraft paper free from water.

3. **Oil-Filled "Condenser' Bushings**

   Oil filled bushings have an oil-impregnated kraft paper "condenser" inside the oil-filled porcelain chamber. This "condenser" is made up of wraps of oil-impregnated kraft paper and foil around the bushing tube or conductor. The "condenser" then acts like a series of capacitors providing excellent insulating characteristics.

   Oil-filled bushings must be stored upright or with the top elevated above the bottom in order to insure that "condenser" layers are always in contact and covered with oil. If there is no exposed kraft paper insulation, the bushings may be stored in covered containers outdoors.

4. **All Porcelain and Epoxy Bushings**

   All porcelain and epoxy bushings are generally used at lower voltages (35 kv and below). They should be stored in a clean dry place.

5. **SF_6 Gas Filled**

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Gas insulated bushings are extremely delicate and must be stored indoors in a clean and dry environment.

13.4 BUSHING POWER FACTOR TAP MAINTENANCE

1. Introduction

Most bushings rated 69 KV and higher have a capacitance or Power Factor tap just above the mounting flange. This tap is used for.

a. Connecting bushing potential devices
b. Measuring the insulation dissipation or power factor of the bushing

2. Safety

a. During the testing and maintenance of bushings and their Power Factor taps, the bushing must be de-energized and disconnected from the high voltage line.
b. De-energize the apparatus to be maintained and tested, tag and obtain a clearance. After a clearance has been obtained, test for de-energization and apply personal grounds.
c. Implement fall arrest equipment

3. Capacitance Power Factor Measurement

a. The bushing nameplate generally gives two capacitance values C1 and C2 and two corresponding Power Factors. The first value, C1 is the factory measured value of the capacitance between the Power Factor or capacitance tap and the bushing conductor. The second value is the factory measured value of the capacitance between the tap and the bushing flange. Both values are measured in pico-farads (pf), sometimes labeled micro-micro-farads (mmf).
b. Measurement of the capacitance values C1 and C2 requires removal of the sealing cap and the insulating compound or oil.
c. Make a conventional "ungrounded specimen" power factor test, described in section 7 of this manual, with the power factor tap being energized. This will measure C and its resulting power factor.
d. Make a conventional "grounded specimen" power factor test with the power factor tap being energized and the bushing conductor being "guarded". This will measure C2 and its power factor.
e. Capacitance values differing from the nameplate value by more than 10% should be examined closely, they indicate either improper testing or possible failure.
f. On newer condenser type bushings, Power Factor measurements over 1.0% indicate the absorption of water or interior tracking of the bushing. Bushings with a Power Factor over 2.0% should be replaced.

NOTE: *Different types of Bushings will have other limits - refer to what the Doble Test Assistant (DTA) guidelines recommend and/or manufacturer*

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recommendations.

13.5 SEALING CAP OR POTENTIAL PROBE INSTALLATION

1. When installing the power factor tap sealing cap or the probe from the potential device, good contact between the tap contact finger and the contact clip is essential. Many times the contact clip loses its tension and tight contact is not possible. Careful inspection of these two items is essential.
2. If insulating compound is to be used, fill the tap envelope with the compound. Clean insulating oil may be substituted for insulating compound. In either case, these materials will help provide a dry environment for the capacitance tap.
3. Insert the probe or sealing cap, making sure that the finger or contact clip does not get bent in the process.
4. Secure the probe or sealing cap in place.
5. If no insulating compound is used, fill the tap envelope with clean transformer oil, leave an air space of approximately 1/4 inch over the oil for expansion. ***Do not over tighten the fill plug!***

13.6 BUSHING INSULATION DISSIPATION OR POWER FACTOR TEST

1. **Introduction**

   The bushings installed in electric power apparatus serve as the entrance and exit points for high voltage and high current leads and provide the insulation between the high voltages of the device and ground. In order to continually provide the necessary high voltage insulating characteristics, the bushing insulation must possess extremely good dielectric (electrical insulating) properties. Changes and deterioration of these properties can result in bushing and apparatus failure. Insulation Dissipation/Power Factor testing of the bushing insulation can quickly identify deterioration in the bushing insulation.

2. **Equipment**
   a. Insulation Dissipation/Power Factor Test Set (M4000)
   b. Shorting Leads and Jumpers
   c. Dissipation/Power Factor Test Form

3. **Test Procedure**

   CAUTION: *There is always the possibility of voltage being induced at the terminals of the device being tested due to overhead lines or the existence of residual static charge voltage.*

   1. De-energize the device to be tested and obtain a work clearance. After a clearance has been received, test for de-energization and apply personal protective grounds.

Flag off area and have a monitor (crew member) watching.

2. Properly ground the bushing terminals of the device to insure that it is fully de-energized and no back feeds exist. Disconnect the bushing terminals from any loads or sources. The device under test *must be de-energized and isolated from long bus runs, bushing potential devices and* arresters.
3. Verify/Copy nameplate and insulation temperature information in the DTA program of the M4000 controller.
4. Clean and dry all bushings. Wet or contaminated bushings will result in a high Dissipation/Power Factor.
5. Ground the Dissipation/Power Factor Test Set to the station ground grid. Connect the leads to the test set and obtain power from a grounded 240 volt outlet
6. Make the appropriate test connections as listed in Table under Section 13.8.
7. Temporarily isolate the bushing from the previously installed safety grounds for test purposes. Make sure all bushing potential devices are in the grounded position.
8. Program computer to run proper test, initiate test and accept results. Continue with other Bushings.

13.7 INTERFERENCE SUPPRESSION

The interference effects are reduced by the Doble M4000 in the following 2 ways:

1. Line Sync. Reversal" uses the technique of averaging the results of two tests with the polarity of each test changed. The two tests are performed at the frequency specified in the line configuration.
2. Line Frequency Modulation" uses the technique of averaging the test results of two tests performed at different frequencies. For 60 Hz the tests are performed at 57Hz and 63 Hz. The voltage polarity is not changed between the tests.

13.8 TEST CONNECTIONS

1. Test connection for measuring the overall Insulation Dissipation or Power Factor of bushings removed from their apparatus.

TEST LEAD CONNECTIONS	
High Voltage	Blue
Terminal	Flange

2. Hot Collar Test; test connection for measuring the Insulation Dissipation/Power Factor of bushings without Power Factor or Capacitance Taps.

High Voltage	Blue	Red	Switch Positions
Conducting Band wrapped snugly around bottom on top skirt	Terminal	-	4

3. Test connection for measuring the Insulation Dissipation/Power Factor of bushings with Power Factor or Capacitance Taps. Ungrounded Specimen Test (UST) measures "C1" insulation. Power Factor Tap grounding cap removed and Tap exposed.

TEST LEAD CONNECTIONS		
High Voltage	**Blue**	**Red**
Power Factor Tap	Terminal	-
or		
Power Factor Tap	-	Terminal

4. Test connection for measuring the Insulation Dissipation/Power Factor of bushings with Power Factor or Capacitance Taps. Grounded Specimen Test (GST) with bushing conductor being "guarded" measures "C2" insulation. Power Factor Tap grounding cap removed and Tap exposed.

TEST LEAD CONNECTIONS		
High Voltage	**Blue**	**Red**
Power Factor Tap	Terminal	-
or		
Power Factor Tap	-	Terminal

13.9 INSULATION POWER FACTOR - TEMPERATURE CORRECTION FACTORS

Insulation Dissipation/Power Factor measurements vary with temperature and insulating materials. In order to determine the condition of the bushings insulation, all measured values are referenced to a standard temperature of 20°C. The appropriate temperature correction factors, if not listed below in table 13-1, should be obtained from the bushing manufacturer's literature.

°C	°F	GENERAL ELECTRIC			WESTING HOUSE	OHIO BRASS	
		TYPE U	**TYPES L-LC LI-LM**	**TYPES *OF-OFI* OFM**	**TYPE 0**	**CLASS GK**	**CLAS S LK**
0	32	1.02	1.00	1.18	1.11	0.90	0.85
5	41	1.02	1.00	1.14	1.08	0.91	0.88
10	50	1.01	1.00	1.10	1.05	0.93	0.92
15	59	1.01	1.00	1.05	1.03	0.96	0.95
20	68	1.00	1.00	1.00	1.00	1.00	1.00
25	77	1.00	0.99	0.93	0.97	1.05	1.05
30	86	0.99	0.96	0.86	0.94	1.11	1.10
35	95	0.99	0.94	0.78	0.91	1.16	1.15
40	104	0.98	0.89	0.70	0.88	121	1.18
45	113	0.98	0.84	0.62	0.85	1.25	1.21
50	122	0.97	0.80	0.56	0.82	1.29	1.22
55	131	0.97	0.78	0.51	0.80	1.31	1.22
60	140	0.96	0.74	0.44	0.77	1.35	1.21
65	149	0.96	0.71	0.39	0.74	1.38	1.21
70	158	0.95	0.66	0.36	0.73	-	-

Table 13-1 Insulation Dissipation or Power Factor Temperature Correction Factors for Various Types of Bushings

***NOTE:** This table is for reference information only -the Doble DTA program automatically enters the appropriate temperature conversion factor needed for each specific manufacturer's bushing.*

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13.10 ABNORMAL READINGS

Most bushings with power factor or capacitance taps have the Insulation Dissipation/ Power Factor and "C1" and "C2" values stamped on the nameplate. Test measurements that do not agree with these factory test values should be investigated further. Table 13-2 gives some suggested maximum Insulating Power/Dissipation Factor values for various types of bushings. Insulation Power Factors above these values may indicate:

a. Water absorption
b. Insulation voids
c. Carbon traces
d. Excessive surface leakage across the outside of the porcelain skirts
e. General deterioration.
f. Instrumentation error

BUSHING TYPE	SUGGESTED INSULATION DISSIPATIONIPOWER FACTOR MAXIMUM LIMIT AT 20°C
Compound Filled	1.5% to 3.0%
Oil Filled Cellulose Tube	1.5% to 3.0%
Condenser or Capacitance Type	1.0%
Epoxy	1.5%

Table 13-2. Suggested Insulation Dissipation or Power Factor Limits For Various Types of Bushings

NOTE. *Please refer to the manufacturers and Doble engineering specifications for further information regarding complete analysis of bushings.*

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SCHEDULE FOR BUSHINGS MAINTENANCE

ACTION	SCHEDULE			
	Initial Upon Receipt or Energization	Monthly	Yearly	3 Years
Read Oil Level Gauge	X	X	X	X
Inspect for Cracks or Damage	X	X	X	X
Infrared Inspection			X	X
Clean Exterior Surfaces	X		X	X
Power Factor Test	X			X

Table 13-3

13.11 CRITICAL DIMENSIONS FOR BUSHING INTERCHANGEABILITY

1. **Introduction**

The critical dimensions and parameters for bushing interchangeability are listed as follows:

KV and BIL
Ampacity
Flange Diameter
Number of Flange Bolts
Bolt Hole Diameter
Bolt Circle Diameter
Flange Thickness
Length of Ground Sleeve
Diameter of Ground Sleeve
Length Below Flange
Lead Type (bolted or draw)

$$\text{*Bolt Circle Diameter} = \frac{\text{Distance Between Two Bolt Centers}}{\text{Sin } (180^0/\text{Number of Flange Bolts})}$$

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Example:-

$$\text{Bolt Circle} = \frac{10.16\text{ cm}}{\text{Sin }(180^0/4)}$$

$$= \frac{10.16\text{ cm}}{\text{Sin }(45^0)}$$

$$= \frac{10.16\text{ cm}}{.707}$$

$$= 14.38\text{ cm}$$

13.12 CLEANING

Insulators are designed to operate with some contamination: however, regular wetting by early morning mist and fog, followed by exposure to various airborne contaminates may lower the insulating properties below safe values. Such problems are particularly severe near steel mills, cement and chemical plants and other factories that disperse semi-conductive particles into the air. In coastal and tropical areas, deposits of salts or fungus become a problem. Many of these deposits are extremely severe and must be removed by hand while others may be washed free after de-energizing the facility.

14.0 SUBSTATION AUXILIARY EQUIPMENT

14.1 METERS

1. Readings on voltmeters, ammeters, wattmeter, VAR meters and watt-hour meters should be recorded on Monthly Inspection Form No. 573 in Section 22 - SUBSTATION INSPECTION AND MAINTENANCE FORMS.
2. During monthly inspections check meters for:
   a. Cleanliness
   b. Condition of contact surfaces.
   c. Tightness of nuts and binding posts.
   d. Proper arrangement and condition of insulated leads, wires and cables.
3. Cleaning, repair or replacement of meters should be preformed if required.

NOTE: FOLLOW MANUFACTURER'S PROCEDURES FOR REPAIR AND TESTING.

4. Meters should be recalibrated and tested periodically as recommended by manufacturer or when an abnormal condition is detected. (See Section 23 - REFERENCE MATERIAL)

14.2 INSTRUMENT TRANSFORMERS

1. Current and potential transformers associated with the substation metering should be visually inspected monthly.
2. Scheduled maintenance inspection should be performed every two years or as recommended by the manufacturer.
3. Determine the following conditions during inspections:
   a. Broken or contaminated bushings.
   b. Corroded or loose terminals.
   c. Rust, corrosion or evidence of oil leaks on case or tank.
   d. Loose joints in conduit around fittings and terminal boxes.
4. Scheduled maintenance is performed in accordance with manufacturer's instructions.
   a. BEFORE PERFORMING ANY MAINTENANCE, INSTRUMENT TRANSFORMERS MUST BE DE-ENERGIZED AND COMPLETELY ISOLATED FROM ANY ENERGIZED SOURCE.

b. Electrical tests, such as, power factor test, oil analysis, ratio, polarity, resistance, current and voltage tests are to be performed during scheduled maintenance in accordance with the recommendations and procedures contained in manufacturer's instructions.

14.3 CURRENT TRANSFORMER TESTING

14.3.1 Introduction

Current Transformers (CTs) are devices used for the purpose of electrical control and measurement. A current transformer is generally comprised of a primary and secondary winding. The primary winding is connected in series with the circuit carrying the current that is to be controlled or measured. The secondary winding is magnetically coupled to the primary winding and provides a proportionate current that is generally in the range of 0 to 5 amps. In the case of high voltage circuits, the current transformer secondary also provides isolation and insulation from the high voltage.

Since Current Transformers (CTs) are used extensively in metering, control and protective relay circuits, high accuracy and reliability are requirements of these devices. Improper function of these devices can result in catastrophic consequences.

In order to assure the required accuracy and reliability of a CT, periodic testing is necessary. This test procedure will discuss the proper methods for performing:

Ratio Test
Saturation Test
Polarity Test

14.3.2 Equipment

Current transformer test set
Test leads
Test form

14.3.3 Test Preparation

1. De-energize the device to be tested and obtain a clearance. Apply safety grounds to ensure that the C.T. is isolated from all sources.
2. Copy nameplate information on the appropriate test form.
3. Isolate the C.T. secondary leads from all control and measurement devices. This is generally best performed at the C.T. shorting blocks.

14.3.4 Ratio Test

The transformer winding ratio is defined as the number of turns found on the secondary winding divided by the number of turns on the primary winding.

$$\text{Ratio} = \frac{\text{Number of Secondary Turns}}{\text{Number of primary turns}}$$

1. Make sure the Current Transformer Test Instrument power switch is off and then connect the test set to a suitable 240 volt source.
2. Connect the X1 terminal to the polarity (or L) side of the CT secondary.
3. Connect the X2 terminal to the non-polarity (or K) side of the CT secondary.
4. Connect the H1 terminal to the polarity side of the CT primary. (See Section 7.9.6 for connection methods for various devices.)
5. Connect the H2 terminal to the non-polarity side of the CT primary. (See Section 7.9.6 for connection methods for various devices.)
6. Temporarily remove the safety grounds installed in step 1 for test purposes only.
7. Turn Power switch "ON".
8. Turn the function switch to SATURATE AND RATIO TEST.
9. Place the RANGE SWITCH in the 600 volt position.
10. Starting at "0", slowly rotate the OUTPUT control knob and raise the output voltage until the PRIMARY meter reads 1.0000

NOTE: Do not raise the output voltage beyond 600 volts or C. T. saturation. *If CT saturation or over-voltage occurs, adjust the voltage so that the PRIMARY voltmeter reads a fraction of a volt (0.5000 or less).*

11. Record the PRIMARY and SECONDARY voltage readings; also record the exciting current.
12. Slowly rotate the OUTPUT knob in a counter-clockwise direction and reduce the output voltage to "0".
13. Place the power switch in the OFF position.
14. Calculate the ratio as follows:

$$\text{Ratio} = \frac{\text{SECONDARY VOLTAGE reading}}{\text{PRIMARY VOLTAGE reading}}$$

NOTE: *If PRIMARY reading* is *1.000, then* the ratio *maybe* read *directly from the SECONDARY meter.*

15. Record the ratio on the test sheet.
16. Replace Safety Grounds.
17. Repeat the test procedure for each tap position and each C.T.

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FOR BUSHING CTs IN POWER CIRCUIT BREAKER OR ACR

CT LOCATION	CT TEST SET CONNECTIONS			
	X1	X2	H1	H2
H1 Bushing	1X1 terminal block in cabinet	1X5 terminal block in cabinet	H1 Bushing	H2 Bushing
H2 Bushing	2X1 terminal block in cabinet	2X5 terminal block in cabinet	H2 Bushing	HI Bushing
H3 Bushing	3X1 terminal block in cabinet	3X5 terminal block in cabinet	H3 Bushing	H4 Bushing
H4 Bushing	4X1 terminal block in cabinet	4X5 terminal block in cabinet	H4 Bushing	H3 Bushing
H5 Bushing	5X1 terminal block in cabinet	5X5 terminal block in cabinet	H5 Bushing	H6 Bushing
H6 Bushing	6X1 terminal block in cabinet	6X5 terminal block in cabinet	H6 Bushing	H5 Bushing

NOTE: *Breaker must be in the closed position*

Table 14-1. Test connections for Ratio and Saturation test on Bushing CTs located in Power Circuit-Breakers or ACR/OCR/ Breakers

FOR BUSHING CTs IN DELTA WYE POWER TRANSFORMER

CT LOCATION	CT TEST SET CONNECTIONS			
	X1 X2	H1	H2	JUMPER
H1 Bushing	Secondary terminals of H1 CT located in the control cabinet	H1 Bushing	H2 Bushing	H2-H3 XI-X2-X3
H2 Bushing	Secondary terminals of H2 CT located in the control cabinet	H2 Bushing	H3 Bushing	H1-H3 X1-X2-X3
H3 Bushing	Secondary terminals of H3 CT located in the control cabinet	H3 Bushing	H1 Bushing	H1-H2 X1-X2-X3
X1 Bushing	Secondary terminals of X1 CT located in the control cabinet	X1 Bushing	NEUTRAL Bushing	H1-H2-H3
X2 Bushing	Secondary terminals of X2 CT located in the control cabinet	X2 Bushing	NEUTRAL Bushing	H1-H2-H3
X3 Bushing	Secondary terminals of X3 CT located in the control cabinet	X3 Bushing	NEUTRAL Bushing	H1-H2-H3
Neutral	Secondary terminals of NEUTRAL CT located in the control cabinet	NEUTR AL Bushing	X1 Bushing	H1-H2-H3

Table 14-2. Test connections for Ratio and Saturation test on Bushing CTs located in Power Transformers-DELTA WYE connection.

14.3.5 Saturation Test

The saturation value of a transformer is defined as the maximum induced voltage possible from a transformer. For all practical purposes, it is the point where the transformer core is fully magnetized.

C.T.s that saturate at a low value may not be able to supply the necessary power to operate protective relays or may introduce large errors in metering circuits.

1. Follow steps 1 through 8 in the Ratio Testing section
2. Starting at "0", slowly turn the OUTPUT control knob in a clockwise direction observing the AMMETER and SECONDARY voltmeter.
3. The C.T. saturation point is reached when a small increase in SECONDARY voltage causes a large increase in output current (AMPERES).

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4. Record the SECONDARY voltage and current (AMPERES) readings.
5. Slowly rotate the OUTPUT knob in a counter-clockwise direction and reduce the output voltage to "0".
6. Place the power switch in the OFF position.
7. Replace Safety Grounds.
8. Repeat the test procedure for each tap position and each CT

14.3.6 Polarity Test

The polarity of a CT indicates the relative instantaneous directions of the currents entering the primary terminals and leaving the secondary terminals of the CT during each 1/2 cycle. In order for most control and metering equipment to function properly, the CTs polarity must be known and observed.

This test involves exciting the secondary of the CT with a known voltage and adding it to the induced primary voltage. If polarity is observed, the resulting voltage (Secondary + Primary) will be greater than the induced (Primary) voltage alone.

1. Repeat steps 1 through 5 in the Ratio Test Section.
2. Turn the function switch to SEC/100 + PRIMARY.
3. Place the RANGE SWITCH in the 600 volt position.
4. Starting at "0", slowly rotate the OUTPUT control knob and raise the output voltage until the SECONDARY voltmeter reads 100.00.

NOTE: *Do not raise the output voltage beyond CT saturation. If CT saturation occurs, adjust the voltage so that the SECONDARY voltmeter reads a lower voltage. (Try 50 volts).*

5. If POLARITY was observed in step 6.1, then the PRIMARY voltmeter should read greater than 1.0000 volts.

   PRIMARY meter reading = Induced voltage + (0.01 x SECONDARY meter reading)

6. Slowly turn the OUTPUT knob counter-clockwise to "0".
7. To check the above results, turn the function switch to SEC/100 - PRIMARY.
8. Repeat step 5.
9. If POLARITY was observed in step 1, then the PRIMARY voltmeter should read less than 1.0000 volts.

PRIMARY meter reading = Induced voltage - (0.01 x SECONDARY meter reading)

10. Slowly turn the OUTPUT knob to "0".
11. If the PRIMARY meter reading in step 9 is greater than that obtained in 5, then POLARITY has not been properly observed or marked on the CT

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12. Replace safety grounds.

13. Repeat steps 4 through 12 for each CT

14.3.7 Problems Found

Typical problems that can be found by performing the above tests are:

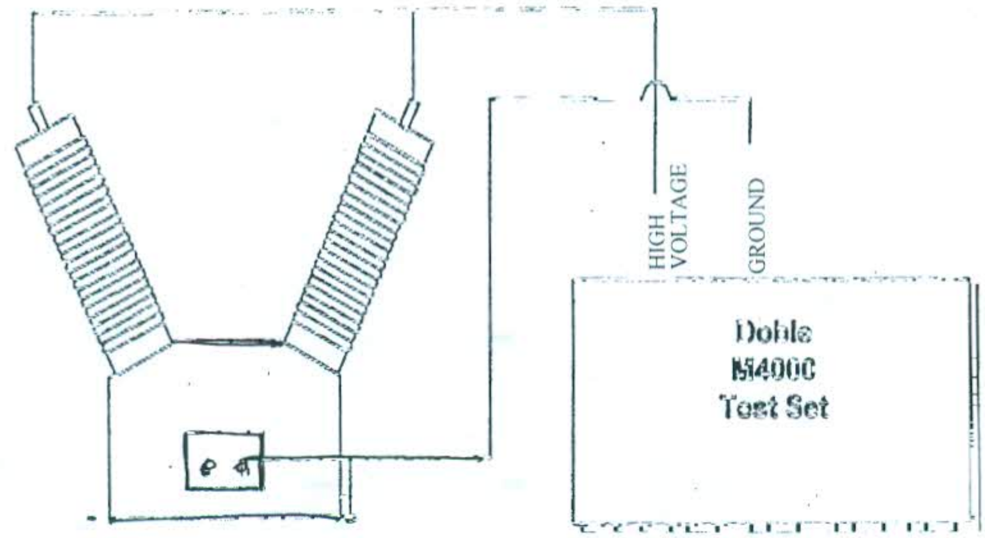
Shorted Turns
C.T. nameplate discrepancies
Polarity reversals
Wiring errors
Open Circuits
Core Saturation problems

14.4 TEST CONNECTIONS - POTENTIAL TRANSFORMERS

By performing three (3) separate tests, the condition of the insulation of a potential transformer can be determined.

NOTE: *One terminal of each secondary winding should be grounded to prevent an over voltage of the secondary insulation.*

14.4.1 Test connection for measuring the overall insulation of the potential transformer.



Test Lead Connections		
High Voltage	**Blue**	**Red**
$H_1 + H_2$	-	-

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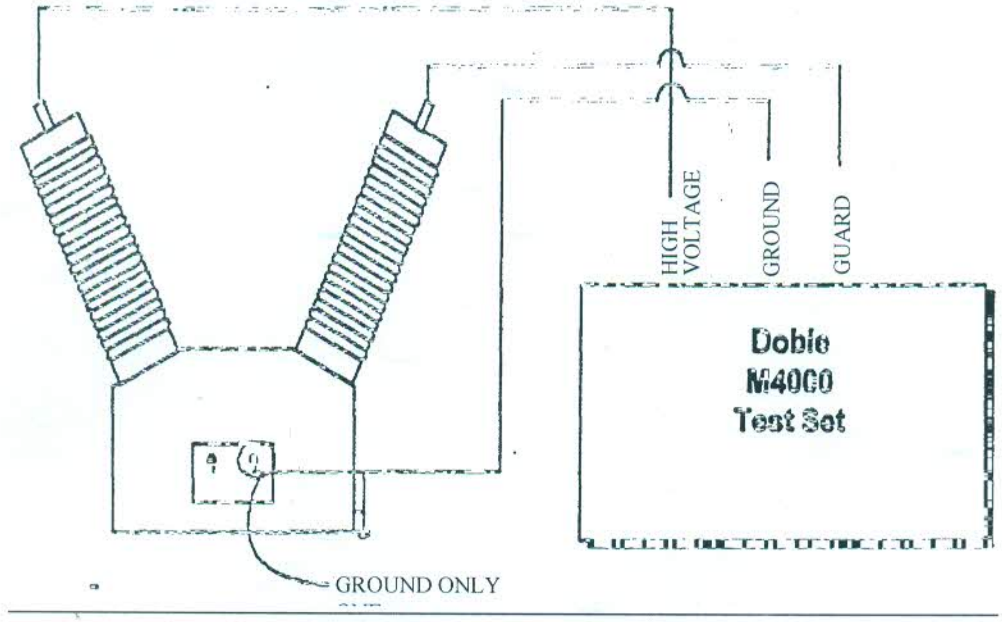
14.4.2 Test connection for measuring the H_1 insulation.

NOTE: *One terminal of each secondary winding should be grounded to prevent an over voltage of the secondary insulation. In this particular test grounding of two secondary terminals will result in a short circuit of the PT and cause excessive currents to flow in the HV winding.*



Test Lead Connections		
High Voltage	**Blue**	**Red**
H_1	H_2	-
or		
H_1	-	H_2

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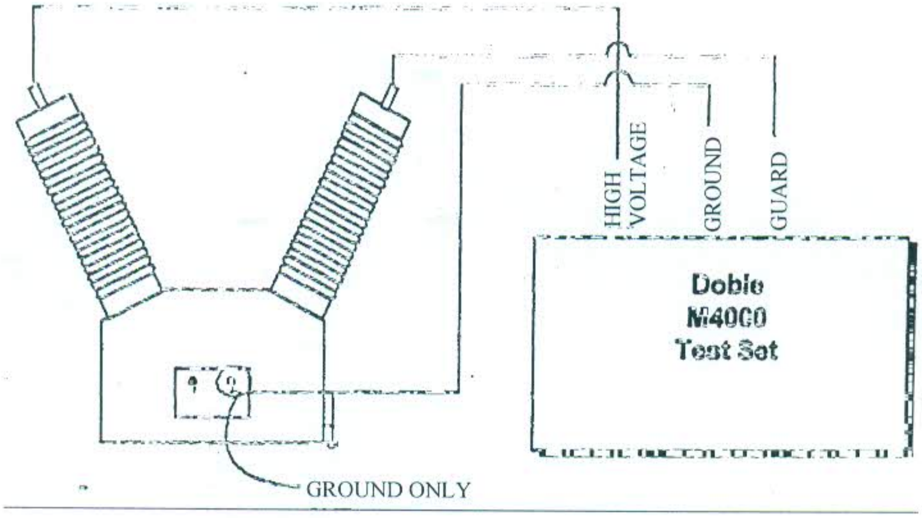
14.4.3 Test connection for measuring the H_2 insulation.

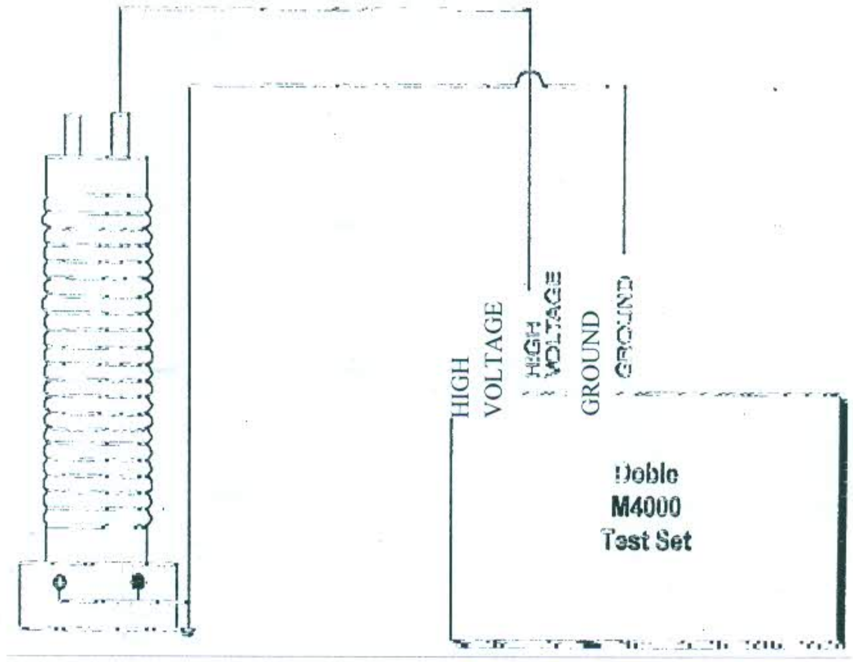
NOTE: *One terminal of each secondary winding should be grounded to prevent an over voltage of the secondary insulation. In this particular test, grounding of two secondary terminals will result in a short circuit of the PT and cause excessive currents to flow in the HV winding.*



Test Lead Connections		
High Voltage	**Blue**	**Red**
H_2	H_1	-
or		
H_2	-	H

14.4.4 Test Connection - Current Transformer

The overall insulation condition of current transformers may be determined as follows:



Test Lead Connections		
High Voltage	**Blue**	**Red**
C_1	Grounded secondary terminals and frame of C.T.	-
or		
C_1	-	Grounded secondary terminals and frame of CT

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15.0 PROTECTIVE LIGHTING

15.1 GENERAL

Outdoor lighting is required to illuminate the equipment and premises of the substation for personnel and as an aid in identifying equipment, buses, switches, etc, at night time.

15.2 VISUAL INSPECTION

Visual inspection of lighting facilities should be carried out every month to check for:

1. Burned out lamps and ballasts.
2. Lighting obstruction, such as, tree growth.
3. Loose fixtures.
4. Normal operation of photo-electric control.
5. Loose circuit connections.

15.3 REPAIR AND REPLACEMENT

Repair and replacement of lamps or other lighting accessories should be performed as required. Following points should be checked at the time of lamp replacement:

1. Loose or missing gaskets.
2. Cracked or broken glassware.
3. Cracked or broken insulators.
4. Loose mountings.

Replace any of the broken or cracked items above and adjust mountings as required.

15.4 CLEANING

Glass-ware and reflectors should be cleaned and washed at least twice a year and more frequently if found necessary due to local contamination conditions.

15.5 PAINTING

To avoid rusting and corrosion of fixtures, painting should be scheduled at least once a year or as frequently as found necessary by experience.

15.6 PHOTO-ELECTRIC CONTROL

Photo-electric control assembly, switches and connections should be checked at least once a year or as required by the manufacturer. Abnormal conditions, such as those given below should be corrected accordingly:

1. Loose connections should be tightened.
2. Relay and switch contacts should be adjusted and evidence of contamination and sparking removed.

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3. Photo-electric control assembly should be tested as per manufacturer's instructions.

ADEQUATE SAFETY MEASURES SHOULD BE TAKEN DURING MAINTENANCE AND REPLACEMENT OF LIGHTING EQUIPMENT.

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16.0 STRUCTURES

16.1 GENERAL

Substation structures are generally constructed of galvanized steel and treated wood with structural members being bolted, riveted or welded in place.

16.2 INSPECTION

Inspection of steel and wooden structures should be performed visually from the ground every two years and at close range every four years. Evidence of rust, loose, broken or missing connections and settling should be observed on the following components:

1. Anchor bolts and column bases.
2. Concrete bases and pads.
3. Ground wires.
4. Guys.
5. Structural members.

16.3 MAINTENANCE

Maintenance of structures should be performed as follows:

1. Spot painting (use rust converter primer and Galvanox or equivalent paint) should be performed as soon as rusting is observed regardless of any established painting schedule. Complete painting of steel structures should not be necessary unless a general rusting condition becomes evident.
2. Loose, broken or missing parts should be tightened or replaced as required to maintain rigid construction. Unless otherwise authorized, all replacement parts should duplicate the original parts.
3. Any ageing or rotten wood should be carefully noted and the damaged wood member should be planned for replacement as soon as possible.

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17.0 CONCRETE

17.1 INSPECTION

Inspection of concrete installations associated with substation structures should be performed visually simultaneously with the structures. Observation should be made to determine the extent of deterioration as indicated by spilling, or settling of the concrete.

17.2 REPAIRS

Necessary repairs of concrete foundation and pads, having spelled areas or surface cracks, should be made using a fine aggregate patching cement, taking care to remove all loose and foreign matter. Severely deteriorated foundations should be replaced if repairs are determined to be impractical. Severely settled (sunken or off-level) foundations should be raised, leveled or replaced as soon as possible.

18.0 SUBSTATION YARD

18.1 FENCE

1. Fences should be inspected each month.

   CAUTION: *A metal fence in close proximity to electrical equipment is subject to dangerous induced voltages from a system fault or other unusual conditions. Observe all safety precautions when performing any inspections of such fencing.*

2. Maintenance other than painting should be performed as soon as possible to correct deficiencies such as:
   a. Existence of opening large enough to allow a small child to crawl under or through the fence.
   b. Mechanical damage and missing grounds.
   c. Unauthorized changes in the ground surface or elevation on either side of fence.
   d. Presence of live parts less than eight feet from the fence.
   e. Presence of material, such as, lumber, boxes, piles of dirt or gravel within three feet of the fence, which can aid climbing.
   f. Presence of weeds and trash adjacent to fence.
   g. Leaning or bent posts and brackets and deteriorated foundations.
   h. Painting of fences should be performed in accordance with established practices and schedules. However, any evidence of rust or corrosion should be spot painted as soon as possible.

18.2 GATES

1. Inspect framework, grounds and fabric of all gates in a manner similar to the fence.
2. Check gate operation, lubrication, ground clearance, steps, latches, locks and other accessories that are a part of gates.
3. Make repairs adjustments and perform maintenance as required on gates and accessories.

18.3 WARNING SIGNS

1. Inspect for presence of warning signs at all gates and other locations on substation fence. Ascertain that the signs are readable and at least one is in sight from any normal approach path.
2. Replace missing or illegible signs.
3. Inspect and tighten fastenings on signs.

18.4 WEEDS AND FLOODING

1. Inspect substation property, both inside and outside the fence, for weeds tree branches and bush growth, which should be removed as soon as possible.
2. Inspect substation property after a heavy rain to determine if there is any standing water or evidence of flooding. Any excess water should be pumped out or drained away immediately.

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19.0 GROUNDING SYSTEM

19.1 GENERAL

All exposed and accessible non-current carrying metal parts of the electrical devices and equipment are grounded to reduce the hazards of contacts by personnel. Inspection and maintenance of the grounding system is essential to ensure safety of personnel and equipment.

***CAUTION**: Extreme care must be taken in inspecting, maintaining and testing grounds and ground systems. NEVER open a grounding connection unless the connected equipment is de-energized, or an adequate bypass is provided. Always wear rubber gloves.*

19.2 INSPECTION AND MAINTENANCE

Ground connections to equipment, equipment enclosures, structural members, fencing and system neutrals should be inspected visually every month.

1. Loose, broken and missing connections should be repaired or replaced immediately.
2. Connections or connectors showing signs of over-heating as evidenced by discolorations, should be reported as this may be the result of improper application or installation.
3. If connections are found to be corroded or rusted, they should be cleaned and corrective measures taken to prevent recurrence.
4. Excessive amount of corrosion should be reported as it may indicate need for cathodic protection.

19.3 MEASUREMENTS

It is recommended that resistance measurements be made annually preferably during the same winter month every year to note result variation not affected by weather conditions. Complete test data should be recorded to determine the trend in resistance value for each installation. The following ground resistance measurements should be made to assure safe operating practices.

1. Measure resistance of all branches of the grounding system from the point of connection on the structure, equipment enclosure, or neutral conductor to the top of the solid ground connection.
2. Measure resistance of ground rod, mat or network to the ground itself.
3. Measure resistance between gates and gate posts.
4. Measure resistance between operating rods and handles of group operated switches and supporting structure.

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5. If the ground resistance measured under 19.3 #2 is found more than 1.0 ohms, additional grounding are to be required to bring it with in 0.5 ohm.

CAUTION: *Care must be taken by personnel testing grounds. Rubber gloves, blankets, etc. are recommended for protection of operators. Ground resistance measurements must never be attempted during lightning storms.*

20.0 TOOLS AND EQUIPMENT

20.1 GENERAL

Tools and equipment necessary to carry out inspection, maintenance and repair must be available to appropriate personnel. They are broadly categorized below.

1. **Safety:** Insulated gloves, blankets, rubber matting, line hose, hot stick, barricades, warning devices, grounding jumper, first aid kit and other safety device and equipment found necessary.

2. **Inspection:** Flash-light, binoculars, fuse tester, measuring instruments, step ladder, etc.

3. **Maintenance and Repair Tools:** Hand tools such as screwdrivers, pliers, spanners, drill sets, ratchet sets, hammers, etc. Digging tools, hot line tools, climbing equipment, scissors, insulated tape, oil filtering equipment (Reference 2.E) and other items found necessary.

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4. **Testing Equipment and Tools:** Equipment necessary to carry out testing of components on location or in workshop should include the followings-

(01) Standard meters for calibration;

(02) Batteries

(03) Battery charger

(04) 1000V Insulation Resistance Tester

(05) Multi-Meters

(06) Power supplies,

(07) Oil Testing Equipment as per ASTM D877

(08) Insulation dissipation power factor test set (Doble M4000)

(09) Infrared camera

(10) Ultrasonic detector

(11) Dew-point analyzer

(12) High voltage detector,

(13) Interfacial tension test set as per ASTM D97

(14) Temperature gauge test set

(15) Ground test set (three point or clamp-on)

(16) Current transformer test set(Turn Ratio Test Set)

(17) Rubber blanket and glove testing equipment

(18) Tan delta test set

(19) All electrical workshop devices, tools and other necessary test sets. Tools must

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be maintained in a functional condition, free from moisture and contamination, such as, dust or grease. Any malfunctioning or deteriorated tools must not be used and must be replaced.

21.0 SPARE PARTS

21.1 GENERAL

An inventory of spare parts and equipment is necessary to maintain reliable service and to ensure fast restoration of service following a failure or service outage.

1. **Quantities:** The quantity of spares which should always be maintained is best determined by manufacturer's recommendations and system operating experience regarding frequency of failures or service outages.

2. **Listing:** For the BREB system, the initial quantities of spares recommended are listed in Exhibit 21-1. These quantities may be changed as per operating experience.

3. **Storage:** All spare parts and equipment should be stored with proper identification in an environment free from dust, moisture and excessive heat. Proper handling is necessary to avoid damage.

21.2 LIST OF RECOMMENDED SPARE EQUIPMENT AND PARTS REQUIRED FOR SUBSTATION MAINTENANCE

EQUIPMENT AND PART	QUANTITY OF EACH TYPE OF RATING
1. Transformers (power)	1 ea
2. Regulators	1 ea
3. Bushings (regulators & transformers)	1 ea
4. Current Transformers	1 ea
5. Potential Transformers	1 ea
6. Surge Arrester - (9 KV)	2 ea
7. Surge arresters - Station Class	1 ea
8. Recloser - Single Phase	1 ea
9. Recloser - Three Phase	2 ea
10. Fuse Links (Power Transformer)	3 ea
11. Fuse Links (Feeder)	6 ea
12. Insulators - Each Size	6 ea
13. Luminaire Lamps (Mercury)	3 ea
14. Lamp Assemblies	2 ea
15. Meters & Instruments	1 ea
16. Lamp Photo-Electric Control	2 ea
17. Nuts and Bolts	10 ea
18. Transformer Temperature Gauge	1 ea
19. Transformer Pressure/Vacuum Gauge	1 ea

NOTE: *1. Additional spare parts (moving and stationary) of items 2, 8, 9, 13, 18 and 19 which require replacement are to be maintained according to manufacturer's recommendations or experience.*

2. Spare fuses and fuse links (items 10 and 11) are to be kept at each substation.

3. All spare equipment & parts except items 10 and 11 are to be kept centrally at PBS HQ.

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22.0 SUBSTATION INSPECTION AND MAINTENANCE FORMS

22.1 GENERAL

This section contains the forms (Form 100-29-16 and Form 100-29-17) used for substation inspection and maintenance. The forms should be completely filled in. If no information is available for a particular part, the blank should be written "N. Av." Information is to be printed using black ink. The writing must be legible since others will be transcribing this information to summary forms. Special care should be taken when reading meters. All substation data are extremely important for good load management.

22.2 GENERAL GUIDELINE FOR FILLING OUT SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM 100-29-17

22.2.1 GENERAL

This Form is to be used when engaging in sub-station inspection and maintenance, whether the work is planned or un-planned. While conducting the inspection further clarification may be found in the respective section of this Manual where the particular type of equipment/item has been discussed. For Example, Section 3 of this form involves the inspection and maintenance of Voltage Regulators. Section 8 of the 100-29 manual details the different procedures to be performed on the periodic inspection of voltage regulators. This form should be used in conjunction with the Inspection and Maintenance Schedule (in Table:22-1 of this section).

22.2.2 APPLICATION

The person responsible for filling out this form should take the time to ensure that the Form No 100-29-17 is filled out as completely and comprehensively as possible. The following instruction should be observed.

1. The form should be filled out using BLOCK LETTERS
2. Put a tick mark in the left margin by only those items which are inspected or maintained. If an item is not inspected, do not put tick mark for that respective item.
3. In the space to the right of the items to be inspected, indicate briefly what work was performed or where the case may apply, indicate the setting level, gauge reading, or test result.
4. Once the form is filled out, relative data should be transferred to appropriate forms (or Electronic Record Card software) such as OCR Records, Voltage Regulator Records, etc.
5. The Sub-station Monthly Information Sheet (Form No. 100-29-15) should be completed before any inspection or maintenance work begins. This information will complete the data on the Form No. 100-29-16.

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BREB Form No. 100-29-15(Version-1)

Name of PBS: -- Date:--------------------------

SWITCHING AND SUB-STATION MONTHLY INSPECTION WORKSHEET (Put "Y" for OK and "N" for not OK at the designated space)		Station Name : MVA Capacity : Inspector Name:								
A	**33 KV Incoming**	1	2							
A.01	Steel Structure (Clean & free from rust)									
A.02	Disconnect Switch (Appearance)									
A.03	Disconnect Switch Gr. Connection to Handle									
A.04	33 KV Lightning Arrester(Appearance)									
A.05	33 KV Lightning Arrester(Connection)									
A.06	33 KV Lightning Arrester(Grounding)									
A.07	33 KV Fuses (Appearance)									
A.08	33 KV CTs									
A.09	33 KV PTs									
A.10	Metering Cabinet									
A.11	Sub-Station Meter									

									3-Ø TR	
		R1	R2	Y1	Y2	B1	B2	SP	TR1	TR2
B	**Power Transformer**									
B.01	Appearance									
B.02	Bushing (Clean & Good condition)									
B.03	Oil level & Gauge									
B.04	Free from oil leak									
B.05	Thermometer OK									
B.06	Thermometer Maximum Pointer Reset									
B.07	Auxiliary Cooling Equipment									
B.08	Gas Pressure & Gauge									
B.09	Silica Gel Breather									
B.10	Noise and Vibration									
B.11	Transformer Grounding									

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C	VOLTAGE REGULATOR	R1	Y1	B1	R2	Y2	B2			
C.01	Appearance									
C.02	Bushing (Clean & Good condition)									
C.03	Oil level & Gauge									
C.04	Free from oil leak									
C.05	Surge Arrester									
C.06	Position Indicator Glass Cover									
C.07	Disconnect Switch (Appearance)									
C.08	Disconnect Switch (Bushing)									
C.09	Disconnect Switch (Contact Points)									
C.10	By-Pass Switch (Appearance)									
C.11	By-Pass Switch (Bushing)									
C.12	By-Pass Switch (Contact Points)									
C.13	Control Cabinet									
C.14	Control Cabinet (Indicating Light)									
C.15	Control Cabinet (Door Gasket)									
C.16	Counter Reading Recorded									
C.17	Drug Hand Reset									
C.18	Operational Check									
C.19	Voltage Regulator Grounding									
D	**11 KV Feeder**	1A	2B	3C	4D	5E	6F			
D.01	ACR/OCR/Breaker (Appearance)									
D.02	ACR/OCR/Breaker Bushing Clean & Good									
D.03	ACR/OCR/Breaker Free from oil leak									
D.04	ACR/OCR/Breaker Control Battery									
D.04	ACR/OCR/Breaker Reading Taken									
D.05	Disconnect Switch (Appearance)									
D.06	Disconnect Switch (Bushing)									
D.07	Disconnect Switch (Contact Points)									
D.08	By-Pass Switch (Appearance)									
D.09	By-Pass Switch (Bushing)									
D.10	By-Pass Switch (Contact Points)									
D.11	Lightning Arrester (Appearance)									
D.12	Lightning Arrester (Connection)									
D.13	Lightning Arrester (Grounding)									
D.14	ACR/OCR/Breaker Grounding									
D.15	Overhead Grounding Wire									

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BREB Form No. 100-29-15(Version-1)

E	**33 KV ACR/OCR/Breaker**	1	2							
E.01	ACR/OCR/Breaker (Appearance)									
E.02	ACR/OCR/Breaker Bushing Clean & Good									
E.03	ACR/OCR/Breaker Free from oil leak									
E.04	ACR/OCR/Breaker Control (Appearance)									
E.05	ACR/OCR/Breaker Control (Battery)									
E.06	ACR/OCR/Breaker Reading Taken									
F	MISCELLANEOUS ITEMS	1	2							
F.01	33 KV & 11 KV Buses / Connection									
F.02	Bus Insulators/ Bushings									
F.03	Overhead Shield wire									
F.04	Capacitor Bank (Bushing/ Fuses)									
F.05	Circuit & Phase Identification									
F.06	Fences & Gates Grounded									
F.07	Exit, Walkways & Driveways Clear									
F.08	Entrance Free of Stored Materials									
F.09	Sub-Station Free From Weeds									
F.10	Gates Properly Locked									
F.11	Sub-Station Fence Intact									
F.12	Station Transformer(s)									
F.13	Security Lighting									
F.14	Convenience Power Outlet Sockets									
F.15	Burned out lamps replaced									
F.16	11 KV Structure									
F.17	Concrete Foundation									
G	**NOTES ON INSPECTION:**									

SWITCH/ SUB-STATION MONTHLY INSPECTION SHEET

POWER TRANSFORMER

Transformer Designation	No Load Tap	Liquid Temp. Max.	Tank Pressure	Liquid Level	Ambient Condition		
					Weather	Wind	Temp.
1-Ø/ R1							
1-Ø/ R2							
1-Ø/ Y1							
1-Ø/ Y2							
1-Ø/ B1							
1-Ø/ B2							
1-Ø/ Spare							
3-Ø/ TR1							
3-Ø/ TR2							

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BREB Form No. 100-29-15

VOLTAGE REGULATOR							
Regulator Designation	Counter Reading	Regulated Voltage	Max^{m} Amp.	Max^{m} Rise	Max^{m} Lower	Liquid Level	Others
R1							
Y1							
B1							
R2							
Y2							
B2							

ACR/ OCR/ BREAKER							
	33 KV ACR/ OCR/ Breaker	11 KV ACR/ OCR/ Breaker					
		Feeder1	Feeder2	Feeder3	Feeder4	Feeder5	Feeder6
Counter Reading							
Contact Wear							
Battery Voltage							
Maximum Amp./ KW							

NOTES ON STATION/ EQUIPMENT MAINTENANCE

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BREB Form No. 100-29-16(Version-1)

SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PBS ______________________ Sub-Station ________________ Date: _______

PUT TICK (√) MARK REMARKS
by Item Inspected
or Maintained Items ____________ (Record Data of Work Completed)

1. POWER TRANSFORMER

Visual	A. Bushing contamination: Loose/Damaged/Contaminated/Okay
	B. Bushing clip: Broken/Cracked/Okay
	C. Record Level of Oil
	1. Main Tank
	2. Tap Changer contaminated
	3. Bushing
	D. Temperature Gauge
	E. Record Gas Pressure
	F. Indication of Pressure Relief Device Operation
	G. Auxiliary Fan Operation
	H. General Conditions
	1. Oil Tank: Damage/Leakage/Okay
	2. Foundation
	3. Tanks, Radiators, Oil Valves and Plugs
	I. Connection: Loose/Corroded/Okay
	J. 240 Volt power Supply and Wiring
	K. Oil Sample Test
	L. Dissolve Gas Analysis Sample Testing
	M. Tap Changer Operation
	N. Insulation Resistance (Doble Power Factor)
	P. Control Cabinet: Loose/Contaminated/Rusted/Okay
	Q. Control Relays: Loose/Contaminated/Rusted/Okay
	R. Records Operations counter reading for load tap changer
	S. Bolt Connections: Loose/Okay
	T. Paints: Rusted/Okay

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SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK by Item Inspected or Maintained — Items ____________ REMARKs (Record Data of Work Completed)

2. VOLTAGE REGULATORS

	A. Bushing contamination
	B. Bushing clipped, broken or cracked
	C. Record Level of Oil
	D. Connection loose or corroded
	E. Oil Tank Damage or Leaking
	F. Counter broken or stuck
	G. Control Panel
	1. Voltage level
	2. Bandwidth
	3. Time Delay
	4. Control switch
	H. Misaligned contacts
	I. Worn out Contacts
	J. Oil Sample Test for Physical and DGA
	K. Damaged or Worn Gaskets
	L. Insulation Resistance Tests (Doble Power Factor)

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SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK by Item Inspected or Maintained | Items ____________ | REMARKS (Record Data of Work Completed)

3. AUTOMATIC CIRCUIT RECLOSER/SF6 BREAKER

	A. Bushing contaminated
	B. Bushing chipped, broken or cracked
	C. Connection loose or corroded
	D. Oil Tank Damage or Leaking
	E. Counter broken or stuck
	F. Mis-operation detected
	G. Moisture indicated by soft spots on liners
	H. Tank liner warped
	I. Blister on Tank liner
	J. Mis-aligned Arcing Contact
	K. Worn Out Arcing Contact
	L. Record Level of Oil
	M. Oil Sample Test (Below 26 KV not acceptable
	N. Damaged or Worn Gaskets
	O. Solenoid Operation Weak
	P. Foundation
	Q. Frame, Tanks, Oil Valves and Plugs R. Insulation Resistance Tests (Doble Power Factor)

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SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK by Item Inspected or Maintained — Items ____________ REMARKS (Record Data of Work Completed)

4. ISOLATING SWITCHES

A. Operating Mechanism

	1. Blade latches and Stops
	2. Smooth Operation
	3. Ground Connection on Operating Handle
	4. Connection loose or corroded

B. Insulators

	1. Contamination
	2. Chipped, Broken or Cracked
	C. Base and Mounting
	D. Blade and Contacts
	E. Linkage and Bearings
	E. Counter broken or stuck

5. FUSES

	A. Fuse Links and Fuse Tubes
	B. Contacts
	C. Mounting
	1. Base
	2. Bushing Chipped, Broken or Cracked
	3. Bushing Contaminated
	4. Alignment and Operation
	5. Connection Loose or Corroded

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SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK by Item Inspected or Maintained — Items ____________ REMARKS (Record Data of Work Completed)

6. LIGHTNING ARRESTERS

	A. Porcelain chipped, broken or cracked
	B. Porcelain Contaminated
	C. Connection loose or corroded
	D. Doble Power Factor

7. INSULATORS

	A. Porcelain broken or cracked
	B. Metal Parts, Base and Mounting
	C. Maintenance Tests
	D. Washing and Cleaning

8. AUXILIARY EQUIPMENT

A. METER CABINET AND CONTROL PANEL

	1. Panel wiring and terminal blocks
	2. Light Control Switches and Indicating lamps
	3. Meter and Instruments:
	a. Calibration of Panel Instruments
	b. Check Watt-hour Meter against standard
	c. Tightness of Cover Gasket
	d. Check Dial Movement Panel Instruments

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SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK
by Item Inspected
or Maintained

Items ____________ REMARKS (Record Data of Work Completed)

B. CURRENT AND POTENTIAL TRANSFORMER

	1. Bushing contaminated
	2. Bushing broken or cracked
	3. Connection Loose or corroded
	4. Oil Tank Damaged or Leaking
	5. Turns Ratio Tests
	6. Insulation Resistance (Doble Power Factor)
	7. Record Level of Oil
	8. Oil Sample Test

9. PROTECTIVE LIGHTING

	A. Glassware
	B. Photo electric Cell Assembly
	C. Connection and Fixtures
	D. Conduit and Fittings

10. STRUCTURES

	A. Painting performed
	B. Rust Removed
	C. Loose, Broken and Missing Parts Checked

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SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK by Item Inspected or Maintained — Items ____________ — REMARKS (Record Data of Work Completed)

11. CONCRETE

	A. Cracks and Deterioration Checked
	B. Repair performed

12. SUB-STATION YARD

	A. Fence
	B. Painting, Intactness, Mechanical Damage
	C. Gates
	1. Locks and keys
	2. Gate Operation
	D. Warning Signs
	E. Weeds and Flooding

13. GROUNDING SYSTEMS

	A. Connection loose or corroded
	B. Grounding Resistance Measurement (Vibroground Test)

14. TOOLS AND EQUIPMENTS

	A. Quantity and Condition Checked
	B. Storage Area Cleaned

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BANGLADESH RURAL ELECTRIFICATION BOARD

SUB-STATION PERIODIC INSPECTION AND MAINTENANCE FORM

PUT TICK (√) MARK by Item Inspected or Maintained — Items ____________ REMARKS (Record Data of Work Completed)

15. SPARE PARTS

	A. Verify Quantities
	B. Stored Condition

Prepared by ____________________
Line Personnel

Countersigned by ________________
AGM(O&M))

Dated ______________

Dated ____________

Copy to: 1. Director, System Operation, BREB
2. Superintending Engineer, Concern Zone, BREB

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TABLE 22-1: SUB-STATION INSPECTION AND MAINTENANCE SCHEDULE

SL No.	Equipment and It's Items	Inspection Frequency		
		Monthly	Annual	NS / S
1	**POWER TRANSFORMER**	M	A	
1.A	Bushing contamination	M	A	
1.B	Bushing chipped, broken or cracked	M	A	
1.C	Oil level recording	M	A	
1.D	Temperature Gauge	M	A	
1.E	Gas Pressure recording	M	A	
1.F	Indication of pressure release devise operation	M	A	
1.G	Auxiliary fan operation	M	A	
1.H	General condition			
	1. Oil tank damage or leakage	M	A	
	2. Foundation	M	A	
	3. Tanks, Radiators, Oil Valves and Plugs	M	A	
1.I	Connection loose or corroded		A	
1.J	240V Power supply and wiring		A	
1.K	Oil Sample test		A	
1.L	DGA sample testing of oil		A	
1.M	Tap changer operation			NS
1.N	Insulation resistance (Doble Power Factor)		A	
2	**VOLTAGE REGULATORS**			
2.A	Bushing contamination	M	A	
2.B	Bushing chipped, broken or cracked	M	A	
2.C	Oil level recording	M	A	
2.D	Connection loose or corroded	M	A	
2.E	Oil tank damage or leakage	M	A	
2.F	Counter broken or stuck	M	A	
2.G	Control panel			
	1. Voltage level		A	
	2. Bandwidth		A	
	3. Time delay		A	
	4. Control switch		A	
2.H	Misaligned contacts			NS
2.I	Worn out contacts			S
2.J	DGA sample testing of oil		A	
2.K	Damage or worn gaskets		A	
2.L	Insulation resistance test (Doble Power Factor)		A	
3	**ACR/ OCR/ Breaker**			

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3.A	Bushing contamination	M	A	
3.B	Bushing chipped, broken or cracked	M	A	
3.C	Connection loose or corroded	M	A	
3.D	Oil tank damage or leakage	M	A	
3.E	Counter broken or stuck		A	
3.F	Electronic control operation	M	A	
3.G	Mis-operation detected		A	NS
3.H	Moisture indicated by soft spots on liners		A	
3.I	Tank liner warped		A	
3.J	Blister on tank liners		A	
3.K	Mis-alignet arcing contact		A	
3.L	Worn out arcing contact		A	
3.M	Oil level recording		A	
3.N	Oil sample test (Below 26 KV not acceptable)		A	
3.O	Damage or worn gasket		A	
3.P	Solenoid operation weak			NS
3.Q	Foundation	M	A	
3.R	Frame, Tanks, Oil Valves and Plugs	M	A	
4	**ISOLATING SWITCHES**			
4.A	Operating Mechanism		A	
	1. Blade latches and stops		A	
	2. Smooth operation		A	
	3. Ground connection	M	A	
	4. Ground connection on operating handle		A	
4.B	Insulators		A	
	1. Contamination	M	A	
	2. Chipped, broken or cracked	M	A	
4.C	Base and mounting		A	
4.D	Blade and Contact		A	
4.E	Leakage and bearing		A	
5	**FUSES**			
5.A	Fuse links			NS
5.B	Fuse tubes	M	A	
5.C	Contacts		A	
5.D	Mounting			
	1. Base		A	
	2. Bushing chipped, broken or cracked	M	A	
	3. Bushing contamination	M	A	
	4. Alignment and operation		A	
	5. Fuses latches and stops		A	

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	6. Connection loose or corroded		A	
6	**LIGHTNING ARRESTER**			
6.A	Porcelain chipped, broken or cracked	M	A	
6.B	Porcelain contamination	M	A	
6.C	Connection loose or corroded		A	
7	**INSULATORS**			
7.A	Porcelain chipped, broken or cracked	M	A	
7.B	Metal Parts, Base and Mounting		A	
7.C	Maintenance test (Doble Power Factor Test)			NS
7.D	Washing and cleaning		A	
8	**AUXILIARY EQUIPMENT**			
8.A	Meter cable and control panel			
	1. Panel wiring and terminal blocks		A	
	2. Light control switches indicating lamps		A	
	3. Meter and instruments			
	(a) Calibration of panel instruments			NS
	(b) Check Watt-hour Meter against standard		A	
	(c) Tightness of cover gasket		A	
	(d) Check dial movement panel instruments		A	
8.B	**INSTRUMENT TRANSFORMER (CT/PT)**			
	1. Bushing Contamination	M	A	
	2. Bushing chipped, broken or cracked	M	A	
	3. Connection loose or corroded	M	A	
	4. Oil tank damaged or leaking		A	
	5. Turns ration test			NS
	6. Insulation resistance (Doble Power Factor)			NS
	7. Oil level recording		A	
	8. Oil sample test		A	
9	**PROTECTIVE LIGHTING**			
9.A	Glassware	M	A	
9.B	Photo electric cell assembly		A	
9.C	Connection and fixtures		A	
9.D	Conduit and fittings		A	
10	**STRUCTURE**			
10.A	Painting performed		A	
10.B	Rust removed		A	
10.C	Loose, Brocken and Missing Parts Checked		A	

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11	**CONCRETE**			
11.A	Cracks and deterioration		A	
11.B	Repair performed		A	
12	**SUB-STATION YARD**			
12.A	Fence	M	A	
12.B	Painting, Intactness, Mechanical damage	M	A	
12.C	Gates			
	1. Locks and keys	M	A	
	2. Gate operation	M	A	
12.D	Warning signs	M	A	
12.E	Weeds and Flooding		A	
13	**GROUNDING SYSTEM**			
13.A	Connection loose and corroded	M	A	
13.B	Grounding resistance measurement (Vibroground test)		A	
14	**TOOLS AND EQUIPMENT**			
14.A	Quantity and condition checked	M	A	
14.B	Storage area cleanness	M	A	
15	**SPARE PARTS**			
15.A	Verify quantities		A	
15.B	Stored condition	M	A	

M = Monthly, A = Annual, S = Scheduled, NS = Not Scheduled

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REFERENCE MATERIAL

1. SUBSTATIONS-GENERAL

1.A. REA Bulletin 165-1
Substation Inspection and Maintenance

1.B. REA Bulletin 161-5
Electric System Review and Evaluation

1.C. REA Bulletin 65-1
Design Guide for Rural Substations

2. TRANSFORMERS

2.A. General Electric Company Publication GEI-5400BC
Installation and Maintenance of Primary Substation Transformers (10,000 KVA and below)

2.B. General Electric Company Publication GEI-65070B
Insulation Oil and Transformer Drying

2.C. General Electric Company Publication GEK-5666
Instructions-Type A Bushings (11 KV)

2.D. General Electric Company Publication GEH-1638D
Instructions-Apparatus Bushings Type U 23 KV - 69 KV

2.E. General Electric Company Publication GEI-65077E
Instructions-Accessories

2.F. General Electric Company Publication GEI-65093A
Instructions Current Transformers-Bushing Type

2.G. General Electric Company Publication GEK-5676B
Instructions Forced-Air Cooling Equipment

2.H. General Electric Company Publication GEI-52524B
Instructions Types JVS and JVT Super Bute Potential Transformers

2.I. General Electric Company Publication GEI-52426E
Instructions Types JKW-200 Super Bute Current Transformers

2.J. ANSI Publications C57 Series
Transformers

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2.K. REA Bulletin 161-22
Application Guide for Transformers

2.L. Baron & Associates Special Model BA-D-HV-2-SPL
Instruction and Specification for Vacuum Oil Purifier

3. VOLTAGE REGULATORS

3.A. General Electric Company Publication No. GEh-4239A
Voltage Regulators

3.B. General Electric Company Publication No. GEK-35252A
Instructions Static Control Component Board

3.C. General Electric Company Publication No. GEK-47289A
Instructions Static Control Component Board VR-1

3.D. Siemens-Allis Publication No. 21X1263-10
JFR Distribution Voltage Regulators - Users Manual

3.E. Siemens-Allis Publication No. 21X4992-02
ACCU-STAT Controls-Instruction and Service Manual

3.F. McGraw-Edison Publication No. S225-10-1
VR-32 Operating, Maintenance and Parts Replacement Instructions

3.G. ANSI Publication C57.15
Step-Voltage and Induction Voltage Regulators

4. AUTOMATIC CIRCUIT RECLOSERS

4.A. McGraw-Edison Publication S280-30-1
Installation Instructions for Three Phase TX Type Reclosers

4.B. McGraw-Edison Publication S280-10-3
Maintenance Instructions for Types 4H and V4H Recloser

4.C. McGraw-Edison Publication S280-15-1
Maintenance Instructions for Type L Recloser

4.D. McGraw-Edison Publication 280-25SB-1
Maintenance Manual for Single Phase Type L Recloser

4.E. Lexington Switch & Controls Bulletin R-100-29-101
"A" Line OCR Service & Maintenance Manual

4.F. Lexington Switch & Controls Bulletin OCR-IM-1
Instructions Automatic OCR Type HR

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4.G. Reyrolle and Company Ltd. Publication No. IOMS-914
Installation, Operation and Maintenance Recommendations for Type-OYT Automatic Recloser

4.H. REA Bulletin 161-14
Maintenance of OCR's and Sectionalizers

4.I. ANSI Publication C37-61
Application, Operation and Maintenance of Automatic Circuit Reclosers

5. SWITCHES

5.A. Siemens-Allis Publication 99x5447-01
Outdoor, Air-Break Switch Equipment

5.B. S&C No. 351-500
Instruction Sheet for XS-type Open Cutouts

5.C. S&C No. 721-30
Instruction Sheet for Tandem Hook Disconnect Switch

5.D. S&C No. 4782R3
Instructions for Hook Disconnect Switch

5.E. Siemens-Allis Index Sheet No. S.O. 79265
Instructions for Vertical Break Horn Gap Switches and SIDE BREAK Horn Switches

5.F. ASEA Publication No. 5309 851E Rev 3
High Voltage Apparatus Three-Pole Isolator Type NRB

5.G. ANSI Publication No. C37.35
Air Disconnect and Load Interruption Switches

5.H. REA Bulletin No. 60-3
Outdoor Air Switching Equipment

5.I. S&C Sheet No. 192622
Tandem Hook Disconnect Switch Outline

6. FUSES

6.A. S&C No. 269-6 and 252-525
Instruction Sheets for Power Fuses, Type SM, SMD and SML

6.B. S&C Sheets No. 192504
SMD-20 Type Fused Disconnect Outline

6.C. S&C Sheet No. 198132R6

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XS Type Fuse Cutouts

6.D. S&C Sheet No. 19064R2
100-29-5 Type Fused Disconnects

6.E. S&C Instructions 252-525
100-29-Type Fused Disconnects

6.F. S&C Sheet No. 86154R2
Fuse Holders

7. SURGE ARRESTERS

7.A. ANSI Publication C62.2
Lightning Protection

7.B. ASEA Publication LB 13-1E
Surge Arresters Type XAF Class 10 kA

8. INSULATORS

9. INSTRUMENTS AND METERS

9.A. General Electric Instruction Book No. 198-4555K10-001
Ammeter & Voltmeter Type AB4

9.B. General Electric Instruction Book No. GEH-908
Control and Instrument Switch SB1

9.C. General Electric Instruction Book No. 198-4555K27-001
Varmeter AB40

9.D. General Electric Instruction Book No. GEH-2762
Demand Register M-30

9.E. General Electric Instruction Book No. GEH-2762
Watt-hour Meter D5-60

9.F. General Electric Instruction Book No. 198-4555K26-001
Wattmeter AB40

9.G. Sangamo Technical Bulletin 15140
Thermal Indicating Demand Ammeters