CHAPTER 3

TRANSMISSION AND DISTRIBUTION SUBSTATIONS

Section I - GOVERNING CONSIDERATIONS

3-1. Type of substations covered.

This chapter includes a transmission and distribution substation which is an assemblage of equipment for purposes other than generation or utilization, through which electrical energy in bulk is passed for the purpose of switching or modifying its characteristics.

3-2. Electrical system relationship.

A substation is an integral and vital part of an electrical system. It does not exist independently of the rest of the system, though it is usually designed so that a failure of a single component will not interrupt loads, except for switching times. Such interruption may force greater than normal loads to be carried by other components of the station while repairs are being made. Most substations are designed so they do not require attendant personnel on a continuous basis. Supervisory control and data acquisition (SCADA) systems, where provided, allow monitoring at a central point.

3-3. Substation safety concerns.

Substations present a potential safety hazard, owing to the large amount of energized conductor surface concentrated in a relatively small area. In general, only portions of an entire substation can be de-energized, although scheduled outages may be required for equipment which can not be bypassed or worked on while energized. All inspecting and repairing personnel must be thoroughly trained. The following requirements are minimum:

a. Familiarity with operating procedures, protective and interlocking schemes, and the equipment capabilities at the specific substation.

b. Knowledge of the proper use of safety equipment, first aid procedures and equipment, and equipment grounding techniques.

c. Access to safeguards such as danger signs, temporary barriers, protective clothing, tools and protective equipment, and all safety manuals and rules. Procedures should clearly indicate insulating requirements and working clearances for any category of energized-line maintenance employed.

d. Keeping proper inspection records and checklists so that observed defects or improper conditions not immediately repairable will be promptly corrected.

3-4. Substation security.

In addition to the personnel safety hazards mentioned above, an electrical substation presents an attraction to would-be vandals, dissidents, or other belligerents. For these reasons, good security is a basic requirement. All means of access to substations, including buildings and yards, will be kept locked when unoccupied and secure when occupied by authorized personnel.

3-5. Periodic inspections of substations.

An inspection checklist, tailored to a specific substation and containing all items to be checked, is recommended. Monthly visual and yearly infrared inspections of the entire substation are recommended.

3-6. Visual inspections of substations.

Visual inspections should include the total substation area including the site, the control house, and all equipment and structures. The energized substation should be inspected from ground level, to ensure adequate safety clearances from energized parts. Binoculars should be used to view buses and other equipment located on structures. Special care should be used when ground connections are checked, since a high voltage could develop across any gap created between a ground cable and a piece of equipment, particularly under fault conditions. For this reason, ground connections shall not be removed for any reason while the substation is energized.

3-7. Infrared inspections of substations.

All matter emits infrared rays in proportion to its temperature.

a. Method. An infrared detecting device can be used to determine loose connections, overloading of conductors, localized overheating in equipment, or similar conditions before they become serious. Some equipment is sensitive to a fraction of a degree. Infrared inspection can be done from a distance, since contact with the item being measured is not required. Substation equipment, such as bare bus, disconnect switches, and connections, can be checked without being de-energized. The inspection is made by aiming the infrared detector at various areas of the substation and noting where the hot spots are.

b. Equipment. Several types of infrared detectors are available. These vary from a simple hand-held instrument similar to a gun, through which the operator can detect hot spots and note their locations, to complex equipment requiring qualified operators and product photographs as a permanent record of the area being checked. The simpler detectors are usually sold outright, while the complex items are usually used by infrared detection services which contract to do the work. Having an instrument readily available can be justified for a large installation with several substations, while a contract to have a survey performed would probably be better for a small installation. However, as a low cost alternative, a camera with infrared sensitive film may be used, or a self-calibrating portable indicating unit can be coordinated with a Polaroid camera.

c. Surveys. When infrared (thermographic) surveys are made, the equipment to be scanned must be identified. Scanning should be made after visual and mechanical conditions have been observed. Report all areas scanned.

(1) *Reports.* If hot spots are found the report should locate the problem area and the temperature rise above a reference 30 degrees C. The cause of the heat rise should be identified such as phase unbalance, overload, poor connections, or other heat producing conditions.

(2) *Test parameters.* Equipment must detect emitted radiation and convert to a visual signal. A detection ability of a one degree C rise between the hot spot area and the 30 degree reference area is required.

(3) *Hot spot indications.* NETA-MTS indicates that temperature gradients as shown in table 3-l will require the following actions.

Table 3-l. Infrared hot spot gradients[1]

Temperature gradient	Deficiency	Action
0" to 3°C	Possible	Investigate
4" to 3°C	Probable	Repair as time permits
16°C and above	Major	Repair immediately

[1]Consider providing photographs an&or thermograms as seen on the imaging system in reports where appropriate to the size and criticality of the equipment examined.

Section II - STRUCTURE MAINTENANCE

3-8. Importance of maintenance.

The useful life of a substation structure is directly dependent upon the care it receives. Surface preservation is of prime importance.

3-9. Galvanized steel structures.

The protective coating produced by the galvanizing process normally has a long life; however, the coating will eventually fail and rust will appear. The life of the coating on structural steel used in substations should generally be longer than 12 years except possibly for the upper flat surfaces of horizontal members. Any failure of the coating will usually occur in spots rather than over an entire surface. Refer to chapter 4, section VII for self-weathering steel requirements.

a. Cleaning. Clean the surface with a wire brush or by other mechanical means to remove rust and dirt. If the surface is contaminated with grease or oil, a solvent should be used to remove those contaminants. Mineral spirits or one ounce (28.4 grams) of trisodium phosphate in one gallon (3.8 liters) of warm water can be used as the solvent. If it is uneconomical or impractical to remove all rust, a reasonably satisfactory job can be obtained by deactivating the rust through chemical treatment. A weak solution of phosphoric acid is suggested for deactivating rust. Use proper skin and eye protection.

b. Painting. If required spot painting covers more than 5 percent of the visible surfaces, the entire structure probably should be painted.

(1) *Priming coat.* Apply a priming coat to the clean dry surface using a good zinc dust/zinc oxide paint. Allow ample time for the paint to dry before applying the finish coats.

(2) *Finish coats. Two* finish coats should be applied using the same type paint used for priming. Ample drying time should be allowed between finish coats. Only one finish coat is needed for areas on which the galvanized coating remains intact. Other paints normally used as final coats for metal (such as aluminum paint) may be used as the final coat in place of the zinc dust/zinc oxide paint.

(3) *Temperature.* Painting of outdoor metal work is recommended only when the temperature is above 45 degrees F (7 degrees C) and when the relative humidity is below 80 percent.

(4) *Durability.* The durability of a paint coating depends on thickness, cohesion, and continuity. Generally, 5 mils or 0.005 inch (0.125 millimeters) is an adequate thickness. The thickness should be uniform, and paint should not be easily scraped off the metal. Welds, edges, and other hard-to-coat areas should be given particular attention.

3-10. Painted steel structures.

Most steel for indoor substations, and some steel for outdoor substations, is not galvanized and paint is used for preservation.

a. Cleaning. All loose paint, blisters, and scale must be thoroughly removed. Feather back the original coating around the damaged area with sandpaper. Where the condition of the finish is poor, the paint should be removed entirely. Wire brushing, sandpapering, or scraping is desirable where only partial surface cleaning is necessary. Paint removers will soften and aid in removal. However, the paint remover must be neutralized before attempting to paint. For removal of oil and dirt, weak solvents such as mineral spirits, other petroleum thinners, or turpentine substitutes should be used.

b. Painting. Painting should be done after cleaning. All bare metal should be covered with a primer. Where only chalking has occurred, one finish coat is sufficient. A zinc-chromate, alkyd-resin primer followed by an alkyd-base paint is a suitable air-dry combination for exterior surfaces. The primer coat should be allowed to air-dry thoroughly and should be followed by two finish coats with sufficient time allowed between coats for drying.

3-11. Aluminum structures.

Structures of aluminum alloy normally need no surface protection. Painting of aluminum alloy members is not recommended except where esthetics is of prime importance.

3-12. Wood structures.

Permanent wood structures should be inspected and treated as described in chapter 4, section IV. Temporary wood structures may or may not be treated, depending on the local climate and expected life of the structure.

3-13. Concrete for structure foundations.

Concrete is used extensively as a foundation for metal structures and for equipment. Concrete should be visually checked during the course of other maintenance and repair. Cracks wider than about 1/16 of an inch (0.16 millimeters) should be repaired with a sand-cement grout. Badly deteriorated concrete should be replaced.

3-14. Structure connections and joints.

Regardless of material, all connections and joints should be checked periodically for tightness of fastening hardware. Loose, broken, or missing parts should be tightened or replaced as required to maintain a rigid structure.

Section III - SUBSTATION YARDS

3-15. Provision of yards.

In some cases, there may be no outdoor yard in connection with a substation. However, these are exceptional situations, and most substations will have an adjoining yard.

3-16. Fences for yards.

Fence maintenance consists of material preservation, maintenance of structural integrity, and maintenance of a good ground. The following procedures are recommended:

a. Material preservation. In noncorrosive locations, double-dipped (ASTM A 90, Class II) hot-dipped galvanizing on chain-link fences will normally furnish adequate protection for many years. In corrosive locations, use of an aluminized fabric should be the preferred installation. When material preservation is required for steel or aluminum chain-link fences, it should be described in section II. Wood fences are not usually considered to provide adequate security for substations, and replacement with chain-link fencing should be considered. Screening, if required, can be provided with privacy slats of polyester-fiberglass or aluminum.

b. Structural integrity. Security requires that structure integrity be maintained by replacing damaged posts or other materials as required. Chain-link fencing should be kept taut. Spalling or broken components of masonry fencing should be replaced.

c. Grounding. Grounding must be maintained as a safety feature. Visual inspection should be made as a part of the monthly inspections, especially at the gate bonding straps. Tests should be made as prescribed in chapter 10, section III. Defects should be corrected immediately.

3-17. Warning signs at yards.

Warning signs conforming to OSHA standards and stating the voltage should be placed on each fence gate, on each substation building door accessible from outside the yard, and at intervals along the fence. At least one sign must be visible from any position along the fence. Location and legibility of all signs should be checked as a part of the monthly inspections.

3-18. Substation yards.

Substation yards at the time of construction should have been graded and cleared of vegetation. The entire yard area should be covered with some kind of earth covering. Concrete slabs, paving, or gravel fill are usual coverings. For very large substations some areas may be seeded for grass.

a. Ground treatment. Removal of vegetation, elimination of low spots in the yard, and control of grassed areas is necessary. If grass is permitted, careful maintenance is necessary both for esthetics and safety reasons. If allowed to grow uncontrolled, weeds, grass, or other plants create fire hazards, are unsightly, impede free action, and may grow tall enough to contact live parts and cause flashovers. Low spots collect debris and stagnant water. Where chemical application for removal of vegetation is required, it should meet environmental requirements.

b. Housekeeping. Miscellaneous storage should not be permitted except in specific areas reserved for this purpose. Storage should not interfere with operations and should be in a protected, tidy, and accessible manner. Birds may cause problems requiring removal of nests and possible provision of bird repellant controls such as tape, images, or sound systems.

Section IV - INSULATORS

3-19. Function of insulators.

The function of an insulator is to support a conductor or conducting device safely. An insulator, being of a nonconductive material, physically and electrically separates the supported item from any grounded or energized conductors or devices.

a. Composition and problems. Insulators are composed of porcelain, glass, fiberglass, or a composite compound. Maintenance is necessary to preserve their insulating ability which can be degraded by contamination or other damaging actions. Most insulator damage will result from gun shots; lightning, surge, or contamination flashovers; and wind damage. Defective insulators can also cause visible corona or interference voltage propagation.

b. Related material. Apparatus type insulators are provided in substations to support devices and heavy lines. See chapter 4, section XII, which provides a discussion of insulation levels.

3-20. Tests of insulators.

Radio interference conditions may be detected by using instruments designed for this purpose. Otherwise, maintenance tests on insulators are normally limited to occasional power factor measurements at the more important installations, where the loss of the facilities must be kept to an absolute minimum. Bus and switch insulators should be power-factor tested in conjunction with similar testing of other apparatus within the substation. Power factor tests are described in section VII.

3-21. Inspection and repair of insulators.

Switch-and-bus apparatus type insulators are the most intricate type and require the highest degree of reliability in service. This is because the several pieces of porcelain and hardware, assembled in a single unit, are usually located at key positions in the systems, where failure is extremely serious. Switch-and-bus insulator failures occur when porcelain is thrown in tension by any thermal movement between nested parts, which can cause cracking and allow the entrance of moisture. An accumulation of foreign deposits, and mechanical damage from external sources also cause deterioration. Evidence of such impairments may cause a flashover puncture accompanied by a destruction of insulator parts. Workers should be CAUTIONED that equipment must be de-energized unless the procedure in chapter 4, section XV is authorized.

a. Ceramic insulators. Ceramic insulators are made of wet-process porcelain or toughened glass.

(1) *Construction.*

(a) Porcelain insulators. Porcelain insulators are manufactured from special clays to produce a plastic-like compound which is molded, oven dried, dipped in a colored glazing solution, and fired in a kiln. The glossy surface of the glaze makes the insulator surface self-cleaning. Large porcelain insulators are made up of several shapes cemented together. A chemical reaction on the metal parts from improper cementing can result in a cement growth which can be sufficiently stressful to crack the porcelain.

(b) Glass insulators. Glass insulators are made from a mixture of sand, soda ash, and lime which is mixed and melted in an oven, then molded, cooled, and annealed.

(2) *Inspection.*

(a) Look for fractures, chips, deposits of dirt, salt, cement dust, acid fumes, or foreign matter, which under moist conditions may cause a flashover.

(b) Check for cracks in insulators by tapping gently with a small metal object ONLY WHEN DE-ENERGIZED, about the size of a 6-inch (15 centimeter) wrench. Insulators free of cracks emit a ringing sound when tapped; cracked ones sound dull and hollow. To avoid damaging good insulators, tap them; do not hit them hard.

(3) *Repair.*

(a) If the main body of a pin type or post insulator is cracked, replace it immediately.

(b) Hone small chips from shells or skirts, and paint with an insulating paint or varnish to

provide a glossy finish and to lessen dirt accumulation.

(c) Since the loss of a skirt on a pin-type insulator reduces the insulation value of the insulator by 30 percent or more, replace such broken units.

b. Nonceramic insulators. Nonceramic or composite insulators include core, weathersheds, and metal-end fittings. A weathershed is the external part of the insulator that protects the core or mechanical load-bearing component and provides the wet electrical strength and leakage distance. The core consists of resin and glass fibers. The weathersheds are of polymeric materials such as epoxy resins or elastomers and normally contain inorganic fillers.

(1) *Construction.*

(a) Fiberglass. Fiberglass insulators are manufactured with rods of fiberglass treated with epoxy resins. Rubber-like compounds are applied to the rods to fabricate suspension, dead-end, and post-type insulators.

(b) Polysil. Polysil insulators are formed by using various sizes of silica bound together chemically with a resin into a compound which is approximately 90 percent silica. Insulators have excellent mechanical and dielectric strength, are nontracking, and do not carbonize under severe arcing conditions. They are very durable for use in an adverse atmosphere. Polysil was developed by the Electric Power Research Institute (EPRI).

(2) *Inspection and replacement.* Composite insulators are frequently used in outlying areas where shooting vandalism is a problem. Damage to nonceramic insulators, particularly from small arms ammunition, may not always be easily detected visually. When such damage is detected, the damaged insulators should be replaced as soon as practical, especially if embedded metal is found in the shank of the insulator. A few holes through only the weathersheds will have little or no adverse effect on the performance of the insulator.

c. Metal parts. Metal parts consist of fittings that connect the insulator at one end to the support and at the other end to the conductor.

(1) *Inspection.* Look for fractures and any rust.

(2) *Repair insulators having defective hardware.*

(a) Wire-brush rusty spots down to bare metal. Apply priming coat of paint and dry. Apply finish coat of paint to spots covered with primer.

(b) Replace insulator if loose cement permits movement between porcelain and metal parts.

3-22. Cleaning of insulators.

Since the insulating qualities of insulators, and their ability to prevent flashovers, depend on preventing contamination buildup, cleaning frequencies will depend on the location. Ceramic insulators must maintain their glass-like glaze and care must be taken in cleaning to prevent this smooth surface from being scratched or dulled. Nonceramic insulators will deteriorate with time as the surface decomposes, although proper cleaning will help to extend their service life. For convenience, safety and thoroughness, insulators should be cleaned while out of service.

a. Causes of contamination. All insulators and also bushings are designed to permit satisfactory operation with some contamination. However, alternate wetting by early morning mist and fog, followed by exposure to dust and wind, can build up harmful deposits. Special contamination problems are encountered near steel mills, cement and chemical plants, and other factories that saturate the air with finely divided, semi-conductive particles. Along coastal areas, salt deposits build up and materially reduce the flashover value. Many of these deposits are extremely tenacious, requiring that the insulator be removed from service and cleaned by hand. Where contamination is serious, special long-leakage suspension insulators for high-voltage lines have been used; but, where severe deposits occur, washing of special insulators is required as often as for standard insulators. To lengthen maintenance intervals, in areas where contamination is severe, ceramic insulators and bushings may be coated with special silicone greases. Greasing is not recommended for nonceramic insulators, a channeled arcing can lead to tracking on greased composite insulators. Many weathershed materials are unsuitable in areas where hydrocarbon vapors are prevalent or where they come in contact with wood poles treated with hydrocarbons.

b. De-energized cleaning methods and materials for ceramic insulators. The following materials and methods are specified for porcelain cleaning. Table 3-2 should also be consulted.

(1) Clean, grit-free, lintless wipers should be used.

(2) An abrasive, of the kitchen-cleanser type, mixed with clear water to the consistency of a thick paste, may be applied with a wiper or stiff-bristle brush. The amount of rubbing depends on the material being removed. Rinse freely with clear water.

Table 3-2. Cleaning ceramic insulators and bushings

Deposit	Type of cleaner	How applied	Results
Acid crust from a chemical plant	Bon Ami[2]	Rag	Satisfactory
	Ammonium bifluoride	Brush	Fair
	Oakite[2]	Hot bath	Satisfactory
	Lockbrite cleaner[2]	Brush	Satisfactory
	Paint thinner	Rag	Satisfactory
Black paint carbon	Skybrite window cleaning crystals[2]	Wash	Satisfactory
	Dilute muriatic acid	Cloth	Satisfactory
	Extra-coarse steel wool	Rub	Good
Cement dust	Hydrochloric acid[3]	Brush	Satisfactory
	Wire brush	Brush	Satisfactory
	Scrape and apply paraffin	Steel wool, rags, and salvasol	Requires annual cleanup
Fly ash	Lockbrite[3]	Steel wool, rags, and salvasol	Used below 32°F (0°C)
	Lockbrite[2]	Rag	Used below 32°F (0°C)
Gummy soil, dirt and oil.	Bon Ami and turpentine[2]	Wash	Satisfactory
Iron ore	Skybrite window cleaning crystals[2]	Brush	Satisfactory
Leather dust	Brush	Dip or wipe	Satisfactory
Lime	Muriatic acid[3]	Hand	Satisfactory
	Lockbrite[2]	Wipe	Satisfactory
Oil soot	Dry cloth	Rag	Satisfactory
Red lead	Paint thinner[4]	Rag	Satisfactory
Salt	Water	Water and rags, steel wool, rags, and water	Satisfactory
Smoke	Lockbrite[2]		Satisfactory
	Larkin cleaner[2]	Steel wool, rags, and water	Satisfactory
Sulfur	Oakite[2]	Rags	Satisfactory
	Standard Oil solvent[2]	Cloth	Satisfactory
Traffic film	Lockbrite[2]	Cloth	Satisfactory
Unknown	Windex glass cleaner[2]	Atomizer and wipe with dry rags	Fair
Vapors from paper mill	Vinegar and bicarbonate of soda paste	Rag-coat porcelain, rub off, and finish with steel wool	Fair
Wood-mill dust	Brush	Brush	Satisfactory

[1]The insulating qualities of ceramic insulators and bushings and their ability to prevent flashovers depend largely on the glass-like glaze of the surface. During cleaning operations, therefore, care must be taken to preserve this smooth surface and prevent its being scratched or dulled.

[2]The use of brand names is to identify the type of material recommended and does not imply superiority over other brands of similar material.

[3]This chemical gives off irritating fumes which are dangerous in high concentration. Do not use without respiratory protection.

[4]Some paint thinners are highly flammable. When use of a thinner having a flash point under 100°F (38°C) is necessary, it will be handled in accordance with applicable safety regulations.

(3) Muriatic acid, diluted with water to a 10- to 50-percent solution, is effective for many extremely tenacious contaminations. The acid concentration should be kept as low as possible, because it tends to attack metal parts and cemented joints. It is applied with a fiber or bristle brush or cloth and permitted to work for approximately 3 minutes, after which the porcelain should be scrubbed clean and rinsed thoroughly with clean water. Rubber gloves and goggles should be worn to protect hands and eyes from the acid.

c. De-energized cleaning for nonceramic insulators. Manufacturers' recommendations should be followed since weathershed construction and ceramic materials vary.

d. Cleaning while energized. Although insulators may be washed while energized by the use of complex equipment, it is not recommended as a general practice for small military installations. At large military installations, where personnel have been properly instructed and trained, ANSI/IEEE 957 should be used as a guide for cleaning energized insulators. If either the serving utility or a local contractor is equipped to perform this service, contracts for this type of work might be justified.

Section V - BUS STRUCTURES

3-23. Definition of bus structures.

A bus structure is an assembly of bus conductors with associated connection joints and insulating supports. It can have bare or insulated conductors. A busway is a grounded metal enclosure, containing factory-mounted, bare or insulated conductors, which are usually copper or aluminum bars, rods, or tubes. Each serves as a common connection between two or more circuits.

3-24. Maintenance of bus structures.

Bus structures need regular scheduling of visual inspections.

a. Schedule. Enclosed buses occurring in switchgear should be inspected visually, in conjunction with scheduled outages for circuit breaker, fuse, switch, or other associated equipment maintenance. Open-type buses may be visually inspected without being de-energized. The frequency of such inspections depends largely on the local contamination problem and will, therefore, vary with each installation. However, each bus should be visually inspected at least once each year as a minimum.

b. Visual inspection. Inspect all bus conductors and connections for evidence of overheating, loose or corroded connections, and poor alignment that might result from short-circuit stresses. Special attention should be given to contacts between dissimilar metals. For example, copper salts falling onto aluminum will chemically deteriorate the aluminum. This situation will be most severe at locations subject to salt spray.

3-25. Cleaning of bus structures.

The cleaning of buses is limited primarily to that of eliminating excessive contamination from the supporting insulators. It is not necessary to remove corrosion from the conductors, except where it either affects contact resistance of connections or can lead to deterioration of conductors.

3-26. Testing of bus structures.

Generally, no testing is required in connection with a bus structure, except that trouble spots should be detected by checking bus temperature. Whenever electric current flows, there is some temperature rise. If this rise becomes excessive, such as at a point of poor contact, trouble will develop. Checking for higher-than-normal temperatures by infrared inspection can reveal these future trouble spots.

Section VI - INSTRUMENT TRANSFORMERS

3-27. Definitions of instrument transformers.

An instrument transformer is designed to reproduce in its secondary circuit (in a definite and known proportion) the current or voltage of its primary circuit with the phase relations and waveform substantially preserved.

a. Current transformers. A current transformer is a constant-current transformer which reduces line currents into values suitable for standard measuring devices such as ammeters and wattmeters and standard protective and control devices. It also isolates these devices from line voltages. The primary winding is connected in series with the circuit carrying the line current, or as a window-type arrangement linked magnetically with the line conductor which eliminates the need for an integral primary winding.

b. Voltage (potential) transformers. A voltage transformer is basically a conventional constant-voltage transformer with primary and secondary windings on a common core connected in shunt or parallel to the power supply circuit to be measured or controlled. The secondary winding insulates devices from the power circuit.

3-28. Short-circuiting dangers.

The basic difference between current and potential transformers *must* be observed. A voltage transformer like most constant-voltage devices should never be short-circuited. A current transformer, being a constant-current device, requires that the secondary circuit always be closed. As long as there is current in the primary winding, there will be current in the secondary winding. On an open circuit the voltage will be the secondary current multiplied by an extremely high open-circuit secondary resistance. This is a voltage which may both damage insulation and prove dangerous to life. Under no circumstances should the secondary of a current transformer be opened while the primary circuit of the transformer is energized, unless the terminals of the current transformer are of the short-circuiting type.

3-29. Maintenance of instrument transformers.

Instrument transformers should be scheduled for a maintenance inspection every 2 years. In addition, they should be inspected visually any time apparatus with which they are associated is inspected, but not less than every 6 months.

a. Safety. Before performing any maintenance on instrument transformers, they must be de-energized and completely isolated from any energized source. Isolation may be accomplished by opening applicable disconnect switches or fuses or by de-energizing appropriate circuit breakers. In polyphase circuits, all phases must be disconnected to ensure that instrument transformers are not energized through interconnected secondaries. Drawout-type voltage transformers, used in metal-clad switchgear, should be completely withdrawn for maintenance.

b. Procedure. Maintain bushings and terminals of instrument transformers as described in section VII. Maintain fuses, if present, as described in chapter 8, section II.

(1) *Case.* Inspect case or tank for evidence of corrosion and leaks. Clean and paint as required. Instrument transformers that show evidence of leaks should be replaced with those of the same rating and returned to a shop for repair.

(2) *Conduit and connection.* Tighten all loose joints in conduit around fittings, terminal boxes and supporting clamps. Clean and paint corroded areas. Verify tightness of all bolted connections. Verify that wiring, grounding, and shorting connections provide good contact.

(3) *Drawout mechanisms.* Test the proper operation of the voltage transformer withdrawal mechanisms (tip out) and grounding operation.

3-30. Tests of instrument transformers.

Instrument transformers rated above 15 kilovolts should receive power factor tests during the scheduled maintenance period for transformers given in table 7-l. Procedure for making these tests is described in section VII. Other tests, which may be made during or after shop repairs, include:

a. Oil analysis.
b. Ratio.
c. Polarity.
d. Resistance.
e. Exciting current.
f. Overvoltage.

Section VII - BUSHINGS

3-31. Definition of bushings.

A bushing is an insulating structure which provides a through conductor or a passageway for such a conductor. A bushing has a provision for mounting on a barrier (conducting or otherwise). The bushing insulates the conductor from the barrier and conducts current from one side of the barrier to the other side. The primary function of a bushing is to provide an insulated entrance for an energized conductor into an apparatus tank.

3-32. Type of bushings covered.

Information in this section pertains to bushings on such substation apparatus as power transformers, sulfur hexifluoride (SF,) and oil circuit breakers, and high-voltage instrument transformers. Although bushings on low-voltage instrument transformers ordinarily require little attention, the following recommendations for inspection and cleaning can be followed for such equipment as well.

3-33. Maintenance of bushings.

Bushings are always an integral part of specific apparatus and should be inspected along with that apparatus.

a. Schedule. External portions of bushings, which are easily viewed and form a part of equipment that is under constant supervision, should be visually inspected on the same schedule as the associated apparatus. Factors that may increase the frequency of maintenance and inspections include:

(1) Construction, condition, age, and history of the bushing.

(2) Conditions under which the bushing must operate. Bushings subject to excessive contamination or temperature should be inspected more frequently than those that operate under normal conditions.

(3) Relative importance of service continuity.

(4) Accessibility.

b. Visual inspection. Bushings should be visually inspected for evidence of any condition that will tend to impair satisfactory performance, including:

(1) Excessive contamination.

(2) Cracked or broken porcelain.

(3) Low oil level (oil-filled bushings).

(4) Broken or deteriorated seals.

(5) Fractured metal parts.

(6) Excessive operating temperature.

(7) Loose or missing parts, such as a power factor test tap cover.

c. Porcelain inspection. When inspecting porcelain, the following procedure is recommended:

(1) *Fractures.* Check for fractures and chips in porcelain. The significance of a crack or chip depends on its location and configuration, since a chipped skirt does not affect performance unless the effective creepage distance is appreciably reduced. If the crack appears to extend into the body of the porcelain, examine it carefully to see whether it is only a harmless surface marking the glaze or some-

thing that may result in an operating hazard. Fractures or chips may be caused by the following actions.

(a) Rigid bus connections that do not allow for thermal expansion or contraction.

(b) Thrust from breaker operation, which may fracture either the top or bottom porcelain if the bottom member is loose.

(c) Uneven or excessive tightening of clamping-ring bolts.

(d) Improper cementing onto the clamping ring.

(e) Mechanical shock caused by blows or projectiles.

(2) *Contamination* Check for foreign deposits, such as dirt, salt, cement dust, rust, carbon, acid oil sludge, filler compound, copper sulfate, or other material that may cause flashover under moist conditions.

(3) *Loose porcelain.* Check for loose or improper seating of the lower porcelain.

(4) *Evidence of flashover.* Flashover may be caused by an operating voltage above the bushing rating, excessive transient voltage, or semiconductive foreign particles contaminating the porcelain.

d. Porcelain repair. In addition to the upper or main body porcelain, some bushings have a lower porcelain member to give added strength against mechanical shock. Porcelain repairs generally are made in either of the following ways:

(1) *Fractures.* When the main section of either the lower or upper porcelain is fractured, replace the bushing. When the cause appears to be a too rigid connection, install a flexible connector or expansion joint made from a flat strap, in addition to replacing the bushing.

(2) *Chips.* When the main body of the porcelain is intact, but a crack is about to detach a large chip of skirt, protect adjacent skirt and remove the chip with a hammer. Smooth the sharp edges with an abrasive stone to prevent injury to workmen, and paint the exposed surfaces with a weather-resisting material to provide a glossy finish that keeps out dirt and grit.

(3) *Contam ination* Remove deposits of foreign materials. Clean as recommended.

(4) *Tracking.* When there is evidence of flashover, check the bushing voltage rating and surge protection. Clean the bushings. Bushings experiencing frequent flashovers should be reported to the operating department, as this may require a review of the application and associated surge.

e. Metal parts inspection. Metal parts of bushings, including the mounting flange and hardware, should be inspected for fractures, cracks, blowholes in cap and assemblies, and a need for repainting. Fractures and cracks are caused by deterioration of cement, which allows the entrance of moisture that alternately freezes and thaws.

f. Metal parts repair.

(1) Remove fractured, cracked, or defective clamping rings and hardware, and replace immediately.

(2) Wire brush spots down to bare metal, apply a priming coat of paint, allow to dry, and then add a finish coat. Repaint periodically with a good weather-resisting paint.

(3) Bushings that leak quantities of filler compound or oil (especially at the clamping and mounting flange assembly) should be removed from service promptly and a replacement installed. These conditions cannot be readily corrected in the field.

(4) Repairs that involve the baking out or vacuum treatment of insulation, replacement of a porcelain rain shield, or modernizing and rebuilding, should be accomplished in a qualified service depot or manufacturer's shop. This work requires expert techniques, as well as special tools and equipment.

g. Cement inspection. The cement between clamping rings, caps, and porcelain should be inspected for crumbling or chipped surfaces and deterioration that will permit the entrance of moisture. Absorption of moisture and subsequent expansion and contraction, as a result of temperature changes, hasten cement deterioration. Litharge and glycerin cement are particularly vulnerable.

h. Cement repair. It is often more economical and desirable to replace rather than repair a deteriorated bushing.

(1) Make a temporary repair by cleaning porcelain and painting the exposed cemented parts with an insulating varnish in accordance with Military Specification MIL-V-173.

(2) Remove litharge and glycerin cemented bushings at the first opportunity and replace with bushings having mod.ern-type cement.

(3) When loose cement permits movement of porcelain, replace the bushing.

i. Gasket inspection and repair. When inspecting and repairing gaskets, look for leakage of filling materials, deterioration of gaskets, and improper seating of gasket material (especially rubber-like and cork composition). If quantities of filler have leaked from the bushing, replace the bushing immediately. Cork exposed to moisture and air turns dark, crumbles, and loses elasticity and binder. Replace all deteriorated or improperly seated gaskets with new gaskets as recommended by the bushing manufacturer.

j. Ground sleeve. Inspection and repair of the ground sleeve includes the following steps:

(1) Check the condition of the ground strap that ties the metal sleeve to the supporting flange, and examine for tight connections.

(2) Replace the ground strap if it is badly corroded.

(3) Tighten the connection.

(4) Where a bushing is installed in liquid-filled apparatus, see that the lower end of the bushing ground sleeve is immersed in the liquid at all times. A ground sleeve is intended to distribute voltage stress longitudinally along the bushing stem, thus preventing the formation of corona above the liquid level.

k. Bushing conductor lead. The following procedures for inspection and repair are recommended:

(1) Look for deteriorated conductor lead insulation, particularly where the lead leaves the bushing stem.

(2) Check the upper end of this type of bushing for evidence of corrosion where the conductor is soldered to the bushing cap.

(3) Remove deteriorated conductor lead insulation; inspect strands for mechanical condition, and retape with varnished cambric tape; then apply l-inch (25 millimeter) linen tape, half-lapped to the required thickness.

(4) Paint with applicable Military Specification MIL-V-173 varnish or other suitable insulating varnish.

(5) Clean bushing cap and porcelain surfaces with soap and warm water, and swab out the tube.

(6) When replacing bushing conductor leads, braze or silver solder the leads and their terminal connections.

l. Line or bus connections. Inspection and maintenance should include the following steps:

(1) See that connections are tight and free from corrosion and dirt. Corrosion and dirt cause overheating of terminals. Contacts that are not tight result in corona discharge and arcing between loose points of contact and cause radio interference. An energized connection suspected of overheating may be checked by fastening an unlighted tallow candle on a disconnect pole, and observing whether or not the candle melts when brought in contact with the connection.

(2) Check for adequate rigidity and see that the connection design does not overstrain the porcelain bushing. Check the foundation for movement.

(3) Check the size of the terminal connector to ensure adequate current-carrying capacity.

(4) Clean dirt and corrosion from connections.

(5) Polish contact surfaces with crocus cloth, install new lock washers, and tighten bolts securely.

(6) Install a terminal connector of the proper capacity.

m. Migration of compound. Inspecting and repairing compound migration should be made in the following manner:

(1) Check the oil and the bottom of the apparatus tank for visual evidence of compound leakage caused by fractured porcelain or leaking gaskets.

(2) If much bushing compound has migrated into the oil or the apparatus tank, replace the bushing with one of a modern design.

(3) Remove fluid from the apparatus tank.

(4) Clean the apparatus tank.

(5) Refill with new or filtered fluid.

n. Internal carbon deposits. Excessive accumulation of carbon should be noted. Electrostatic flux causes free carbon in the oil to collect on porcelain, herkolite, and/or micarta. Free carbon immersed in oil will form frostlike figures that adhere tightly to insulating materials. If enough deposit collects, flashover may result, particularly if moisture is present. Therefore, carbon deposits should be wiped off with suitable solvent, flushed with clean mineral oil, and wiped with a clean lintless rag saturated with clean oil.

o. Arcing gap. Arcing or coordinating gaps, if present, should be free from any obstructions and the gap set at proper spacing.

p. Oil gage. Some bushings are provided with means of indicating the level of the filler. Check these devices for proper operation and see that glass is not cracked or broken.

q. Oil level. Inspect the oil level frequently. Low oil levels may be caused by overfilling or by oil being forced up into any expansion chamber not equipped with a core seal.

3-34. Bushing power factor tests.

The power factor of a bushing (or any other insulator) is an indication of the effectiveness of the insulation to function properly. A low power factor (1 percent or less) is an indication of good insulation. Because of differences in materials, a single power factor test is of little value. However, a series of power factor tests allows the results to be compared, and a trend can be established. Increasing power factors indicate deteriorating insulation and corrective measures should be taken. Power factor testing is recommended for bushings rated over 15 kilovolts and for all bushings, regardless of voltage rating, in substations rated over 5,000 kilovoltamperes.

a. Schedule. Bushings should be power-factor tested at the time of installation and at intervals as given in table 7-l for transformers. Spare bushings should be -power-factor tested when received from the factory, and at approximately 2-year intervals thereafter. For convenience, it is well to schedule such tests to correspond to those applied to other equipment at a given location. In this way, the test equipment and personnel may be used to the best advantage.

b. Equipment. Insulation power factor can be measured by several methods, including the voltmeter-ammeter-wattmeter (Doble) method and the balanced bridge method. A number of power factor test bridges are available and are probably the most convenient way to measure the power factor. Commonly used circuits are described in ASTM D 150. Further information is available in IEEE 62.

c. Test personnel. Power factor testing involves high voltages and fine measurements. Test personnel should be well trained and highly skilled in the operation of the test set being used. For safety, two people should be used to conduct the test.

d. Test conditions. To obtain the most reliable results, power factor testing should be conducted under the following conditions:

(1) If outdoors, the weather should be fairly clear.

(2) Air temperature should be above 40 degrees F (5 degrees C). Power factor tests have little value when made at freezing temperatures.

(3) Relative humidity should be less than a maximum of 80 percent.

(4) Insulation being tested should be dry and clean.

(5) Insulation temperature must be known and should not be less than the air temperature; otherwise, condensation will take place and hot-collar losses will be high because of surface leakage. Temperature may be measured with a thermometer in contact with the porcelain.

(6) Current leakage by creepage along insulation surfaces should be eliminated by the application of the proper guard circuit of the tester. Guard circuits vary with testers of different types, and the manufacturer's recommendations should be followed.

e. Test comparisons. In order to yield better results that can be compared, power factor tests on the same item should be made at the same voltage and frequency. Measurements at different temperatures should be corrected to 68 degrees F (20 degrees C) to facilitate comparisons and establishment of a power factor trend. See table 3-3 for correction factors.

(1) Power factor is a "worst condition" value, and it is necessary to isolate bushings from the rest of the equipment being tested only if the test indicates trouble. In such a case, each item must be tested separately to determine which is failing; a

Table 3-3. Temperature correction factors for power factor[1]

Temperature	Correction factor (K)
50°F (10°C)	1.25
59°F (15°C)	1.11
68°F (20°C)	1.00
77°F (25°C)	0.89
86°F (30°C)	0.80
95°F (35°C)	0.71
104°F (40°C)	0.65
113°F (45°C)	0.57
122°F (50°C)	0.51
131°F (55°C)	0.46
140°F (60°C	0.41
149°F (65°C)	0.37
158°F (70°C)	0.33

[1]pf at 20°C = pf at T°C x K

bushing must then be disconnected at both terminals and tested separately.

(2) A consistent test procedure should be followed on a given piece of equipment in order to satisfactorily establish a trend. Power factor test values of a bushing individually tested, for example, cannot be directly compared to test values obtained when a bushing is connected to a winding or a bus.

f. Ungrounded specimen test. Power factor of a bushing may be determined by attaching the high-voltage lead of the test set to the top terminal of the bushing and the low-voltage lead to the capacitance or power factor test tap (if the bushing has one) as shown in figure *3-l*. The bushing flange is then grounded to the test set and power factor measurements made.

(1) Record temperature of bushing. Connections to the bus at the bushing need not be removed unless such connections seriously affect the readings. Experience in making measurements will facilitate making a decision in this regard.

(2) Some bushings not provided with either a capacitance or power factor test tap may be tested essentially in the same manner, if provisions for isolating the bushing flange from the grounded apparatus tank are present. Under such circumstances, with the bushing flange grounded, the low-voltage lead of the test set is connected to the bushing flange and the test set is grounded to the apparatus tank.

g. Grounded specimen test. Where bushings to be tested have fixed conductors and are not equipped with facilities for making the ungrounded specimen test, the power factor may be measured in the following manner:

(1) Remove top and bottom connections to bushing.

(2) If the bushing cannot be removed, the bushing flange must be insulated from the apparatus.

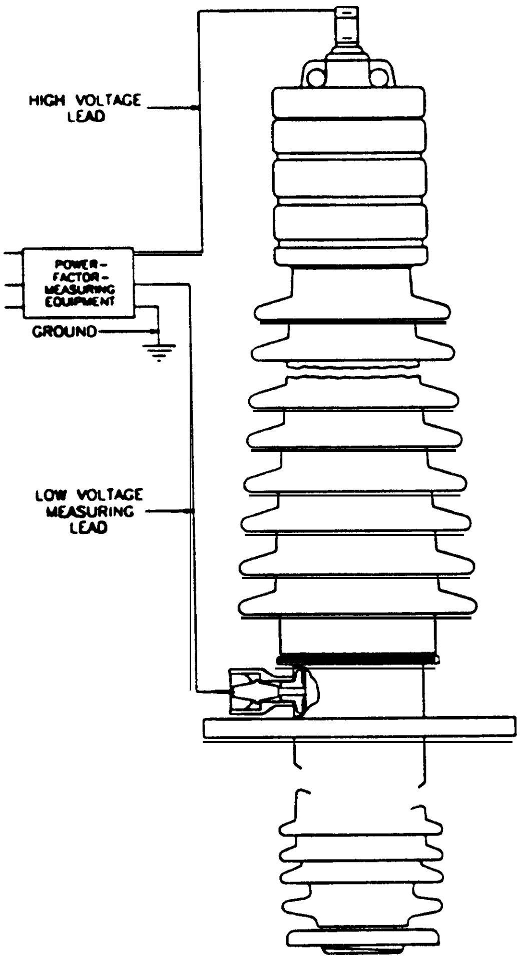


Figure 3-l. Connections for ungrounded specimen power factor test

(3) Connect the high-voltage lead of the power factor test set to the top terminal of the bushing and the low-voltage lead to the bushing support.

(4) Ground the test set to the apparatus tank, and measure the power factor

(5) Record temperature of the bushing.

h. High-voltage cold-guard circuit test. When bushings to be tested have detachable cable conductors, they may be tested in the following manner:

(1) Remove the bushing terminal and insulate the conductor from the bushing tube by stuffing a small amount of insulation into the space between them. If bushing is equipped with an insulating head, it is only necessary to remove the connector between the upper and lower rings.

(2) Clean the porcelain ring of the insulating head.

(3) Connect the guard circuit to the cable lead and the high-voltage lead of the test set to the bushing tube.

(4) Ground the mounting flange of the bushing.

i. Collar tests. The overall power factor test on bushings may be performed by placing a flexible conducting rubber or metallic foil or braid collar around the porcelain under the first top skirts; connecting the collar to the test cable guard circuit; grounding the mounting flange; and applying test voltage to the central conduct of the bushing. The collar should be of a type specifically designed for bushing collar tests. Figure 3-2 shows connections for hot- and cold-collar tests.

(1) *Hot-collar test.* This test is performed by grounding the central conductor and the mounting flange and applying test voltage to the collar on the bushing. When hot-collar losses are found to be high because of high relative humidity creating surface leakage, the bushing should be cleaned. Furniture or floor wax should be applied with a clean lintless cloth. The wax should dry for 5 minutes and then be rubbed briskly with a clean cloth to obtain a high polish.

(2) *Cold-collar test.* This test is performed by grounding the collar and mounting flange and applying test voltage to the central conductor of the bushing. The difference between the overall watt loss and the cold-collar loss is known as watts difference. In general, there appears to be no advantage in the cold-collar test. The hot-collar test is recommended.

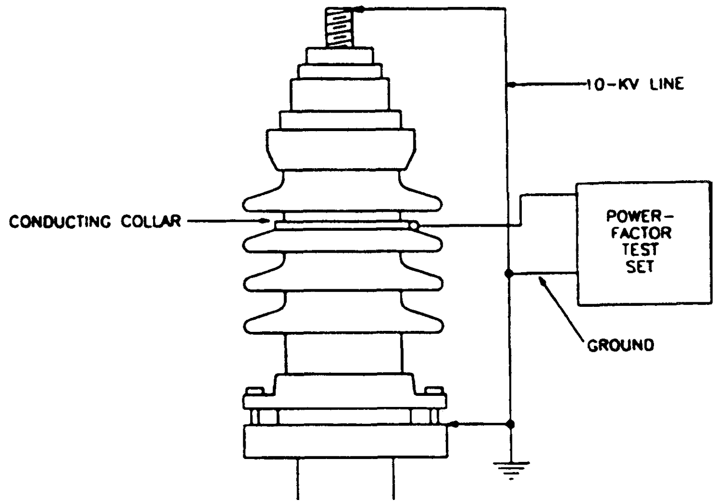
j. Interpretation of power factor test results. The limiting value at which different test operators remove bushings from service ranges from 6 to 12 percent power factor on bulk-type bushings and from 2 to 6 percent on plastic and oil-filled bushings. These ranges are based on bushing temperatures of 68 degrees F (20 degrees C), the power factor values being higher at higher temperatures. Because the measurement of power factor is highly specialized and power factor values vary with different types and makes of equipment, the procedure following such tests should be based on the recommendation of the qualified persons engaged to perform the tests.

3-35. Bushing insulation resistance test.

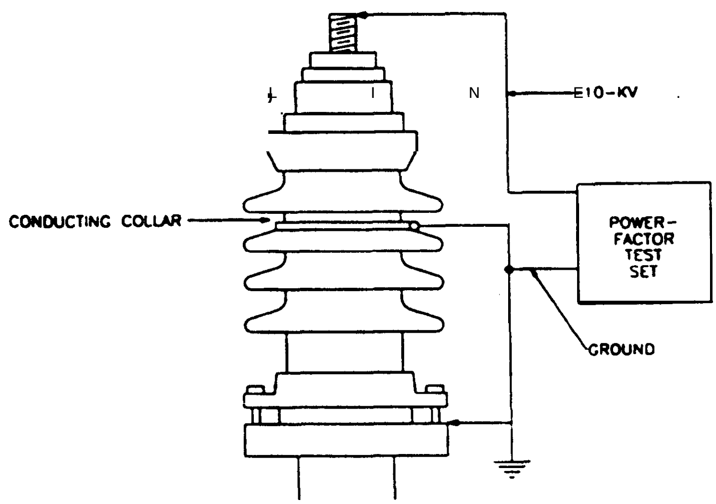
Insulation resistance tests measure insulation losses by applying a dc voltage. This test is not so widely used as the ac power factor test for bushings; but, in the absence of facilities to test power factor, insulation resistance tests on bushings may prove useful.

a. Procedures. The general procedure for insulation resistance testing is described in chapter 5, section VII. The following paragraphs contain specific details for testing bushings.

b. Test values. See table 3-4 for requirements for insulation test values. Resistance readings should be carefully compared in one or two ways.



HOT-COLLAR TEST



COLD-COLLAR TEST

Figure 3-2. Connections for hot- and cold-collar tests

Table 3-4. Insulation resistance tests on electrical apparatus and systems[1]

Maximum voltage rating of equipment	Minimum test voltage, dc	Recommended minimum insulation resistance in megohms
250 volts	500 Volts	25
600 volts	1,000 Volts	100
5,000 volts	2,500 Volts	1,000
8,000 volts	2,500 Volts	2,000
15,000 volts	2,500 Volts	5,000
25,000 volts	5,000 Volts	20,000
35,000 volts	15,000 Volts	100,000
46,000 volts	15,000 Volts	100,000
69,000 volts	15,000 Volts	100,000

[1]This table is reproduced from MTS-1993.

(1) Readings taken on a number of similar bushings at the same time.

(2) A series of readings taken on the same bushings at different times.

c. Test conditions. It is essential that suitable conditions be maintained during tests.

(1) Bushings cannot be checked while connected to the windings of transformers.

(2) Bushings must be dry and warm enough to prevent the condensation of moisture from the atmosphere.

(3) The weather should be reasonably clear and the relative humidity less than 80 percent.

(4) Record the bushing temperature at time of test.

(5) Adjust resistance value to 68 degrees F (20 degrees C).